Tarja Kallio-Tamminen

QUANTUM METAPHYSICS

The Role of Human Beings
within the Paradigms of Classical and Quantum Physics

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Abstract

This study investigates the question of why quantum mechanics still lacks a generally-accepted interpretation in spite of a century of serious deliberation. It is guided by the question whether quantum mechanics requires a radical rethinking of the fundamental ontological and epistemological presuppositions on which the current world-view, a conception of nature adopted at the turn of the modern era, is based.

During recent centuries, physics has provided the main tools for the human enterprise of understanding reality and our own role in this context. The classical paradigm of science was based on the idea of an objective material world which obeys strict deterministic laws. It was greatly affected by Newtonian mechanics whose differential equations were easy to interpret as describing the movement of material particles in space and time. Consequently, classical physics inspired a strong belief in a deterministic and clockwork-like universe, external to the human observer.

In the quantum framework, the traditional space-time description of classical physics is overtaken by a more abstract description of state. The complex wave-function which resides in abstract multi-dimensional space is the most important term in the theory. It can never be directly observed and the interpretation of this abstract entity has been a source of long controversy. Some researchers consider it to be just a mathematical tool or instrument suitable for predicting the actual outcomes we can observe, others argue that the wave-function refers to some kind of transcendental quantum level. In any case, the wave-function is responsible for the non-local and statistical constitution of quantum physics which are difficult to understand and explain within the mechanical and deterministic paradigm of classical physics. With the new description of state, some kind of indivisibility, internal spontaneity and change appear to be a an unavoidable part of reality.

The core of this study consists of the chapters investigating quantum theory and the debate concerning its interpretation which has now continued for almost a century. Chapter 4 starts with a brief explanation of the results of physical research that led to the creation of quantum theory, and describes the main features of the theory in common language avoiding mathematics and any further interpretation. Analysis of new features of the theory such as wave-particle dualism, non-locality, statistical predictions and the measurement problem helps in understanding why quantum mechanics is difficult to perceive within the mechanistic-deterministic framework of classical physics. The theory seems to provide encouragement for the endeavour of reconsidering classical presuppositions concerning the nature of reality. The Copenhagen interpretation of quantum mechanics actually proposed a radical reappraisal of both previous conceptions of reality and the role of humans, whereas many subsequent interpretations have attempted to find a route back to the classical mechanical and deterministic framework by postulating a variety of auxiliary hypotheses.

This research material, i.e. the structure and interpretations of quantum mechanics, is studied against the background of previous conceptions of reality and the changes they brought about in western culture, in order to analyse and evaluate the credibility of the metaphysical presuppositions adopted by the classical paradigm of science. The author argues that contrary to the common presuppositions of the classical paradigm, the relationship between the human mind and nature may not be entirely one of detachment, and everything that happens may not be explainable by reducing individual events to mechanical interactions between particles.

In the concluding chapter, she extends Niels Bohr’s philosophy of complementarity and outlines an onto-epistemological framework within which many of the apparent paradoxes of quantum mechanics could be understood and solved. Even if profound revisions in the conception of reality are rare, the common world-view has, in western culture, changed radically in antiquity and at the turn of the modern era. The current change could be comparable in its extent, providing tools for a reconciliation of the age-old schism between natural science and humanistic concerns. By questioning the particle-mechanistic conception of matter, the new ontology offers a more fruitful starting point for understanding man’s relationship with nature. The non-local and statistical character of the state-description offers an opportunity to reconsider the subtle relationship between mind and matter. Mental states may be real and scientifically-approachable even if they are not totally identifiable with brain states. Human beings can be reconciled to the natural world without there being any need to restrain their unique character.

Contents

Preface

Even when I was at school, I found modern physics interesting. It appeared to me that the theories of relativity and quantum mechanics were part of a search for fundamental and almost incomprehensible profoundities in nature which I wanted to understand better. My studies of particle physics and preliminary examinations of particle collisions in the bubble chamber images at the Helsinki University Department of High Energy Physics offered new insights to the basic natural symmetries controlling composite events: the wild spectrum of particles born out of collisions could only come into being exactly as permitted by a few basic laws of conservation. I learned to trust the precision of the physical method. I had not the slightest doubt that all of the phenomena encountered in nature would, sooner or later, be explainable on the basis of physical laws. Natural science appeared to have provided a much more credible and even more comprehensive picture of the basis for reality than the imperfect and unsubstantiated speculations based on human nature provided by natural philosophers or mystics throughout human history.

Little by little, however, I learned that the basic questions concerning the fundamental nature of reality, the ones that interested me most, lacked clear answers. Courses in quantum mechanics taught me how to solve wave functions in a variety of situations, but no-one explained their real meaning. References to the role of theory as a mathematical instrument for prediction, or discourses on probability waves and the indeterminate nature of the world resulted in more questions than answers. When I eventually resorted to the philosophy of science, I realised that simple answers simply did not exist. Almost a century of debate concerning the interpretation of quantum mechanics had not even resulted in a consensus on whether there were problems with the subject or not.

In the Department of Philosophy, I came to realise that physical facts were of necessity based on theory and more or less coloured by them, that theory had to be evaluated and examined in the light of external and more general criteria, and that these criteria reflected fundamental ontological and epistemological beliefs which were neither final or immutable. When examining and interpreting the basic physical theories, it is not even possible to be certain that either the language or the logical arguments we employ represent reality as it truly exists. Since quantum theory and the new elements associated with it can be interpreted in so many ways, I was no longer surprised that Instrumentalism and Positivism had become so popular with pragmatic and practically-oriented physicists. Even so, the adoption of such relativistic attitudes struck me as a form of surrender, of being satisfied too easily. Why should we abandon the traditional realism connected with physical research when quantum theory had confronted us with something endlessly fascinating – a treasure chest of the unexpected? If questions of interpretation remained unanswered, we would lose a unique opportunity to gain a deeper understanding of the true nature of reality.

Niels Bohr, famous for having developed the theory of the atom and generally considered to be one of the greatest physicists of the 20th century, was quite certain that quantum mechanics, just like every deep and fundamental problem, carried with it its own solution: i.e. it forces us to change our way of thinking.[1] This starting point suited my own approach. I was quite certain that through quantum mechanics, nature had taught us something which would alter our approach. The limitations in the metaphor of nature as a machine that was introduced at the beginning of the modern era had become obvious, and the search had to begin for new models and ways of thinking, which could incorporate and make comprehensible the new features and insights provided by quantum mechanics. The road to even a modest understanding was a long one. Before the pieces of the puzzle began to slip into place, I had to abandon many of the beliefs that I held to be self-evident, and wade through several flimsy quagmires, both large and small.

When I began my own research more than ten years ago, I used the principles of Realism and Naturalism to clarify what the long debate on the interpretation of quantum mechanics truly contained and indicated. I carried with me the strong desire that a suitable interpretation would offer a more fruitful starting point than those adopted previously for the investigation of human nature and its relationship to the external world. Both the ecological crisis and the significant crumbling of cultural values are, in my opinion, closely connected with the modern era skills of adopting a mechanical and objective view of nature. If humans cannot learn to see more clearly both their own position and the possibilities that nature offers, they are unlikely to accept sufficient responsibility for shaping a decent future. Looking back, I can only repeat the old adage – look and you will find.

Initially, I approached the subject of questions connected with the interpretation of quantum mechanics as broadly as possible. In addition to scientific papers by physicists and philosophers, quantum mechanics has spawned an unparallelled number of popular books and articles. My

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[1] Weisskopf 1990, 63.

increasingly familiarity with the material revealed a multiplicity of starting points and interests: discussions, bewilderment, and argument. It was typical to speak of momentous and profound change: the need for it, a yearning for it, or its outright rejection. The discussion was fragmented between many positions: a proponent of a traditional approach concerning a certain presupposition could, in a different location, propose a radically new formulation. In some pieces, shaking the foundations of classical physics inspired fantastical arguments about parallel universes or ”active” information that guided particles. In others, a variety of magical explanations surfaced to explain observed phenomena, explanations that appeared impossible within the context of classical physics. In fact, problems varied from one writer to the next in such a manner that it was by no means easy to frame either common questions or even common areas for which solutions were being sought.

The philosophy of science addressed the discussion concerning models and reality at a more abstract level. One end of the spectrum was represented by relativistic philosophy, according to which ”any model is acceptable if it explains the facts”. This attitude was even more unacceptable to me than the preceding ’naïve realism’, on the basis of which some physicists postulated a variety of auxiliary hypotheses to allow them to hold on to the classical conception of reality. On the other hand, I also valued the down-to-earth approach adopted by physicists and viewed Relativism as having done good work in awakening us to our own freedom in creating models and beliefs. At this point, however, I should reaffirm that even though we can freely postulate a variety of models, we cannot close our eyes to their consequences. In our quest by trial and error, reality dictates the boundaries.

As my studies progressed, the Copenhagen interpretation, in particular the thoughts of Niels Bohr, became my most important source of inspiration.[2] I became certain that the basic presuppositions of classical physics concerning both the external position of human beings and the objective nature of physical description required radical revision. It is no longer possible to separate the truth-seeking, knowing and sentient human being from the wholeness of nature without at the same time surrendering the basic objective of natural science, i.e. a deeper understanding of reality. The fact that these ontological and epistemological reflections resulted in a plunge into antiquity, and that the supposedly-dead ideas of Plato and Aristotle appeared to

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[2] I did my Master's Thesis in physics on the EPR paradox and in philosophy on the different interpretations of quantum mechanics, see Kallio-Tamminen 1990. The thesis through which I earned my Licentiate degree (a degree conferred by Finnish universities that stands between a Master's and a Doctor's degree) concerned Niels Bohr and his reconsiderations of conceptions of physical reality, see Kallio-Tamminen 1994.

me to offer new and significant material, was a reward for my journey that I could not have predicted. To earn such a bonus, I am almost ready to do everything all over again.

On many occasions during this, in some people's opinion, perhaps over-brave attempt to produce a comprehensive outline of the bases on which our conception of reality rests, I have been frustrated by the need to accept the shortage of time available for human beings so that I could achieve a sufficiently deep insight into all the subjects that I am dealing with. I believe that more detailed investigations by specialists in different areas could confirm many of my arguments, but even if this does not happen, my work will not have been wasted if it awakens interest among physicists in the basic questions of philosophy, or results in increased understanding among philosophers of the significance of the facts produced by science. I also hope that, among my readers, I can reduce the widely-disseminated fiction that the world is a somehow boring and wholly-known place in which the manner in which we spend our lives has no meaning.

Now that this work is complete, I want to thank all the people who have helped and supported me on my journey. I am especially grateful to my professor, Ilkka Niiniluoto, for his many valuable comments. Without his positive support, I might not have started this attempt to build a bridge between the worlds of physics and philosophy. For his early comments on the direction of my work, I thank Professor Henry Folse, an expert in Bohrs' philosophy. Emeritus Professor K.V.Laurikainen, sadly no longer with us, encouraged me in ways that cannot be overestimated.[3] Important for the development of many of my thoughts have been presentations to the Society for Natural Philosophy which he created, and which has subsequently been a source of stimulating discussions. Many thanks for my achieving the final work are due to Professor Eeva Martikainen, director of an interdiciplinary research project on "Theology and Natural Sciences" financed by the Academy of Finland. She offered passage for a philosopher who started out from physics to a group which worked at the Department of Theology. In the summer of 1999, this project organised a seminar at which both Professor Kari Enqvist and Professor Olli Koistinen provided valuable feedback on my work. In the autumn of the same year, the project made it possible for me to spend one term as a visiting scholar at Cambridge University in the UK. The effect of this journey, the university library and bookshop on the final formulation of what I believed to be an almost completed work was significant. Discussions with Professor John Polkinghorne and Jeremy Butterfield Ph.D introduced new perspectives on my subject matter. I am especially grateful to Professor Rainer R. Zimmerman, who visited Cambridge at the time I

[3] For more on this subject, see Kallio-Tamminen 1999.

was there, and whose inspiring work in philosophy of physics offers challenging views for the future. Discussions with Paavo Pylkkänen Ph.D. and Inga R. Gammel Ph.D were also extremely stimulating. My husband Tapio Tamminen Ph.D, an anthropologist, has in many ways influenced my thoughts concerning the formation of human cultures. For the English version of the text I am grateful to Rick McArthur who in a splendid manner delved in to clarification of the subject.

1. Introduction

Humans have always attempted to improve their understanding of reality by explaining the phenomena encountered in their internal and external life. The foundations of the current world-view were laid down at the beginning of the modern era when René Descartes maintained that his method of systematic doubt provided a basis for self-evident and certain knowledge. Descartes divided reality into two domains: *res extensa* and *res cogitans*. It was believed that with the help of theory, the thinking mind could discover the eternal universalities and truths that controlled the world, even though understanding the connection between the subjective mind and the external world of matter turned out to be difficult. Newtonian mechanics offered a firm foundation for our modern scientific-technical culture based on natural sciences. Physics became the source for truthful knowledge concerning reality, and by exploiting its precise and supposedly universal laws, humans have learned, step by step, to improve both their understanding and control of the physical world's conformity to laws. Also, it is increasingly common for approaches to subjective phenomena to be undertaken using methods that conform to the paradigm of classical physics (for example in neuro- and cognitive science), even though building human actions and free will into a mechanical and deterministic framework is not without problems.

In recent decades, the modern scientific-technical culture has become the target of increasing criticism.[4] Universal, timeless and absolute theoretical knowledge has increasingly been seen as inadequate in solving the concrete, practical and local problems in the middle of which people live their lives and make their choices. Critics have also drawn on the authority of Aristotle. This great philosopher of antiquity was sensitive to both the conditions prevailing in specific situations and to humanity's many dependencies, and he warned against striving too hard for certainty, inevitability or universality in things for which these are not natural.[5] The physics which has been so powerfully changing our world-view is now more often viewed as holding back necessary renewal and as a relic of single-dimensional thinking which cannot be expected to make a significant contribution to the creation of a new operational strategy for mankind. As consequence of this criticism, the traditional schism between natural science and humanism that is based on Cartesian dualism has become increasingly acute.

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[4] For philosophers and environmentalists, see e.g. Feyerabend, Kuhn, and Toulmin, von Wright, Capra, Devlin, Skolimowski, and Habermas.

[5] Toulmin 1990, 70, 75.

As I see it, profound change in ways of operating and thinking requires us to overcome this antagonism: to reassess our conception of reality in a way which takes account of humans and their significance in the world. Humanists who emphasise the role of humans usually fail to mention that the strongest challenge to the correctness of mechanistic-deterministic ways of thinking has come from within physics itself, when modern physics collided with the limitations of earlier ways of thinking at the beginning of the 1900s. This crisis was overcome by developing new and better theories. In light of these, it seems possible that the attempt to find universal and exact knowledge which started at the beginning of the modern era had in fact provided tools which will also permit improved modelling and understanding of the human being, our history- and context-based behaviour – without the requirement to artificially truncate either human creativity or humanity's many dimensions.

In particular, the almost century-long debate concerning the interpretation of quantum mechanics, the basic theory behind modern physics, is an indication of deep crises in the understanding of reality. The complexity of this discussion and the conflicting conclusions reached indicate how quantum mechanics collides with fundamental philosophical problems. From the viewpoint of quantum mechanics, the whole of the western ontological-based approach to natural philosophy is considered to be mistaken, but on the other hand new ontological models have also been constructed.[6] Certainty has been sought via mathematical language and its age-old Platonic forms and symmetries, while ways of explanation which use the Atomistic and Reductionist explanations of Democritus and ordinary language have been viewed as inadequate to capture holistic and constantly-changing features of reality. [7]

The quantum mechanics created in the 1920s required a radical change of paradigm in physical research. Visualisable Newtonian mass-point mechanics was replaced by an abstract mathematical formalism which, just like classical mechanics in its own time, can be applied to solve a huge variety of new research targets. Modern physical theories based on quantum mechanics are well known for their precise predictions, but no-one can define the basis of their predictive ability in a certain way. In spite of decades of discussion, there is no interpretation of quantum theory which enjoys general acceptance. Physicists have realized that final solutions to

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[6] Petersen 1968.

[7] Heisenberg 1985, 45-54.

many ontological and epistemological questions have not yet been found.

In the debate concerning interpretation, the strong influence of classical particle-mechanistic thinking on the modern world-view and approach to reality has become the subject of increasing criticism. In addition to questions concerning how ideas of determinism, reductionism and localisation shape our understanding of matter, the debate about interpretation also concerns the traditional conception that the subject and the object are independent of one another: can an external observer who is carrying out experiments make objective observations without having an influence on the studied system because of his own actions, and can the theories he constructs based on empirical observations and reason corresponds to reality's actual structure?

Questions dealing with the interpretation of quantum mechanics belong primarily to the domain of the philosophy of science. This precise branch of philosophy, which began to bloom in the 1900s, specialises in problems concerning the basic presuppositions and ways of thinking adopted in scientific enquiry, and in the explication, analysis, and formulation of imprecise, ambiguous or only implicitly-adopted views.[8] Quantum mechanics has already offered philosophers of science copious quantities of material in connection with debates concerning the nature and character of laws, but my proposition is that quantum mechanics could also shed further light on fundamental questions such as the nature, objectives and results of science, and problems associated with the growth and truthfulness of knowledge. If the discussion about the interpretation of quantum mechanics can be seen as a manifestation of a profound change of paradigm in how we conceive reality, a preliminary hypothesis of this study, analysis of the discussion could highlight the nature and methodological role of the presuppositions and hypotheses that have traditionally been the province of scientific philosophers. Also, the discussion regarding interpretation is easier to follow and analyse when seen in the context of long-term research programmes and paradigms.

Even though the philosophy of science has been dealing with the intricate problems associated with the nature and interpretation of scientific theory and its relationship to reality for a long time, some scientific commentators awakened by the profound puzzles in the current state of physics have simply deduced that the problems with the interpretation of quantum mechanics mean the end of science, or at least a limit on its applicability, since in the debate even the

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[8] Niiniluoto 1980, 22, 32-33.

scientific method and its objectives have been questioned.[9] A less-dramatic approach is to view the crisis raised by quantum mechanics as evidence of the ending of the current scientific-philosophical paradigm. It was Niels Bohr's belief that quantum mechanics demonstrated the limitations in the traditional space-time description of classical physics. The mechanistic and deterministic image of nature formed at the beginning of the modern era has provided the background for all research carried out in that era, but its Reductionist and Meristic[10] methodology cannot necessarily explain all aspects of reality. It is quite possible that portraying the whole of reality in the form of a model which assumes that the world consists of distinct and individual parts and research objects cannot succeed. If quantum mechanics is able to reveal that the earlier mechanistic-deterministic paradigm has limitations, the theory can also provide indispensable material for developing a new and more successful way of handling and conceiving reality.

In the twentieth century, modern physics presented radical challenges to earlier modes of thinking and its mathematical tools served to overcame previous limitations, but the metaphysical presuppositions which provide the background to the practice of science have not, even between physicists, changed as radically as Niels Bohr, for example, hoped they would. At the beginning of the 20th century, Bohr and Einstein engaged in an extended debate on the foundations of quantum mechanics, a debate which has been compared to the dispute between Leibniz and Newton in the 1600s concerning basic conceptions of reality. Although the debate between Bohr and Einstein concerned the completeness and consistency of quantum mechanics, the primary source of problems was their differing thoughts concerning language and scientific description. Bohr saw quantum mechanics as complete and consistent, and since the theory was indeterministic and could not be visualised in any single model, he was ready to abandon the traditional way of assigning any visualisable model the status of representing reality. He stressed the epistemological lesson provided by quantum theory together with the complementary manner of description, and emphasised that the natural scientist should not be seen as a purely external observer, but also as an active influencer who causes irreversible qualitative changes in the visible world.

Even though Einstein also rejected classical physics, he did not want to reassess the classical conception of reality on the basis of quantum mechanics. He attempted to hold on to most of

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9 Horgan 1997. Laurikainen 1997.

10 Meristic or atomistic methodology is based on the assumption that material things and natural phenomena can,

existing metaphysics and took the classical conception of reality as a given. As was then customary teaching in classical physics, laws describing reality should be both local and deterministic, and it should be possible to reduce all happening to the properties and movements of actually existing particles. Bohr emphasised the holistic character of quantum mechanics. He did not believe that all the phenomena handled within modern physics could be visualised as real happenings within space-time. The general opinion was that Bohr won the argument, and nowadays it is even possible to prove experimentally that Einstein's locality principle is incorrect.[11]

Bohr's ideas about complementarity and his emphasis on the epistemological lesson provided by quantum mechanics was however largely omitted by physicists continuing the work: in the face of expanding the theory and its practical applications, philosophy has had to give way. In the search for a unified theory, modern research has in a way followed the Einstein road which aims at universal and objective description. Instead of trying to explain the paradoxes in the observed empirical world, physicists have held tightly to mathematical beauty and elegance, believing that everything that exists can be condensed into a small number of basic equations. Quantum field theory first succeeded in unifying electromagnetic and weak nuclear interactions, and strong interactions were subsequently combined into the same (gauge) field theory. Many believe that gravity will also be brought within the so-called ”theory of everything”, even though efforts to bring together quantum theory and the theory of relativity have not so far been successful.[12]

While there can be no doubt that physical theories have developed, understanding the true nature of reality has become more confusing. The abstract equations of physics no longer appear to offer a clear and unequivocal view of the essence of material things. Theories of everything speak of entities such as superstrings that vibrate in multi-dimensional hyperspace, but the question of their actual concrete character remains unanswered.[13] In principle, the majority of the

without problems, be analysed and reduced to their constituent parts which define the whole.

[11] The EPR paradox and the question of locality will be discussed in more detail in Section 4.2.4. and Bohr's and Einsteins views on the nature of physical description are dealt with in Section 4.3.7.

[12] It would be necessary to combine quantum mechanics and the theory of relativity in order to understand the singularity behind a black hole. This extremely small point contains the whole mass of a collapsed star and because of its size, understanding it would necessitate the use of quantum mechanics, which is able to function when distances are small. We do not, however, have a quantum-mechanical version of the general theory of relativity, and we are therefore only able to speculate about how quantum gravity would change our understanding of the fundamental nature of space. We encounter a similar type of problem when we attempting to understand the beginning of the universe. See Parker 1986, 124-126.

[13] John Horgan has interviewed many experts in physics regarding the view that a superstring is neither matter nor energy, but some kind of mathematical ur-stuff that generates matter, energy, space and time but does not itself correspond to anything in our world. Horgan 1998, 71.

objects featuring in modern physics are unlikely to be ever observed. No-one even knows whether protons, photons or quarks are real microscopic objects, or whether the qualities attached to them – spin, parity, charm or flavour etc. - which only become manifest during interactions, should be viewed as independent properties of these objects. The use of words from ordinary language as metaphors outside their normal area of application has proved problematical. For example, the basic substance of quantum fields can be suggested equally well as either real matter or consciousness. [14]

This frustrating state of affairs has resulted in a situation where the task of unveiling the structure of reality, the traditional (and perhaps naïvely-realistic) goal of physics, has given room for different types of instrumentalism or operationalism. Physicists have started to place increased emphasis on the pragmatic value of knowledge while concentrating on the optimal description and control of physical phenomena. These kinds of anti-realist doctrine studied in the philosophy of science do not however provide any answers to the questions of what physics actually is investigating and how the results obtained should be interpreted. Only the traditional quest for truth in the natural sciences makes it possible to truly understand and explain the facts and regularity in nature.

The approach adopted by physicists which avoids the comprehensive philosophical reorientation proposed by Bohr has not provided any solutions to the measurement problems of quantum mechanics, and we cannot, in principle, expect any new light to be thrown on the subject of man's place in reality. Bohr's objective was the complete renewal of the framework of classical physics and his principle of complementarity was a radical reassessment of the relationship between human beings, language and reality. Complementarity is not however generally seen as offering a consistent alternative to the traditional mechanistic-deterministic and visualisable methods of explanation – even though the non-deterministic and non-local features of quantum mechanics cannot be handled within the framework of classical physics. It is obvious that with the passage of time, the essential core of Bohr's approach has grown dimmer and been forgotten. As his ideas have not been analysed in sufficient depth outside the prevailing mechanistic-deterministic paradigm from the wider perspective of natural philosophy, the philosophical value

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[14] Physicists usually think that the abstract equations are connected to matter, but in interpretation discussions references to consciousness are more common. For more detail see Section 4.4.5.

and significance of his thinking have not been generally acknowledged or understood.[15]

Naturally, using nothing but its own resources, physics cannot build the general framework that Bohr proposed for the understanding of reality. Nonetheless, the vital role played by physics in this process should not be underestimated. Physics is the best and most reliable source of information about reality, and its achievements have traditionally limited the possibilities of credible metaphysics. Since quantum theory has now resulted in the questioning of many of the basic assumptions adopted in the modern era by offering new and incompatible empirical material, for example concerning questions of measurement or causality, the metaphysical relevance of physics is once more enhanced. Speaking of metaphysics, or of constructing new metaphysics, is not however viewed as necessary on the basis of classical Realism, Instrumentalism or Positivism. Among physicists, the question of whether the abstract equations of physics could provide new knowledge about a metaphysical basis for reality has not been the subject of serious discussion. One significant exception to this rule is Abner Shimony, who sees that the significance of metaphysics is growing. During the 1900s, in his opinion, natural science has advanced to deal with questions which allowed it to produce empirically-verifiable evidence concerning issues that were earlier classed as metaphysical. Since philosophical criticism has, through both logical and semantic analysis, at the same time become sharper, Shimony suggests that it is possible to talk about hypothetico-deductive, experimental, metaphysics.[16]

Even within the contemporary philosophy of science, it has became apparent that metaphysics, formerly a subject to be avoided, can be the subject of rational discussion. It is possible to extend our understanding of nature through criticism of the conception of reality. Descriptive concepts which incorporate our fundamental ontological assumptions about reality and which help us to understand the meaning of abstract theoretical descriptions should be subject to constant re-evaluation. This is something on which Niels Bohr also placed great emphasis. Suitably interpreted, quantum formalism could become a source of new experiences and metaphors similar to that of Newtonian mechanics in its day. Using this basis, the process of obtaining better insight into the foundations of reality could proceed.

In medieval thought, man occupied a more significant place in the universe than the realm of physical nature, but according to the main current of modern thought, nature holds a more

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[15] Recently, the radical nature of Bohr's philosophy has attracted attention. For example, A. Plotinsky argues that Bohr's philosophy called forth a reconstruction of both classical physics and metaphysics. See Plotinsky 1994.
[16] Shimony 1989, 25-27.

determined and permanent place than man.[17] Mind was separated from matter at the start of the modern era and the traditional mechanistic-deterministic approach employed in natural science did not deal with the reality in which humans act, are cognisant and make their choices. When shaping the world from a mechanistic-deterministic foundation, the computer has provided the best analogy for modelling the human brain, even though the understanding of consciousness as a subjectively-experienced side effect of a physiological process raises many questions. Should we accept the view that our ’inner reality’ really is such a minor and trivial factor in the whole of nature that its influence can be ignored when designing proper theories of everything? As quantum theory seems to demand changes in our understanding concerning the essence of matter, it may open up new possibilities for dealing with psycho-physical problems. Quantum mechanics has added the concept of consciousness to the vocabulary of physics, and it has encouraged some interpreters to outline ontological models which overcome the Cartesian dualism between mind and matter and allow humans to be understood as part of the natural order. In a framework of this type, it is not necessary to exclude from the scientifically-approachable realm such non-algorithmic human skills as understanding, reasoning by means of analogies, qualitative comparison, and choice.

It is currently impossible to predict what impact the collapse of, or serious limitations on, the centuries-old mechanistic-deterministic way of thinking will have. It is certainly not unreasonable to expect as least as far-reaching a revolution as that which took place at the beginning of the modern age when the mechanistic-deterministic way of thinking was adopted.[18] At that point in time, human experience and reason become the source of knowledge. There is no reason to abandon this starting point. Scientific objectivity does not, however, have to be based on the complete ontological separation of subject and object that has been the traditional approach taken by natural science. It is my opinion that additional experience and more-comprehensive theories can now provide the keys to creating an approach which has greater potential for taking account of both how humans influence reality, and what kind of possibilities for future development inter-dependent natural systems may contain.

Research target and the method employed

[17] Burt 1980, 17-18.
[18] Collingwood believed that we live in the midst of a deep crisis concerning the conception of reality, see Collingwood 1960. The same thought is present in the argumentation of many of the physicists in the Copenhagen Group. Their ideas are examined in Section 4.3.1.

This study is an attempt to find out why quantum mechanics still lacks a successful interpretation in spite of a century of deliberation. It covers the long history of human enterprise in understanding reality and our own role in this. In recent centuries, physics has provided the main tools for this enquiry. Classical physics was not just a physical theory, it also had a great impact on the conception of reality prevailing in western culture. It inspired a strong belief in a super-deterministic and clockwork-like universe that controlled all occurrences. For centuries, the presuppositions of the classical paradigm of science offered a productive starting point for all serious inquiry. Only quantum mechanics explicitly forced scientists to consider metaphysical presumptions such as Mechanism, Determinism and Reductionism by bringing with it many characteristics that are not directly explicable within the customary 'classical' world-view. Contrary to common belief, the relationship between the human mind and nature may not be entirely one of detachment, and everything that happens may not be explicable by reducing individual events to mechanical interactions between particles.

In this study, the debate stirred up by quantum mechanics and alternative attempts at its interpretation is investigated against the background of previous conceptions of reality and their changes. To allow proper understanding of the scope and significance of the change that quantum physics has brought about in the customary understanding and conception of reality, Chapter 2 provides a lengthy historical background. This opening chapter presents the conceptual tools we have inherited from the early natural philosophers and reveals the historical continuity behind many of the fundamental questions and distinctions that are relevant when evaluating the unexpected characteristics of quantum theory. Basic understanding of the historical background is a necessity as quantum theory cannot be interpreted within the mechanical and deterministic paradigm of classical physics. My aim is not, however, to embark on a detailed discussion of the history of ideas. The discussion in these supportive 'historical' chapters rests in the main on standard secondary literature and is an expression of the established opinions articulated within the mainstream of western intellectual tradition.[19]

The mechanistic-deterministic way of thinking adopted at the beginning of the modern era, in which the detached observer is considered as having no connection with the object being observed, has had a powerful effect on both western culture's conception of reality and its world-view. Nature is believed to be a material system that obeys deterministic and reductionist laws. This conception of reality may, in the end, turn out to be incorrect. In a historical and

[19] The "historical" chapters concentrate on issues that I consider to be relevant, but in contrast to the established

philosophical context, a conception of reality can be understood as a comprehensive onto-epistemological paradigm or research programme which guides operations in a particular culture in a particular era, and with which scientific conceptions are also in agreement.[20] In the modern era, scientific methods and accepted ways of thinking have been in accordance with the idea of the clockwork-like reality adopted by classical physics. The generally adopted research programme has provided suitable tools for the solving of countless problems that are accessible in its realm. On the other hand, in spite of its usefulness, the employment of a given paradigm may have prevented the identification of such questions or connections that in the light of another paradigm could have been viewed as natural. In particular, the mechanistic-deterministic framework has failed to provide tools for describing human beings and any changes in the objective natural world that may be consequences of our activity.

Discussion in this study is guided by the thought that quantum mechanics might require a radical rethinking of the fundamental ontological and epistemological presuppositions such as mechanical determinism or Cartesian dualism that were adopted by classical physics, as Niels Bohr and the Copenhagen interpretation pointed out. Even though profound revisions of our conception of reality are rare, metaphysical assumptions in western culture concerning reality have been the subject of dramatic change both in antiquity and at the turn of the modern era. The current change could be comparable in its extent, and might provide tools for a reconciliation of the schism between natural science and humanistic concerns that is characteristic of modern times. In contrast to the ”superdeterministic” tendencies typical of classical science, human choice and free will could have a place in the new framework that emerges.

The core of the study consist of the chapters that deal with quantum mechanics and its interpretation. Chapter 4 starts with a brief account of the results from physical research that led to the creation of quantum theory, and describes the theory's main features in common language avoiding mathematics as well as any further interpretation. Analysis of new features of quantum theory such as wave-particle dualism, non-locality, and indeterminism or the measurement problem, helps in understanding why quantum mechanics cannot be understood within the

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requirements for a doctoral dissertation, they do not aim to be original.

[20] The view has been influenced by Kuhn’s paradigms and Lakatos’s research-programs and their hard-cores. Already in 1800s William Whewellin saw that the development of scientific theories and growht of knowledge implied persistent clinging into the accepted theories and starting points. See Kuhn 1970, Lakatos 1970 and Whewell 1860.

mechanistic-deterministic framework of classical physics. The survey in Section 4.3. casts light on the discussion concerning interpretation, revealing how the Copenhagen interpretation required a radical reappraisal of both the previous conception of reality and the role of human beings, while subsequent interpretations have in many ways attempted to find a route back to the classical concept of reality by postulating a variety of auxiliary hypotheses. In spite of the problems, there is a persistent desire to represent nature as deterministic and mechanistic, and to see humans as observers who can provide an objective view of the processes of reality while occupying and preserving an external viewpoint.

Through analysis of the research material, i.e. the structure and interpretations of quantum mechanics, the author seeks to assess the credibility of presuppositions adopted by the classical paradigm. In the spirit of the Thomas Kuhn's philosophical approach, the prolonged problems concerning the interpretation of quantum mechanics could be seen as signifying the confusion and bewilderment associated with the collapse of the modern era’s megaparadigm, the metaphysical ”normal-view” of reality. Bohr refused to accept the assumption in classical physics that theory directly and without problems reflects or corresponds to reality. He tied the basis for scientific description to human experience and language, maintaining that we attempt to create unambiguous descriptions of our experiences, of all the phenomena that we encounter. The complementary descriptions that are available to us approach reality, but none of them can achieve it completely. A “God’s eye view “ of reality is impossible since the observing subject is ontologically part of reality and has an effect on its formation. The obvious advantage of Bohr’s approach concerning the relationship between man and nature becomes clear when discussing the so-called 'measurement problem' in quantum physics. While the classical way of thinking has been unable to provide a satisfactory answer, the whole problem vanishes within Bohr’s framework of complementarity.

In the concluding chapter the author extends Niels Bohr’s philosophy of complementarity and outlines an onto-epistemological framework within which the apparent paradoxes of quantum mechanics could be understood and solved. The proposed model questions the traditional particle-mechanistic ontology of as well as the idea of a detached observer. The question of whether complex quantum state-functions could also be used for the modelling of our internal mental states is posed. As reality is considered to be a multi-layered monistic process which can be influenced by human beings, the external observer of classical physics becomes able to exert a qualitative influence on evolution. All our human capabilities, knowledge, values and goals, can be seen as intertwined and influential ingredients in the dynamic web of reality.

The suggested model aims to provide a synthetic view which is conceivable on the basis of contemporary knowledge. It preserves the foremost objectives of natural science while seeking to give credit to the arts and valued human qualities. It avoids postulated metaphysics, but admittedly contains metaphysical assumptions which cannot be avoided in any world-view or conception of reality. The proposed framework may appear too soft for a hard-core scientist and too technical for a humanist. Whether the current presuppositions are suitable or favourable compared to the ones on which the world-view of modern times has been constructed can only be evaluated in the wider context of the history of philosophy and development of culture. The questions that should be considered are whether they give us a better starting point for understanding the complexities of reality and ourselves, and whether they can help us create a more-preferable relationship with our innermost needs and the needs of the environment in which we live and whose resources we exploit.

2. Formation of the Western Conception of Reality

Throughout history, natural philosophy, both theology and precise scientific research have influenced the formation of the western conception of reality. They have, each in their own way, provided answers to the questions of what is being and how we can know it. The degree to which they are credible, their dominance and their boundaries have changed over time in a way which can be considered an essential part of the development of the conception of reality. For example, natural science became separated from philosophy only in the 1700s,[21] and questions perceived as theological have hardly-ever been in such a peripheral position in the realm of so-called "serious knowledge" as they are nowadays. If the concept of reality changes in a radical manner, it can be assumed that the structure and content of the different ways of approaching reality will also be constituted in a new way.

In attempting to understand reality, western philosophy and metaphysics have since ancient times attempted to move from phenomena to truth, from the fluid to the fixed, and from perception to pure understanding. The basic nature of reality has been sought through concepts

[21] The term ‘scientist’, by which the natural scientist is distinguished from the philosopher, was introduced by W.

such as substance, structure or process. Sometimes, reality has been assumed to have a single foundation, at other times as being constructed of many different parts. The foundation of nature has been found to be both eternal and non-variant as well as dependent on continuing change and motion.

While the terms used in explanation have changed greatly throughout human history, actual physical explanation has managed to get along by using relatively few themes. The terms employed include atomism and continuity, evolution and decay, reduction and holism, universal order and chance, and these appear to be linked through opposition to each other. The emergence of new themes has been exceptional. Bohr's concept of complementarity is said to be one such new theme.[22] In Western philosophy, the object of knowledge is generally thought to be completely independent of the subject, but Bohr's views throw new light on this basic metaphysical presupposition.[23] According to his interpretation, quantum mechanics does not demand that the formation of reality must be thought of as being completely independent of the activity and the existence of the human observer.

A substantial proportion of the ways and concepts we use to perceive and analyse go back to ancient times. In those days, something akin to an immense number of thought experiments were carried out, and these created methods for use in later times. The whole of the later development of western culture is often said to be a commentary on ancient thoughts, and in the deeper processes of change, new elements were typically drawn from this source. For example, the Renaissance, in which the beginning of natural science can be located, drew its strength from the ancient thinkers. The mechanistic and atomistic representation of nature which was created can be easily identified as a heritage of the teachings of the ancient Atomists Leucippus and Democritus.

In the interpretative debate concerning quantum mechanics, many references are made to philosophers, but examination of the ancient debate has, until now, received relatively little attention. In fact, many pre-Socratic natural philosophers dealt with topics that are linked to the same basic questions as those now raised by quantum mechanics. In addition to questions concerning primary substance, motion and change, one subject of intensive discussion among ancient philosophers was the question of whether two items can be in the same place at the same

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Whewell in 1890. Ketonen 1989, 92.

[22] Holton 1978, 10.

[23] Hooker 1972, 186-192.

time.[24] Even a speculation as abstract as this has received new actuality from the consideration of identical particles in quantum mechanics. In addition to connections between individual issues, the whole of the change in the present conception of nature has been compared to the transition from substance to form in ancient thought when the teachings of the Atomists were replaced by Pythagoras' and Plato's ways of thinking.[25] During this Socratic "golden age", philosophers also made human beings, rather than nature, the focus of their attention. If historical cycles and the spiral nature of development are to be trusted, there is hope that the current reassessment of the mechanical way of thinking contains the seeds for a new cultural blooming.[26]

Although analogies and connections to ancient times may be useful in conceptualising the current situation, this does not imply that nothing new has been learned along the way and that no new thinking is required to overcome the present crisis in our world-view. Mathematics has made enormous developments since ancient times, and the number of results and facts from empirical experiments is greater than ever. To overcome ways of viewing and analysing that have their roots in ancient thought, it is, however, necessary to know and recognise them. In spite of its fundamental character, the current interpretative debate has seldom, until now, reached the depths that were plumbed in ancient times. Of the physicists who have attempted to interpret quantum mechanics, Werner Heisenberg is exceptional. He has discussed the connections between modern physics and ancient thought in many of his works, one of which, *Physics and Philosophy*[27], has become a classic of popular science literature.

The survey of the history of natural philosophy and science conducted in this chapter is an attempt to describe those methods of grasping reality that earlier thinking has bequeathed to us.

2.1. Natural Philosophy in Ancient Times

Typically, Greek thought searched for clarifying universal and archetypal principles that helped in understanding the manifold phenomena found in the world.[28] This endeavour took on different forms and was developed to a peak during the era of Plato and Aristotle, but it was clearly apparent in pre-Socratic thinkers. In their detailed natural philosophy, which was a search for

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[24] Sorabji 1988, 44-124.
[25] E.g. Heisenberg 1958 and 2000.
[26] In his book *The Theology of the Natural Philosophers*, Werner Jaeger makes the same point.
[27] Heisenberg 1958.

natural causes, the pre-Socratists made a distinct departure from the earlier tradition of mythic-religious explanation. Although extensive philosophical systems had already been created in early Chinese and Indian thought, the external world did not become an object of independent research in those philosophies. It was only in Greece, when natural science and philosophy were created, that efforts were made to explore the causes of, and connections between, different phenomena.

In Greek Ionia, favourable circumstances for the development of philosophy existed in the period 600-400 B.C. if such an enterprise is seen as requiring leisure time, adequate wealth, and divergent ideas and cultural impulses. Thales (ca. 625-545 B.C.), whose influence can be seen in the Ionian Miletus, is generally regarded as the first natural philosopher and the founder of the so-called Milesian School. Numerous schools representing different viewpoints on natural philosophy developed in Greece. They often maintained contacts of some sort with one another, and the questions posed in their circles were derived from each other. In these circles, philosophising was generally regarded as a kind of adventure or "thought expedition". Ionian natural philosophy never reached a wide audience, but remained more or less an activity engaged in by the elite.[29]

2.1.1 The Substance of Being

In Greek natural philosophy, the starting point is the quest for a basic principle which can explain the colourful variety of myriad phenomena that we observe. Thales, Anaximander, and Anaximenes, all of whom belonged to the Milesian school, were seeking an all-embracing answer to the question of the formation and composition of what existed. They believed that a comprehensible order could be found behind the manifold phenomena observed in the world, i.e. a single fundamental substance or principle out of which everything was formed and which ruled all occurrence. This search to find a natural cause for everything was in opposition to the traditional religions and their mythical narrations explaining creation. The Milesians thus added a new way of explaining to the mythological explanations, one which is usually regarded as pre-scientific. The approach they adopted, which was based on reason and the observation of natural phenomena, turned out to be a fruitful one.[30]

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[28] Tarnas 1998, 3.
[29] Thesleff and Sihvola 1994, 29-32.
[30] Heisenberg 1985, 56. Stenius 1953, 21, 52.

The idea of a single fundamental substance behind all being was conceived by Thales. He postulated water as the unchanging foundation, with all perceivable creatures in the world being formed as variations. This apparently simple explanation could not have been proposed if Thales had not realised that a rational answer based on material causes could be given to the question concerning the nature of Being. A similar search to find natural and basic invariances and fundamentals has directed the whole scientific thinking of later times.[31] Anaximenes proposed air as the primary substance. In depicting its alteration into other physical states (so-called 'aggregate' states), he introduced quite clearly the idea of an original cause or principle that preserves its own essence while undergoing manifold alteration. The same idea appears in the conservation laws of modern physics.[32]

Anaximander portrays the primary substance as the unlimitable and undifferentiable *apeiron*. According to him, the fundamental substance could not be any concretely-perceivable matter, because in the creative processes of reality, all separated elements come into being as opposite pairs out of one undifferentiable primary substance.[33] The same theme was already handled by Hesoidos around 700 B.C. In his epic moral poems, he pictured the *apeiron* as a chaos or a void that contains all opposite qualities: out of this *apeiron* worlds rose and into it they subsequently collapsed. One can find connections between this idea and the modern concept of vacuum, a state which is energy-rich and out of which particle-antiparticle pairs arise together.

Although the Ionians searched for a natural cause to explain the world, they did not abandon the words of the gods. When Thales said that "everything is water and that the world is full of gods," he obviously distinguished gods from the primitive matter that made up the world. Thales' followers replaced his transcendental god with an immanent god embodied in the world. The primary substance was, at one and the same time, matter as well as living and divine. As well as being capable of achieving the motion and changes it desired, it created in itself all the differentiations which can be observed in the world.[34]

The Ionian way of understanding reality was apparently influenced by the language employed. In fact, language has been viewed as having determined both the way of asking questions and the

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[31] Stenius 1953, 20.
[32] Tarnas 1998, 471-472.
[33] Collingwood 1969, 34. Stenius 1953, 24.
[34] Stenius 1953, 34. Collingwood 1969, 40. Tarnas 1998, 19.

starting point adopted by the early natural philosophers. In Greek, the question ‘What is nature and how can it be understood?’ took the form “What are things and organisms made of?”, since the term ‘nature’ originally meant that essence that belonged internally to something or which caused it to be what it was. For example, the nature of oak was to be hard, and barking belonged to a dog. When questioning the nature of nature, the Ionians were seeking its internal principle or a characteristic that made creatures behave as they behaved. It was only later that the word ‘nature’ began to also mean all the objects belonging to nature, in a way that the term might be used as a synonym for the word ‘world’.[35]

The attempt by the Milesian school to understand the world as the differentiation of some primary substance or element has been criticised in later philosophy for the problematic presuppositions associated with the whole endeavour. Whenever there is an attempt to construct cosmology on the basis of some homogenous primary substance, it is necessary to postulate this substance as being the basis for all appearing things. The first result of this is the question of how a clear conception of this non-visible primary substance can be formed simply by thought. Secondly, it should be possible to present a credible explanation of why and in which way this homogenous primary substance differentiates exactly into the world that we observe.[36] Although Ionian speculations about the nature and development of the world are easy to prove non-credible in the light of present knowledge, the question of examining the structure of reality from the starting point of ontology has not enjoyed a clear solution. Western natural philosophy, which is regarded as emphasising ontology, let alone physics, cannot ignore the question of presuppositions. The fact that something about the structure of the world is already assumed cannot be ignored. For example: the assumption that reality is completely determined by laws, or that it ultimately consists precisely of certain kinds of stuff, objects or characteristics. Even if such general ontological statements and presuppositions may seem to be well grounded from an empirical point of view, they still cannot be tested directly.

By defining the primary substance as undifferentiable and unobservable, Anaximander was more successful than either Thales and Anaximenes in avoiding the danger of squeezing reality into a concrete entity of already-known components, a danger which is inherent in the ontological approach. The abstract *apeiron*, the foundation of reality remained unknown and out of reach to human beings. According to Werner Heisenberg, the question of whether the fundamental

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[35] Collingwood 1969, 43-44.

[36] Collingwood 1969, 40-43.

substance may be one of the known elements, or whether it has to be something essentially different, arises in modern physics in a slightly different form. In atomic physics, there is the question of out of which basic particles matter is composed. From atoms, physicists have moved to elementary particles and quarks, but ultimately they strive to construct a general and fundamental equation of motion from which all the characteristics of the particles can be derived in a mathematical way. This fundamental equation may point to some known wave or particle types, or to waves that are essentially different in character and have nothing in common with known types of wave and elementary particle. In the latter case, all the different elementary particles would have their source in some universal substance, and none of them would be any more fundamental than the others. Heisenberg believed that this view, which corresponds to the doctrine of Anaximander, would turn out to be correct.[37]

If such a fundamental metaphysical question about the character of reality can be solved, the questions which the Greek natural philosophers posed on the basis of ontology must be regarded as being fruitful. It is apparently possible to make progress in rational understanding of the nature and structure of reality even though basic presuppositions could never be verified in a direct manner. Hard on the heels of the Milesians, who employed reason and empirical observation in their investigations, ancient thinkers also resorted to mathematics and logic in their attempts to understand reality. Opinions concerning the relationship and the importance of these various ways of acquiring knowledge have changed throughout history, but the contribution of any factor should not be underestimated.

In addition to Being, the fundamental substance and the structure of existence, the question of Becoming also demands some type of solution.[38] How can the ever-changing variety of phenomena that appear to our senses be combined with an unchangeable basis for these same phenomena? Heraclitus[39] (ca. 535-475 B.C.), whose influence was in Ephesus near Miletus, proposed that the basic nature of reality is dynamic and creative, as did Anaximander. He emphasised the change and flux in everything, but unlike the Milesians, Heraclitus did not attempt to reduce the diversity of reality to anything material. The material world was not

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[37] Heisenberg 2000, 70-71.

[38] None of the Ionians made earth the primary substance. They perhaps wanted a substance which could in some way explain its own movement like the ceaseless tossing of the water in a sea or the rushing of the air in the wind. Guthrie 1950, 32.

[39] Heracleitus was one of the best-known of the Greek philosophers, whose inscrutable reputation is largely a result of the broad possibilities in interpreting his teachings. Only 130 aphoristic fragments are left from Heracleitus' works.

permanent, since nobody could step into the same flow twice – today's river consists of different water than yesterday's.

In spite of its ever-changing character, the world of Heraclitus was no chaos. He observed that behind everything, logos or measure has an effect which governs change and preserves balance between the various opposites. Through logos, the world forms a unity in which opposites balance each other out. It is at the same time one and many, and everything that exists has its own 'rule-governed' role in the logos of the universe. This struggle between dynamic opposites results in the most delicate harmony and development, and in their striving towards a static balance, the opposites had created everything in the world including human beings.

The universal logos was associated with fire, an all-embracing principle of life. Fire was not so much an element, but an eternally-continuing process. Heraclitus also regarded the human soul as one form of this universal fire. He believed that while he had received his own wisdom as a result of introspection in the form of some direct empathetic experience of the logos of reality, most people never understood their connection to the logos. Aspiring to worldly pleasures, they lived in continuing disharmony because their souls were in touch with the elements of water and earth, which destroyed the soul's fire. The use of reason, listening to nature and the pursuit of truth both in speech and deed might, however, "dry out" the soul and grant the human being wisdom, so that he or she might become aware of acting in conscious cooperation with the deeper order of the universe.[40]

According to Werner Heisenberg, modern physics is, in a certain sense, very close to the doctrine of Heraclitus, who solved the opposition between Being and Becoming by making change itself the fundamental principle. The "fire", which represents change in Heracleitean philosophy, can be interpreted as both substance and the moving force of matter. If "fire" is replaced by "energy", statements by Heraclitus can be repeated almost word for word using a modern perspective. As it is transforming into motion and heat as well as light, energy is what moves. Also, it is a substance of which the total amount does not change. Experiments examining the creation of elementary particles have shown that energy can be converted to particles; atoms, and other things are made of energy.[41]

A somewhat different solution regarding the problem of primary substance and change was

[40] Stenius 1953, 61-76. Tarnas 1998, 45-46. Thesleff and Sihvola 1994, 45-48.

proposed by Pythagoras [42] (ca. 572-497 B.C.). It is here that the notion that mathematics, i.e. that mathematical order is the basic principle whereby the multiplicity of phenomena can be accounted for, is said to have originated. In the Pythagorean doctrine, mathematics and numbers took a position similar to that of basic matter for the Milesians. The ultimate basis of all Being was no longer envisaged as a material that could be sensed – such as water in the philosophy of Thales – but as an ideal principle of form. In addition to matter the Pythagoreans added the notions of order, proportion and measure. The most essential feature of creatures was the numerical organization and form arising in them, which were governed by numbers, and the colourful multiplicity of phenomena could be understood by recognising in them unitary principles of forms, which could be expressed in the language of mathematics. If different geometric figures represented different qualitative characteristics, the only quality that needed to be attributed to matter was the capability of taking a geometric shape.[43]

By numbers, Pythagoras apparently did not simply refer to whole numbers, but also to numerical ratios and proportions. For him, both forms and numbers represented a deeper order, harmony, hidden behind visible phenomena. Pythagoras is said to have made the famous discovery that vibrating strings under equal tension sound together in harmony if their lengths are in a simple numerical ratio. The harmonious concord of two strings does indeed yield a beautiful sound, and it was certainly one of the momentous discoveries in the history of mankind that mathematical structure, in this case numerical ratio, was a source of harmony and beauty. It is somewhat ironic that the theorem[44] which carries the name of Pythagoras was experienced in ancient Greece as a blow against the idea that numbers could be used as a general basis for explanation. The ability to deal with irrational numbers through geometry did however exist, and this is thought to have laid emphasis on the concept of form in later Greek thinking.[45]

In ancient times, Pythagoras was regarded as both a religious and a scientific figure. The discovery by Pythagoras that the length of a string and its resulting pitch when struck were in numerical ratio to each other was regarded as both a religious revelation and a sign of the fundamental harmony in nature. Students of his esoteric school believed mathematics to be the

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[41] Heisenberg 2000, 72.

[42] Pythagoras was born on the island of Samos off Miletus. He later moved to the western Greek colony of Croton in Italy where he founded an esoteric school in which mystery religions and mathematics were linked.

[43] Guthrie 1950, 39-40. Stenius 1953, 47, 51. Heisenberg 1985, 58.

[44] Pythagoras' theorem about the ratio of the sides in a rectangular triangle was known to the Babylonians at least one thousand years earlier.

[45] Thesleff and Sihvola 1994, 39-40. Heisenberg 1985, 57. Stenius 1953, 45-49.

way of not only understanding nature, but also of achieving spiritual development. When grasped mathematically, reality was completely rational and the revelation of its mysteries was considered to lead the human soul to ecstatic communion with the cosmos. Pythagorean mysticism derived from the Orphic movement. Orpheans viewed the soul as a divine being that was chained to the body as if in a prison or a grave. They sought salvation through ecstatic experiences, while Pythagoras placed his trust in mathematics. Pythagoras claimed to remember his earlier incarnations and was the first Greek to form a consistent doctrine about the transmigration of souls. He also heard the vibrations of the universe.[46]

Apparently, Pythagoras was not very interested in the physical structure of the universe, even though his mathematical approach initiated a development which led to Euclid, Aristarchus and Archimedes and later turned out to be of fundamental importance to later natural research. At the beginning of the modern era Galileo formulated the scientific ideal in the form: "Let us measure everything that can be measured, and let us make measurable everything that cannot yet be measured". Even today, however, there is a dispute over the nature of the numbers and the reasons why they are fit for the portrayal of reality. Quantum theory is regarded as having led to a new appreciation of Pythagoras' ideas, because it allows nature to be represented as a multitude of vibrations with different frequencies. For example, in a much-researched form of unified theory, string theory, almost punctually small strings vibrate in different ways and the different forms of vibration create different particles in direct analogy with the observation by Pythagoras that strings vibrating in different ways create different tunes.[47]

2.1.2. Unchanging Reality

Parmenides (c. 515-450 BC), an inhabitant of Elea, a Greek colony in southern Italy, was critical of the Milesians' proposition that being was based some particular kind of substance. His approach to fundamental truth was based on abstract logic, which proved that something that already existed could not change into something which it was not. Thus one could not become many, and that which was static could not begin to move. According to Parmenides, the whole of the attempt by the Milesians to find a unitary principle of all things was mistaken. They maintained that being was one, but it actually became many when they addressed it. But if only

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[46] Aspelin 1995, 24, 36. Thesleff and Sihvola 1994, 38-39. Tarnas 1998, 23, 46.

[47] Singh 1997, 23. Aspelin 1995, 36-37. The nature of mathematical description will be discussed in more detail in sections 4.4.6 and 5.2.

being is, and unbeing is not, there cannot be anything outside this being which articulates it or can bring about changes. Since unbeing cannot be being, it was impossible for the Milesians to justify change and multiplicity. Being must be conceived as eternal, uniform and unlimited by space and time. [48]

Parmenides considered the senses to be a poor witness when compared to logic. As perceived by the senses, movement, change and multiplicity had to be virtual and subjective, since of necessity, logic reveals true being to be one and unchanging. Specifically, Parmenides criticised Anaksimandros for inconsistency when he treated *apeiron* as a substantial invariant: it was at the same time both a natural law and a basic element out of which everything was composed. Also, Parmenides was in strict opposition to Heraclitus. He did not approve of Heraclites' practice of making fire a changeable principle. Even though it was not, in Heraclites' flowing world-process, necessary for fire to *be* as it changed all the time, in Parmenides' opinion, the fact that it changed destroyed the main point in the search for the basic invariance. Invariance had to be static, it could not be accompanied by change.[49]

Parmenides' conception that fundamental reality had to be static, one and unlimited had a powerful influence on subsequent natural philosophy, whose central problems were questions of the possibilities of change and the relationship between the real world and the world of phenomena.[50] The sense-world revealed by sense perception was generally starting to be accepted as something virtual, and at the same time the perceiving subject was excluded from eternal objective reality. A change perceived by the senses did not signify a change in actual reality. Empedocles (c. 495-435 BC), Anaksagoras (c. 500-428 BC) and at a later date the Atomists attempted to solve the dilemma between Rationalism and Naturalism that was raised by Parmenides by searching for sophisticated compromises. None of them, however, disputed Parmenides' contention that the most-fundamental and truly-existing reality could never be visualised and could never disappear.[51]

Parmenides' unswerving logic was based on a dichotomy that closed out either one option or the other. It typically applied the *reductio ad absurdum* type of argument: when some statement led to a contradiction, the opposite was taken as true. Parmenides' logic also included many crude

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[48] Heisenberg 1985, 56-57. Being was undivided and unlimited as Unbeing could not divide Being from Being. Neither could Being make any divisions. There was only continuous Being.

[49] Stenius 1953, 87-92.

[50] Guthrie 1950, 49-50. Stenius 1953, 95.

mistakes from the modern viewpoint. For example, he did not differentiate between the existential, indicative and predicative use of the verb to be, and he took it as a given that only what actually existed could be addressed. Both Plato and Aristoteles were to point out these problems at a later date. Parmenides' reliance on logic was however a revolutionary step in the history of thought. He had ensured that reality could be accessed through abstract language and organised reasoning without having to resort to sensation, intuition or inherited beliefs. In a more pointed fashion than the Milesians, Parmenides introduced the demands of truth into philosophy. His arguments also indicated the perplexing consequences of taking seriously the thought that only the unchanging can be comprehended and that only the unchanging actually exists.[52]

Empedocles [53], who lived in Sicily, criticised Parmenides for his arrogant starting point, i.e. that humans could approach the whole of reality in a rational manner. He did not believe that the viewpoint of the gods was within the power of mortals[54]. Empedocles did not wish to surrender the whole world of coming into being and passing away as a mere illusion, he wanted us to trust our senses insofar as they gave us clear instructions. He altered Parmenides' contention that non-being was impossible into the claim that emptyness was impossible. In such a case, nothing could arise out of void and everything that existed was material. Movement and multiplicity could be combined with the eternal and changeless so that different materials and objects consisted of four eternal elements: earth, fire, air and water.[55] This is the first example of what may be called a 'corpuscular' theory of matter. Its essential feature is the assumption that all processes in inanimate nature really consist of imperceptible corpuscles of particles which persist in unchanged form thoughout all processes. Elements are mixed in different materials in different proportions, but their total quantity remains unchanged. 'Birth' and 'death' are just words used to describe the combination and division of elements.[56]

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51 Tarnas 1998, 21.

52 Guthrie 1950, 47-50. Thesleff ja Sihvola 1994, 50-53.

53 In antiquity, Empedoklesta was highly valued. The later Greek philosophers (following Plato and Aristotle) refer to him repeatedly as the creator of the theory of elements and therefore as the creator of physics itself. He expressed his thoughts in poetic form and tried to achieve a synthetis between the study of nature and religious mysticism. Jaeger 1947, 129. 131-133.

54 Parmenides had said that he had been greeted by Truth herself and had received a revelation such as no mortal either before him or after him could ever enjoy. Unlike his all-too-confident predessor, Empedocles does not demand knowledge but asks the Muse to bestow on him 'as much (of her wisdom) as is becoming for ephemeral man to hear'. Jaeger 1947, 134- 136. A considerable quantity of Empedocles' texts are still available. In English, see Empedocles 1981. (The Extant Fragments. Edit., with an Introduction, Commentary, and Concordance by M.R. Wright. New Haven and London. Yale University Press. 1981.)

55 In contrast to the earlier philosophers who had singled out one basic substance, Empedocles concluded that they all stood on equal terms as there was not a single primal stuff but several. In contrast to Parmenides, he concluded that Being is not monistic but a plurality. Kenny 1998, 13-14.

56 Dijksterhuis 1986, 9. Jaeger 1947, 137. Stenius 1953, 107-125.

Empedocles believed that the combining and dividing of elements followed from the power of Love to unite and the power of Strife to divide. When the world was formed, the different elements had been combined in a loving association, but the power of Strife had caused them to diverge. This in turn led to an idea of development which has points of contact with Darwin's theory of evolution and natural selection. In the end, elements powered by Love started to move closer together again, and this marked a return to the initial condition. The names Love and Strife given by Empedocles do not only stand for 'Attraction' and 'Repulsion', but for two forces that reign throughout the inorganic and organic worlds. Empedocles seeks to understand inorganic processes in terms of organic life rather than vice versa.[57]

The Athenian Anaksagoras (ca 460 BC) criticised the view taken by Empedocles. In explaining the multiplicity of beings, Anaksagoras was also not satisfied with Empedocles' four elements, he believed they consisted of countless different minute qualities which had substantive properties. Qualitative change in beings should be understood as different mixings and separations of these qualities, and all these countless qualities must have been contained in the primal mass at the outset. Empedocles did not postulate any kind of unchanging reality existing behind what could be observed, but Anaksagoras maintained that movement was caused by a transcendental will, the 'Nous', which gave the universe both form and order.[58]

Anaksagoras was a purist who could not believe like Empedocles that in a material universe, observed movements could be the result of a struggle for power between semi-mythical Love and Strife. With Anaksagoras, the philosophy of nature for the first time consciously encounters the problem of mind. He realised that humans did not consist entirely of flesh, hair, bones, nails and sinews, and he tried to find a place for the reality of mind in the scheme of the world. When mind was not present in all things but merely in some, he concluded that mind was something that was not mixed with the other infinitely-many materials and qualities mingled into the things of nature. We have his own words on this point. A lengthy passage begins 'Everything else has a share of everything: mind, however, is infinite and self-ruling, and is mixed with nothing, but is alone, itself by itself.[59]

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[57] Jaeger 1947, 138.
[58] Stenius 1953, 133-138, Tarnas 1998, 21. Jaeger 1947, 159.
[59] Jaeger 1947, 160.

Zeno (ca. 490-430 BC) from Elea and his contemporary Melissos from the island of Samos admired Parmenides and endeavoured to prove his teachings correct. Since the universe was one, indivisible and unchanging, the multiplicity of different things and materials and their movement were illusory, only phenomena connected with the human world of sensations. Zeno developed an ingenious series of paradoxes to show that movement was inconceivable. His flying arrow and the paradox of Achilles and the Tortoise have found their place in almost every popular volume on the history of philosophy . At public lectures, Zeno astonished his audience by arguing that a flying arrow could not really be moving because if it was, it could never be in a certain point. If, on the other hand, it was actually in a certain position, it could not also be moving to somewhere else. It therefore never moved. Achilles was a famous athletic who according to Zeno could never catch up with the tortoise that was walking ahead of him. In the time that Achilles runs halfway to the tortoise it moves forwards, and so in each of the time intervals that Achilles attempts to make up the gap, the tortoise opens up a new one, and so on *ad infinitum.*

Later, Aristoteles commented extensively on Zeno's paradox. He pointed out that it was not possible to speak of movement in a single moment, because the observation of movement always required that the time be checked at least twice. The impossibility of observing movement in a single moment, however, does not provide an acceptable solution to the generally accepted idea that a body is in a specific position at a specific time. The differential calculus developed by Leibniz and Newton in the 1600s made it possible to calculate both the trajectory of the arrow and the point at which Achilles overtook the tortoise. This approach may not remove all the problems connected with Zeno's paradox concerning the divisibility of time and movement, and the concept of infinity, since these are still of interest to philosophers and mathematicians.[61] There is no common opinion about whether it is legitimate to assume, as Zeno does, that distances are infinitely divisible.

A glimpse of the concept of unchanging reality originating from the school of Parmenides has been preserved in the modern notion of invariant natural laws. The same tradition of thought is also reflected in the oft-repeated argument that only atoms or other tiny building blocks of material are somehow real whereas the qualitative changes and emergence in the multiple constructions that we can observe is only phenomenal.

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[60] Stenius 1953, 133-138, Tarnas 1998, 21. Jaeger 1947, 159.

The antique Atomists Leukippos and Democritus[62], who influenced the Ionian colony in Southern Thrace in the second half of the 4th century B.C., searched for the primary substance common to all material things in the same way as other Ionian philosophers. At the same time, they also attempted to respond to Parmenides' argument which rejected change and multiplicity. The Atomists' basic solution was the same as that of Empedocles and Anaksagoras. The infinite multiplicity of things and phenomena was reduced to tiny building blocks, atoms, which could mingle with each other, either combine or divide, in various proportions.[63] The eternal atoms were too small to be detected by the senses, they were infinite in number, and they came in infinitely-many different kinds. The atoms moved in infinite empty space which was called 'the void'.[64]

According to the Atomists, the eternal and indestructible atoms moving in empty space were what truly existed, but their movement was made possible by the empty space between them. In addition to being, non-being continued to exist as a possibility for both movement and form, or, in other words, as empty space. The antithesis of being and non-being in the philosophy of Parmenides is here made coarser into that of full and void. The Atomists broke up Parmenides' sphere of being into small fragments and scattered these fragments in what the Eleatics had called non-being, i.e. the void. While, according to Parmenides, the whole of reality was like a single eternal and indivisible atom, the Atomists placed an infinite number of these in the void. Democritus did not see any reason why this non-being, empty space in which atoms could move, could not actually be being. It merely divided something that was single and indivisible into many parts.[66]

From the contemporary viewpoint, the atomic hypothesis seems to go a long way in the right direction when it reduces the whole multiplicity of diverse phenomena, the many observed properties of matter, to the position and motion of atoms. On the other hand, the atom thus becomes a mere building block of matter, and considering the properties, positions, and

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61 Thesleff ja Sihvola 1994, 54-55.

62 Only a few fragments written by the Atomists are available, but their ideas are often referred to in secondary literature without a clear distinction between these two thinkers being drawn. Theskeff and Sihvola 1994, 63.

63 The multifarious phenomena detectable in nature were born out of different arrangements and movements of atoms just like comedy and tragedy which could both written with same letters.

64 Kenny 1998, 16-17. Stenius 1953, 159-163. The atomists also developed the thoughts of Melissos. In his search to establish the ideal of Parmenides' teachings, Melissos identified the invariant and that which is, and filled the whole of infinite space with being.

65 Heisenberg 1985, 46, 57.

66 Stenius 1953, 156. Thesleff ja Sihvola 1994, 64-66. Dijksterhuis 1986, 9.

movement of atoms in space is something quite different from what was meant by the original concept of being. When atoms also have a finite extension, we run the risk of losing all the simplicity that was hoped for by adopting the idea of the smallest components of matter. As soon as they have spatial properties, we can ask difficult questions about the structure and divisibility of atoms.[67]

A fundamental tenet of antique Atomism is that matter is not infinitely divisible. According to Democritus, if we take any chunk of any kind of stuff and divide it up as far as we can, we will have to come to a halt at the point when we reach tiny bodies which are indivisible. Leukippos and Democritus understood that if that which existed was infinitely divided, then every tiny fragment of material was just as “huge” and “multiplicitous” as the whole universe. To put it another way, this was the way in which the early Atomists conceived that two infinite wholes could be as large as one another, even if one was actually part of the other[68], and thus they postulated that atoms were eternal and indivisible. In modern atomism, this ancient thinking on the problem of division has been forgotten and indivisibility is treated more ‘physically’ than ‘logically and mathematically’. However, the question of the divisibility or indivisibility of quanta has brought this problem back into the arena.[69]

The Atomists defined atomic properties in theoretical and quantitative terms without making any direct references to normal sensory properties. Atoms had a specific form in space, but they did not have colour, taste or smell. According to Democritus, questions of the nature of reality could not be answered directly on the basis of sensory phenomena, since sensory evidence was undeniably subjective and possibly misleading. One person would sense water as cold, another would sense it as warm. Because atoms had only quantitative and measurable properties in Democritus’ teaching, in his epistemology one can see an attempt to draw a line between objective quantitative knowledge and subjective qualitative knowledge.[70] Democritus divided primary and secondary qualities in a manner similar to that used later by, for example, Galilei, Descartes and Locke. Primary properties were those possessed by the objects themselves, while secondary qualities arose out of the effect of these entities on our senses. As an example of this, sweetness and saltiness were considered to be no more than subjective phenomena which did not

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[67] Heisenberg 1985, 46-47, 57.

[68] Kenny 1998, 16. This notice is comparable to the definition of infinity in contemporary logic.

[69] Ketonen 1989, 6. Stenius 1953, 168.

[70] Thesleff and Sihvola 1994, 66, 68.

belong to actual reality.[71]

The teachings of the Atomists completely rejected the idea that nature had some kind of purpose or striving for cosmic justice. Democritus did not attempt to describe the details of how atoms were part of material things and events, but he explained everything else in terms of the motion of atoms. The causes of this motion, however remained a mystery. The Atomists had rejected any kind of teleology, and by rejecting the idea of any kind of cosmic power sources they also neglected the question of how movement began, as Aristoteles in his time noted. Whereas Heraclitus' Logos, Empedocles' Love and Strife, and Anaksagoras' Nous were certain kind of causes whose efforts resulted in movement, the Atomists sort of turned everything upside down by making the movements of microscopic atoms in the void into the basis for material and the macroscopic world. According to some researchers, Atomists seeking the cause of movement followed Anaksagoras and hypothesised that some kind of rotating whirl motion was a basic movement in the cosmos. The origin of this circular motion was perhaps no longer being questioned since the Ionians of old understood movement as a natural property of all material; basic elements such as air and fire appeared to move by themselves.[72] The birth of any new body or system did however require that particles should come into contact with each other. According to Leukippos, atoms did not move at random, everything that happened was the result of irresistible mechanical causes.

In the opinion of the atomists, the soul was formed of extremely smooth and fine atoms and was also subject to the same inevitability as other happenings in nature. Knowing and thinking were explained by the influence of atoms on the senses in a way that the soul material received fine films or skins of atoms which objects were constantly throwing off from their surfaces. These particular films more or less retained the shape of the object as they drift through the air to the eye, thus stimulating the human sense organs.[73] In this way, humans received a subjective impression of the external world, but no certain knowledge. The finest part of the soul was anyway capable of searching for lasting truths in the fields of, among others, mathematics and atoms. The teachings of the Atomists were later adapted by Epicurus (ca. 300 B.C.), a well-

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[71] Stenius 1953, 170. Democritus explained in detail how different flavours result from different kinds of atom. Smells, colours, sounds and qualities which could be felt were similarly explained by the properties and relationships of the underlying atoms. Kenny 1998, 17.

[72] Thesleff ja Sihvola 1994, 60, 67.

known materialist who attempted to pin down the material of the soul in a concrete manner. He considered it to be just as much a part of the human being as a hand or a leg, and that it consisted of very small and rapidly-moving atoms. Epicurus fiercely rejected the Pythagorean viewpoint that the soul's relationship to the body was that of a musical harmony, i.e. that the soul was just a condition of the body which was released by death.[74]

Epicurus took a very suspicious attitude to all forms of speculation which did not have an immediate target in objective reality. In his approach he strongly linked Atomist teachings aimed at uncovering the structure of reality to a set of moral values in his ethical programme[75], but he has also been seen as trivialising the essential scientific theories of the Atomist school. For example, Epicurus rejected Democritus' solid logic when maintaining that atoms could, occasionally, deviate from their normal behaviour with extremely small, spontaneous deflections. By this change he wanted to make understandable how atoms moving in space could meet each other. At the same time, he tried to save his teachings from accusations concerening fatalism which appeared to be a consequence of consistent determinism. By disputing lessons of inevitability, Epicurus guaranteed a place for free will, whose location in a deterministic world is a source of problems.[76]

Democritus' description of nature in terms of the interplay of countless atoms in empty space left no room for teleology or the deification of any moving forces or single primal ground. Nevertheless, he saw a serious epistemological problem in the very existence of religious ideas in the human mind. In his opinion, talk about gods could also be explained as material "films or membranes" which flew through space. Gods consisted of a combination of particularly-strong and long-lived fine atoms which in normal circumstances did not attempt to influence the life of humans, but could appear to people, for example, in dreams. They could also inspire poets, prophets and sages. The term *enthúsiasmos*, which means 'a situation in which a god has stepped inside a man' is said to have been first used by the Atomists.[77]

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[73] Guthrie 1950, 59. Explanations concerning the behaviour of these films when they encountered human sense organs were quite detailed and complex. For example, measurement of the amount of air coming to the eye before a certain film revealed distance. The films pushing ahead dark or clear air also provided an explanation for why we are able to see from a dark room into a lighted one but not vice versa. Ketonen 1989, 10.

[74] Ketonen 1961, 8-14. Stenius 1953, 170-174.

[75] Through his consistent world-view, Epicurus was attempting to liberate people from being unnecessarily afraid or having vain wishes. The gospel that the soul disappeared in death and nothing new could happen in the world had a special appeal to the weak and powerless and gave them peace of mind. Ketonen 1961, 17-21.

[76] Aspelin 1995, 127-128. Ketonen 1961, 4, 7. Dijksterhuis 1986, 13.

[77] Jaeger 1947, 180. Thesleff and Sihvola 1994, 68.

Even though the teachings of the antique Atomists were speculative and much more general and imprecise than that of the later doctrine of atoms in physics based on experiments, common to both was a mechanical approach to nature in which every event and change could be attributed to a mechanical cause, i.e. to the deterministically moving particles. The mechanistic approach to nature adopted at the beginnning of the modern era represented a workable starting point for the collection of experimental evidence and can be seen as a prerequisite for the modern scientific programme. Science and more detailed research did not, however, prove the mechanical atomistic approach to nature to be correct.[78] The elementary particles of modern physics are very abstract compared to the atoms of the Greeks. They are not eternal and indestructible units of material as Democritus' atoms were, but can be destroyed and created through collisions. Even though elementary particles continue to be thought of as consisting of indivisible quarks, these quarks cannot be individually identified. Collisions between particles in high-energy accelerators do not produce quarks, only other elementary particles which are essentially as large as the original particles.

Even the basic qualities of atoms proposed by the Greek Atomists, i.e. movement and a specific form and location in space, are not consistent with modern elementary particles. They can be described as concrete particles in specific situations, but in other connections their portrayal has required reference to waves. To present the basic construction of modern 'atoms' in a fully 'accurate' manner, quantum mechanics is only able to offer a mathematical probability function.[79] The particle-mechanistic way of thinking of classical physics inherited from the ancient Atomists is not able to offer explanations for the new features and observations of quantum mechanics. Thus the speculation by pre-Socratic philosophers about the basic substance of reality and its division have once again come to the fore. In contrast to what physicists in recent centuries generally believed, no final answers have been found to the problems concerning one and many, being and non-being, or temporal and eternal.

In the Socratic bloom of ancient thinking, Plato and Aristotle adapted and employed pre-Socratic ideas when forming their extensive philosophic teachings. In particular, they opposed the mechanical materialism of the atomic school which abandoned teleology. Plato is said to have even proposed that the works of the Atomists should be destroyed, as he considered their

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[78] Stenius 1953, 170-171.
[79] Heisenberg 2000, 79.

teachings to be dangerous.[80] In his own philosophy, Plato rejected the Atomists' starting point that the world as experienced by our senses was the whole of reality. Side-by-side with the changeable sense-world, he placed an invariant and eternal world of ideas which the incomplete sense-world reflected. Aristotle was strongly critical of earlier approaches to change and movement. He was not satisfied with the explanation that all happenings were just unintentional collisions between atoms. According to Aristotle, the Atomists had not made motion any more understandable than earlier pre-Socratic philosophers. They had not put forward any cause for the inevitability of movement or a clear conception of how and why change took place. Aristotle's own teachings on movement cited several causes, and he saw no logical objection for combining final causes with natural laws.[81]

2.1.3. The Golden Age of Form

The focus of thought shifted from Milesia to Athens when Ionia lost its cultural and political vigour as a result of the Persian wars. The most glorious days of Ancient Greece were in the fifth century BC, during fifty years of peace prior to the conquests of Alexander the Great. Athens became a unique melting pot for new thinking and, in the opinion of its inhabitants, the civilization and culture of the city was superior to anything that had gone before. Their urban society was dominated to such an extent by the belief that humans could achieve unlimited possibilities and any purpose whatsoever that it is reasonable to speak of a "general belief" in progress. [82]

Through their search for natural causes, the Ionian natural philosophers had obviously somewhat rocked the position of earlier mythology-based thinking, but it was only in the Athenian period that earlier religious conceptions of reality were generally replaced by a more scientific way of seeing: events stopped being viewed as the designs of mythical and capricious gods. Little by little, because of many differing explanations and baffling paradoxes, a reaction against physical speculation also set in. People were not satisfied with the incomprehensible and remote view of the world presented by natural philosophers and they began to question the ability of the intellect to obtain real knowledge about the cosmos. A new class of philosophers, the Sophists, who

80 Thesleff ja Sihvola 1994, 63, 66.
81 Stenius 1953, 169-173, 190. Aristoteles 1992 , 31, 101.
82 Kenny, 1998, 19-20. Thesleff and Sihvola 1994, 73-76.

shared a common scepticism, a mistrust of the possibility of absolute knowledge, rose to prominence. They doubted all human beliefs and in their opinion, the pre-Socratics had failed to create an understandable world-view. Speculation concerning natural philosophy started to be regarded as a waste of time and estranged from reality, and philosophy focused on problems associated with human life, society and culture.[83]

The Sophists were peripatetic teachers of wisdom, who came to Athens from different directions and based their activity as teachers upon the idea of the *physis* of man. Philosophical thinking began to view man's character as part of the nature of the universe and it was believed that society and the state arose from the natural dispositions and general laws of human nature.[84] Philosophy was therefore expected to concentrate on the search for solutions to both political and pedagogical problems. Using similar rhetorical and dialectic skills to those employed by Zeno in addressing the visualisation of movement, the Sophists questioned existing traditions and preached new cultural ideals. They believed they could persuade the mob to follow almost any opinion and the training they offered in civil and political presentation was in widespread demand.[85] The value of beliefs and opinions began to be more generally seen in the extent to which they were beneficial, i.e. how well they served the needs of each individual. According to the teachings of Protagoras, a well-known pedagogue and social philosopher, humans were the measure of everything. As truth was relative and changed from person to person and from culture to culture, each individual person could only trust their own personal beliefs. In addition to the Sophists, the Sceptics systematically doubted all dogmatism. In their opinion, two alleged truths could only be compared by appealing to some third criterion which also lacked a firm foundation.[86]

It is possible to draw parallels between this cultural situation and present times. The belief in old values and gods had been lost, and science had not been able to fulfil all the expectations invested in it. Disappointment in continuous progress resulted in there being space for trends which are reminiscent of modern Relativism and Postmodernism. A similar period of scepticism and relativism occurred in Europe following the Renaissance, when the collapse of the restrictive world order of the Middle Ages led to a period of freedom and creativity, but also to many

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83 Guthrie 1950, 63-66.
84 Jaeger 1947, 175.
85 Because of the new democratic system, lower-class citizens (if they were males and not slaves) could also progress if they mastered the skill of convincing rhetoric.
86 Aspelin 1995, 62-63. Stenius 1953, 174-182, Tarnas 1998, 26-30, 77.

irreconcilable opinions and explanations.[87] The widespread uncertainty which prevailed at the beginning of this new age led Descartes to search for a new basis for certain knowledge. The mechanistic-deterministic research programme of the modern era was to a great extent based on his thinking. These issues are further discussed in sections 2.3.2. and 3.1. of this thesis.

During the crisis phase of antiquity, Socrates and Plato fought back against Scepticism and Relativism. They did not accept that truth was subjective: it could not depend on human will or the strength given by power. The anarchy of opinions could only be overcome if politics, morality and pedagogy could be treated via the scientific method. While defenders of the rule of strength such as the Sophists claimed that terms such as virtue, justice or beauty were just words, i.e. names given by human customs and conventions, Socrates believed that such concepts might refer to something real and durable. Making such a kind of reality understandable was the task of philosophy and this assignment was something that his student Plato made all his own. Plato wished to make ethics and politics into scientific disciplines which employed methods just as sure and certain as those used by measurement and medicine.[88]

Plato

Plato (427-347 BC) began the development of his extensive philosophy by searching for a durable foundation for ethical terms. In the beginning, he concentrated on studying the concept of virtue, how humans perceived their desires in different situations and how they could choose what was right and good. Plato maintained that all the objects of knowledge, i.e. things which could be defined, did exist, but were not to be identified with anything in the perceptible world. We could be good, beautiful, big or small, as we had a part in an ideal world outside space and time. This participation anchored our existence in eternal and unchanging ideas: the Idea of Good, the Idea of Beauty, the Idea of Big or the Idea of Small. Thus Virtue had its complete and independent existence outside our minds in the eternal and unchanging world of Ideas, but it could, via people, be manifested in the changing sense-world in a more or less complete manner.

Everything that was manifested in the visible sense-world had its origin in a higher reality, in the world of Ideas.[89] To Plato, the world of Ideas (i.e. forms and patterns) was more real than the

87 Tarnas 1998, 276.
88 Aspelin 1995, 84-84.
89 Guthrie 1950, 87-90.

perceived and changing sense-world which received its form and its properties via the timeless universals. By drawing a line between the eternal world of Ideas and the changing world of the senses, Plato made a synthesis of the teachings of Parmenides and Heraclitus.[90] The objective world of Ideas contained eternal and perfect prototypes of the natural world. It was a reality of its own, accessible only to reason, it was not born and it did not perish. Accompanying this was the continuously-changing reality that could be perceived by the senses, something that was born in specific locations and which would at some moment disappear as if it had never existed.[91]

Plato’s philosophy was throughout humanistic. He brought together morality and metaphysics and wanted to see the world as a rational and significant whole that could be comprehended by the application of human reason. In certain respects, he rejected the platitudinous and trivial scientific explanations of the pre-Socratics that he had admired in his youth. At the same time, the main feature of Plato’s philosophy was an orderly conception of the being constructed according to mathematical laws.[92] In this way, Plato did not perhaps so much reject the reality examined by natural philosophers, he simply inhabited it with new issues concerning human life and society which he considered to be more important than physical speculation. To Plato, knowledge of Virtue or Justice was not by nature any different to other types of theoretical knowledge. To him, the whole of the search for knowledge was a search for the eternal and unchanging ”Ideas”. In the same way that moral behaviour required certain ideas, science required other universal ideas so that the chaos of the sense-world, change and multiplicity could be made understandable. By representing different aspects of reality, philosophy should move from the particular to the universal, from appearance to a deeper understanding of the real nature of things.

Plato undoubtedly espoused the Pythagorean concept of the significance of form. According to Plato, mathematical ideas, numbers and geometry which could be approached by reason represented hidden explanations or causes for the organisational structure of the universe. Idea, the form, was the truly fundamental pattern behind all phenomena. The visible world had been created when God gave the elements form with the help of ideas and numbers, attempting to make them as beautiful and good as possible.[93] Numbers became paradigmatic representations of

[90] Ketonen 1989, 34. Stenius 1953, 177-184.
[91] Plato 1982, 171, 196-197. (28b-c,52a)
[92] Ketonen 1989, 24-27, 40-41.
[93] Platon 1982, 198. (53,b).

the deeper world of ideas, even though it was not necessary for all ideas or forms[94] to be mathematical. Plato contrasts the imperfect shapes of the corporal world of the senses with the perfect forms of mathematics. Material things are copies, shadow images of the ideal shapes in eternal reality.[95]

Plato's dualistic teachings concerning the two worlds was in agreement with the old Pythagorean-Orphistic view of the soul and the body. The body was the way in which humans participated in the incessant changes and happenings of the world, while the soul belonged in essence to the eternal world of ideas. Even though the universal principles were manifested as specific objects on the sense-world, experiences resulting from the sense-world did not, in Plato's opinion, offer real knowledge, only opinions with a propensity to mislead. If a human wished to obtain infallible and correct knowledge, he had to use his reason and intuition to address the eternal world of Ideas. Knowledge (Greek: *episteme*) always concerned the immutable and the transcendental, while the temporal and perceived world could be no more than the subject of supposition or assumption (Greek: *doxa*). The logical inevitability of ideas could be revealed either by transcendental meditation or by analysing empirical experience using strict dialectic and mathematical methods. The human being's eternal soul could also recall knowledge which it had possessed at an earlier time. Astronomical contemplation and interpretation of the movements of heavenly bodies offered a direct route to understanding the deepest conceptions of reality, while the geometry of the heavens and the gods were, in Plato's way of thinking, indissolubly intertwined. The movements of the gods were revealed in the moving geometry in the sky.[96]

For Plato, Ideas were not neutral objects to be addressed in a cold and analytical manner, they were rather deep transcendental entities which awakened intense feelings and even mystic exaltation in philosophers and lovers of wisdom. There was some kind of internal connection between the absolute universals, forms and ideas which ruled and explained the chaos of life and the mythical beings: On one hand, Plato spoke of Ideas as abstract archetypes, on the other as godlike and mythical figures. For both Plato and Pythagoras, discovery of the mathematical forms that controlled reality revealed a godlike intelligence in transcendental perfection. After Plato, ancient thinking and neo-Platonism reiterated the view of an intelligence controlling and

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94 Plato used the Greek words "idea" and "eidos" (form) interchangeably. Tarnas 1998, 6.

95 This idea is elaborated in the discussion concerning wavefunctions in Section 5.2.1. In Heisenberg's words, we are nowadays tempted to continue Plato's thinking: these ideal shapes are actual because and insofar as they become "act"-ive in material events. Heisenberg 1985, 58.

regulating the universe. The terms *logos* and *nous* referred to both the human intellect and godly intelligence, and little by little they came to mean the transcendental source of all archetypes. The philosopher's task was to address the internal links to this highest spiritual-rational principle which was connected to both the universal order and organisation of the cosmos and the possibility of obtaining knowledge about it.[97]

Plato presented his conception of the universe in his *Timaios*. [98] This dense text is generally accepted as a summary of the questions concerning natural philosophy, astronomy and biology that were treated in his academy, and it is also the central source for information concerning the handling of scientific questions in the third century BC and earlier.[99] In addition to the creation and construction of the world, Plato dealt with individual subjects as different as the creation and construction of compounds and the birth of sense perception in great detail. In *Timaios*, Plato actually identified three different categories in reality. In addition to the perceived forms that corresponded to the forms of the eternal Ideas, the sense-world required an undifferentiated substance that could take any form, depending on the forms that penetrated it. This formless substance could appear in any form as it became influenced by them.[100] As Empedocles had earlier postulated, all extended material forms consisted of the same four primary materials or elements: earth, fire, air and water. Plato employed the teachings of Pythagoras in comparing these elements with regular solids, tiny particles whose properties resulted from their distinct geometric form. Earth, which was heavy and slow-moving, consisted of cubes, fire consisted of regular tetrahedrons, fire consisted of regular octahedrons, and water consisted of icosahedrons. Form was related to the quality of each element. The regular solids were to serve as symbols for certain tendencies in the physical behaviour of matter.

The regural solids were not strictly atoms, i.e. they were not the indivisible basic units of Materialist philosophy. Plato regarded them as composed from the triangles that formed their surfaces: by exchanging triangles, these smallest particles could be commuted into each other. Particles could be dismantled and reconstructed. The collision of particles in different conditions could result in the elements changing into one another. [101] In this way, Plato was able to escape the problem of the infinite divisibility of matter. As two-dimensional surfaces, triangles were not

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[96] Collingwood 1960, 55. Tarnas 1998, 6-9, 53-54. Aspelin 1995, 88-90.
[97] Tarnas 1998, 13, 41, 46-47.
[98] Platon 1982,159-245. (17a-92d)
[99] Thesleff and Sihvola 1994, 145-147.
[100] Platon 1982,194-195. (50c-e)
[101] Platon 1982, 198-201. (53d-56a,57a-d.) Heisenberg 1985, 48.

bodies, they were no longer matter, and matter could not therefore be further divided *ad infinitum.* The limits of material structure were no longer set by matter itself, but by mathematical form or symmetry which thus became the most important factor in substance. The form, certain structure underlying phenomena, determines the material objects. Fundamentally they do not result from collisions with other material objects such as the atoms of Democritus.

In the opinion of many, modern physics has strengthened belief in the fundamental nature of mathematical structure, i.e. that mathematical structures control the organisation of nature. In interpreting quantum mechanics, numerous modern-day physicists such as Roger Penrose and Roland Omnès, have been powerful advocates of Platonism who consider Plato's *logos* to be a reasonable hypothesis that is worth taking seriously.[102] Werner Heisenberg believed that Plato was very much closer to the truth about the structure of matter than either Leucippus or Democritus. Modern physics favours Plato because the smallest units of matter are not physical objects in the ordinary sense of the word. They are forms, structures – or in the Platonic sense, Ideas which can only be spoken of in an unambiguous manner using the language of mathematics. Heisenberg even suggested that the development of physics could, via mathematical symmetry, lead to a holistic understanding of the structure of matter - a goal that also inspired Plato.[103]

As with the pre-Socratics, the objective of knowledge for Plato was the discovery of invariance. The Greeks identified only static invariances as truly existing, which caused certain problems in the real understanding of change and multiplicity. The doctrine of Ideas did not offer a clear vision of the relationship between the invariant Idea-world and the continuously-changing sense-world. Plato explained the world perceived by the senses as a manifestation of the eternal Ideas indicating that the creation of this world had happened according to the model offered by Idea-world. When it was necessary, however, to shape the sense-world out of chaotic material, movement remained as a component of the world.[104] In handling movement, Plato emphasised that it did not actually appear in any locations where matter was homogeneous. In addition to non-homogeneous matter, movement required interaction: something that was being moved could not exist without something that moved it. In this respect, Plato's vision of the relationship between the elements and movement is reminiscent of modern physics' four basic interactions. According to Plato, initiating movement in each element required something that attracted its

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[102] Omnès 1999, 273. Penrose 1990.
[103] Heisenberg 1985, 46, 51, Heisenberg 1971, 6-7.
[104] Stenius 1953, 185.

own quality.[105]

Plato's influence on the formation of European culture has probably been as great as that of the Atomists. Even though his influence on the explanation of phenomena that belong within the realm of the natural sciences cannot be taken as being small, Plato above all proclaimed the eternal nature of the spirit and its uniqueness in comparison to perishable materials.[106] To Plato, the essential nature characterising beings was their soul and aliveness. When creating the world, Demiurgi located understanding in the soul and located the soul in the body. According to his providence, the universe came equipped with life, soul and intellect. The corporal body of the universe could be seen, but its soul was invisible and consisted of three parts: the same, the different, and the existing. The soul's notice of the same and the different was true, since it was born out of its own movements around itself without either speech or sound. When the soul is dealing with something that is born and perceivable with the senses, only opinions and beliefs can be born which however at their best may be reliable and veracious.[107]

Aristotle

While Plato attempted to use the intellect to go beyond the sense-world and discover a transcendental order that lay behind it, his student Aristotle represented pure naturalism. To Aristotle, the changing sense-world perceived by humans was as primary and fundamental part of reality as it was to the Atomists. Based on an immense store of empirical perceptions and its classification, Aristotle targeted an all-embracing and systematic total view of the basic structure of living and non-living nature. By analysing conformity to laws and possibilities in the real world, Aristotle began, step by step, to view the Idea-world postulated by his teacher Plato as an unnecessary duplication of the real world.

Aristotle noticed that the division of reality into two parts resulted in logical difficulties, and that the existence of the Idea-world could never actually be verified. In fact, unchanging Ideas could not be properly used to explain either change or even the existence of objects in the sense-world, because their origins were completely separate from one another. Aristotle stated that even

[105] Platon 1982, 203-204, 211. (57e-58c, 63e)
[106] Compare Ketonen 1989, 22, 24, 40
[107] Platon 1982, 171-172, 179-179. (28b, 36c-37c)

though ideas or universals were essential to knowledge, they did not need to be any kind of concrete substantial entities. They were only a specific kind of general concept or pattern that could be perceived intellectually in certain situations. In his teachings, Aristotle gradually converted Plato's Ideas to ideals or forms according to which beings changed or developed by their own nature. Ideas became forces which had influence within the sense-world.[108]

Aristotle offered his basic thoughts concerning reality in his *Metaphysics*. This work was complemented by his natural philosophical *Physics*, in which Aristotle attempted to prove that Parmenides' handling of the illusory nature of movement was incorrect. According to Aristotle's observations, there were different types of movement in nature. Movement could occur in connection with position, quantity or quality. Movement linked to quality was change[109], and this type of movement or development could never be addressed by investigating mechanical collisions. Aristotle believed that earlier natural philosophers had been led astray along a path which concerned birth, decay and change because they had not understood how something could anyway be born out of non-being. His view was that there was no logical impediment to non-being actually being some type of potential non-being which could in some specific circumstances become being. [110] Incorrect understanding of movement in nature was connected to a misunderstanding concerning the nature of matter. Prior investigations into nature had treated matter as ”dead material”. Empedocles, as well as Democritus, had failed to speak about the form or essence of being, even though, according to Aristotle, students of nature should without question recognise both these aspects of nature. It was essential, because nothing that belonged to nature was pure matter, even if it could be without containing matter.[111]

Aristotle was neither a materialist or an idealist. In Being, he assigned a place for matter as well as for concepts and his approach emphasised the thinking discovered by Plato according to which substance was something which could take account of form. Matter was the substance of being and the universal concepts were its form. Neither of these essential aspects of reality appeared alone, they were at one and the same time different and indivisible sides of reality: every being appearing on the sublunar world was a combination of substance and form. ”Materia” did not signify simply the matter from which a particular being was formed, it also meant beings which could be made into something else. Clay could be used to make bricks and

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[108] Stenius 1953, 186-187. Tarnas 1998, 55-57, 67. Aristotle's critique of Plato's doctrine of ideas can be found in his *Metaphysics* (Section 9 in Book I and again in an almost identical fashion in Book XIII sections 4-5).
[109] Aristotle 1992, 101.
[110] Aristotle 1992, 11-12, 22-23.

bricks could be used to make houses. The Atomists' presumption that there were limits to the division of matter was, according to Aristotle, in contradiction to the movements of particles. He believed that matter could be divided without limit. To Aristotle, the basis of material being was *materia prima*, an indestructible substratum which was common to all elements. This material without qualities could not however exist as such. Existing was the substance that was born when the substratum was joined to any of two basic opposites, wet or dry, hot or cold. The results of such joinings were the four basic substances: earth, water, fire and air.[112]

The form-substance duality was closely connected to the duality of potentiality and actuality, another pair of basic concepts that Aristotle used in explaining the world. Unformed matter, reminiscent of the *apeiron* proposed by Anaksimandros, had a yearning for form and shape, each its own depending on the particular circumstances of its essence. When an entity moved from a state in which it had relatively less form to a shape in which it had more form, it was a question of potentiality becoming actuality. Substance always had potential to the extent that it could become a particular form: when a substance had actuality, it had acquired form. Form influenced the potential of all material beings which could become actual. For example, seeds held the form of plants, and clay held the possibility of making bricks. The bronze of the bronze founder was matter related to the finished bronze casting, which had form. To the sculptor, the forged item was matter striving to create form, i.e. the finished sculpture.[113] Rather than striving to reduce all beings to unchanging basic parts, Aristotle turned his attention to the new structures that were being formed in the different levels of reality. Nowadays, this type of systematic formation or construction can be modelled with the aid of system theory or probability functions.

As with all beings, people also had two sides, form and substance. These were the soul and the body. Aristotle defined the soul as the principle of life or the form of the body. In modern-day language, this might be called the living organism's functional organisation. By saying that something had a soul, Aristotle only meant that it was an organism that was capable of living. Body and soul could not exist without being dependent on one another.[114] Everything that had the potentiality to be also had the potentiality of non-being, while (once again) the eternal was the only thing that was always actual. Its own nature made its continuing existence inevitable. God, forms and substance without form were the eternals. Actual was also the human soul's

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[111] Aristoteles 1992, 29.
[112] Ketonen 1989, 50-51. Aspelin 1995, 105-106.
[113] Aristoteles 1990, IX kirja, 152-167 (1046a-1052a). Ketonen 1989, 51-52.
[114] Thesleff and Sihvola 1994, 178.

highest part, the active intellect, whose sole purpose was knowing which was independent of the functions of the body. The active intellect came to humans from the outside and remained after death. Aristotle identified God as form, a mover who did not move, who thought of forms which were the categories of his own thinking. In certain forms, humans could participate in the life of gods. In this way, humans could enjoy a clear concept of form, but they were not able to achieve a clear understanding of formless matter.[115]

Aristotle's idea of development, the presumption that differing immaterial causes could influence the formation of reality, was a poor match for both the mechanistic thinking of atomists and the materialism of the Epicureans. The defenders of these teachings did not, according to Aristotle, understand that the formation of nature was the result of different kinds of causes and that the student of nature should know them all. Aristotle made a point of distinguishing four different kinds of explanatory factors or causes: substance, form, mover and purpose.[116] These four classes of causes were linked to four different types of 'why-question': (1) Of what material did a thing consist? (2) What was its essence? (3) What caused it? (4) What purpose is it expected to fulfil?[117] According to Aristotle, achieving the complete scientific understanding of something required knowledge of all these causes. Modern science has however attempted to eliminate final causes which refer to purpose from explanations, and has mainly concentrated on the investigation of effective causes. Also, any such effect has been thought to result from some previous event, while Aristotle primarily made reference to the person who brought about the change.

Aristotle understood the scope of knowledge in a wider manner than Plato. Knowledge could also be gained from empirical experience, since humans could, with the help of intuition, learn by experience. It produced knowledge and not just opinion. Reason was able to reach the universal in the individual, i.e. the form which defined a being's quality. In shaping his axiomatic scientific ideals, Aristotle stressed the role of perceptions by the senses in addition to that of the intellect in forming scientific theories. In his opinion, axioms, basic statements of scientific discipline, became known by induction based on perceived phenomena. Axioms were a particular kind of definition which expressed what the beings and things under investigation actually were. From these basic sentences, new truths conerning reality, i.e. theorems, could be

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[115] Collingwood 1960, 83-91. Ketonen 1989, 53-54.

[116] Aristoteles 1992, 38. Causes are also discussed in Chapter 3 and Chapter 4 of the first book of *Metaphysics*. Aristoteles 1990, 12-16.

deduced in a logical manner. While Plato, who stressed the role of reason in acquiring knowledge, advocated strict rationalism, Aristotle has sometimes been viewed as an empiricist to whom, in the final analysis, knowledge was based on sensory perception. The conflict between rationalism and empiricism was, however, only radicalised at the beginning of the modern era, when empiricism was developed into a consistent philosophical programme.[118] Aristotle did not advocate modern experiential philosophy or Nominalism. Even though he did not believe in Plato's ideas, he thought of understanding as targeting the unchanging essence of things, their permanent basic character. Things were organised into specific classes and our intellect discovered these unchanging natural classes just as our senses discovered individual objects.[119]

2.1.4. The Significance of Antique Thought for Modern Science

The natural philosophers of antiquity rejected earlier mythical and religious ways of explanation and began a search for intellegible answers to the fundamental questions about the nature of reality and its formation. The character of the Milesian attempt to make reality and its phenomena understandable and controllable has been seen as pre-scientific, and their endeavour has left its stamp on both science and modern-day culture.

Although Plato and Aristotle, the most prominent thinkers of antiquity, employed the teachings of the pre-Socractics as their starting point, they paid more attention to human life and society in their all-embracing philosophies. In addition to matter, they stressed the importance of form, and fought against the Atomist's teachings to the extent that they advocated mechanical materialism and the rejection of teleology. Because of this humanistic bias, Plato's and Aristotle's thinking and divisions in natural philosophy or physics should not be underestimated.[120] Their fundamental criticism of the Atomists' way of thinking has largely been forgotten as a result of the advent of classical physics. Democritus' idea of "dead matter" has become the foundation of our world-view, and the hypothesis of Plato and Aristotle that matter is something that can receive form has been abandoned.

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117 Niiniluoto 1983, 237. Scholastics in the Middle Ages called these causes "causa materialis", "causa formalis", "causa efficiens" and "causa finalis".

118 Niiniluoto 1980, 39, 42. Ketonen 1989, 57.

119 Aspelin 1995, 113.

When highlighting Galilei's approach to knowledge, Aristotle is often seen as no more than a classifier of empirical information who did not understand mathematical science.[121] Aristotle primarily observed organic nature and did not achieve Galilei's concept of dynamic or relational invariance, in practical terms the differential equation, which could be used to accurately visualise and predict the movement of macroscopic bodies in space and time. By employing these equations of motion of classical physics, it is possible, for example, to calculate the trajectory of a stone thrown through the air or at which precise point Achilles met the tortoise. In this new approach, the invariant was not a given system or condition but the relation which made it possible to understand how certain relationship can in some conditions remain unaltered. For example in free fall, the relationship between velocity and time remains invariant.[122]

As will be described in more detail in sections 2.3. and 3.1. of this thesis, the research tradition adopted at the beginning of the modern era stressed mathematical description, and instead of substantialist terms describing essences it asked for relationships, i.e. how change actually takes place. Copernicus challenged the Ptolemaen earth-centred view of the universe and Galilei combined the mathematical method inherited from Pythagoras with the atomism of Leucippus and Democritus. Newton completed the idea of natural reality that was controlled by exact eternal laws. The world of matter began to be understood as an immense clockwork mechanism whose inevitable procession could not be influenced in any way. It was believed that all real happenings in reality could be reduced to particles moving in space-time. The objective laws which controlled their behaviour could be represented mathematically.

In this transition, the mathematical approach adopted by Pythagoras and Plato was combined with the atomism developed by Leucippus and Democritus and in spite of its excess of abstract mathematics, modern science has until now been ontologically committed to the Atomists' practice of reducing everything to some basic particles in time and space.[123] It can be said that the particle-mechanistic approach to reality has offered physics an operating framework which has supported on-going research until the beginning of the 1900s. The machine metaphor was adequate for the explanation and understanding of many deterministic processes in the mature.

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[120] Aristotle's explanations concerning change and movement are considered superior to previous notions. His *Physics* was a cornerstone of university science in Europe from the 13th century to the 17th century. Kenny 1998, 71.

[121] F.ex. Kaila 1939, 60-61, 68-70. Heisenberg 1985, 59.

[122] Stenius 1953, 95-97, 188-189. Kaila 1939, 64.

[123] From the turn of the modern era up to the end of the 19th century, the substrate of the natural laws was clearly matter, but together with electromagnetism, talk about the ether and fields also appeared. Stenius 1953, 90.

Classical physics concentrated primarily on the discovery of effective causes and has regarded the Aristotlean emphasis on formal and final causes as unnecessary. By rejecting the idea that the same happening can be influenced by different causes, Newtonian thinking is not necessarily able to address all the movements and change phenomena that Aristotle observed. Neither is it able ask questions concerning the internal nature or essence of things or of different kinds of possibilities that nature might contain. The classical paradigm of science stripped all meaning, intention, and values from mechanical and deterministic reality.

Even though the differential formulas of Newtonian science were superior in describing and predicting phenomena involving the movement of macroscopic bodies, one can ask whether these laws only applied to the world of “dead matter” postulated by the pre-Socratics and which was the subject of criticism by Plato and Aristotle. Even though the mechanistic-deterministic conception of reality has developed into something which is essentially taken as self-evident among the educated public, modern science has not really advanced either the explanation of life or consciousness or our understanding of them. The relationship between man and his natural environment has proved difficult to conceptualize and the advent of quantum mechanics has rewealed deep flaws in the basic foundation of the way of thinking adopted at the beginning of the modern era. Difficulties in the interpretion of quantum mechanics have resulted in problems with the particle-mechanics way of thinking coming to the fore. For example, using modern physics as his basis, Niels Bohr criticised the Atomists in very much the same way as Plato and Aristotle. “The discovery of the elementary quantum of action revealed a feature of wholeness inherent in atomic processes which goes far beyond the ancient idea of the limited divisibility of matter.”[124]

Criticism by Plato and Aristotle of Atomist thinking finds support when surveying modern research into elementary particles. This has proved Democritus’ assumption that atoms are eternal to be incorrect. The smallest building blocks of matter are not eternal and indestructible units of material but can be destroyed in collisions and change into one another within the limits set by the laws of conservation. As will be explained in more detail in sections 4.3. and 5.3. of this thesis, more detailed investigation of these smallest building blocks showed they can only be “accurately” described with the help of a mathematical probability function. This ‘wave function’ appears to be some kind of form or pattern that offers the possibilities which may, in our reality, become actual. The emphasis on mathematical form in modern physics leads to the

[124] Bohr 1963, 2.

question of whether explanation once again has room for the sophisticated ideas concerning the nature of matter proposed by Plato and Aristotle.

The deliberations undertaken by ancient thinkers concerning the basic substance of reality and its division are once again topical. Is Being fundamentally a single and unchanging whole, or does it consist of many different parts? Is it temporary or eternal? How are movement and change born? It is my belief that sorting through the the basic ideas and divisions employed by the antique natural philosophers can make a substantial contribution to the interpretation of quantum mechanics. Many perplexing problems and phenomena in modern physic such as indeterminism, irreversibile historicism and non-locality which cannot be explained in the mechanistic-deterministic framework of reality might be much simpler to understand in Aristotle's world, in which happenings are unfolding and eruption based on the guidance of timeless form.

In spite of the many victories of classical physics quantum mechanics has shown that physics is no longer able to work exclusively with differential equations which describe changes in position of particles which take place in time and space, it needs multi-dimensional and complex vector spaces whose symmetrical properties are linked to the laws of conservation and the invariance perceived in nature. On the basis of quantum mechanics, it is justifiable to doubt whether all the types of change and happening possible in nature can truly be visualised as the movement of bodies through space. Scientific explanations are usually seen as ruling out anything but material causes, but on the basis of quantum mechanics, it is possible to ask whether it is reasonable to stay with effective material causes when the most important term on which the corresponding theory is based, the ‘wave function’, cannot be visualised in space-time and its contents cannot be entirely reduced to the material world.

The abstract concept of state in quantum mechanics has usually been visualised as a probability wave. Even though the ontological interpretation of such waves continues to be a subject of dispute, on the basis of current knowledge it is justifiable to claim in accordance with Werner Heisenberg that what modern science says is matter is a description of different structures and rhythmical movements which according to Greek terminology could be understood as a theory of

[125] The usefulness of the ideas of Aristotle and Plato in the interpretation of quantum mechanics is further discussed in Section 5.1.

form.[126] The concept of quantum states has points of contact with the central ideas of Plato and Aristotle. Because of its wave description, quantum mechanics has been seen as necessitating renewal of both the particle-mechanistic way of thinking and the concept of matter. In some experimental situations, the shaping of matter appears to be connected with mathematical forms, waves, which can be viewed as manifesting something new out of what is generally accepted to be 'dead' material. In this connection, modern thinking can be thought of as undergoing the same type of change from substance to form as happened in antique thought when pre-Socratic thinking was replaced by Platonic-Aristotlean ways of conceiving reality which emphasised the role played by form.[127]

Quantum mechanics does not, of course, force us to accept either Plato's doctrine of a mathematical idea-world or Aristotle's world of potentiality. However, as is discussed in more details in Section 5.2. of this thesis, regardless of whether it is presumed that the probability functions or additional dimensions of modern theories are true representations of the structure of some trancendent world or just systematising tools for empirical evidence, they offer new kinds of tools for use in natural philosophy: they might permit us to achieve a better-than-before description of such ontological tendencies of reality which Plato attempted to pin down with his Idea-world and Aristotles tried to associate with his different causes and concept of potentiality. Their philosophy, which emphasises immaterial form and universal principles, is better equipped than the idea of mechanical clock-work to ponder the relationship between man and his inner world and the rest of the universe.

The mathematical tools of modern physics are able to predict the probability of certain kind of individual events which may occur in different contexts. Modern physics' indeterministic laws could make possible an improved approach to internal phenomena in living nature and the structure of future possibilities that are linked to these. Just as the differential equations and laws of causality of the modern age transcended and went beyond the ability of the Greeks to describe movement at the macroscopic scale, the mathematical tools of modern physics could make it possible to handle the changing and varying phenomena in nature in a more concrete and

[126] Collingwood 1960, 92.

[127] The usefulness of the ideas of Aristotle and Plato in the interpretation of quantum mechanics is further discussed in Section 5.1.

[128] For example, Heisenberg suggested that the mathematical formalism of quantum mechanisc dealt with some kind of potential realm which he located between the sense world and Plato's world of ideas.

accurate manner than either Plato or Aristotle could ever have achieved.[129] In addition to conformity to indeterministic laws, nature may have tendencies and structures of possibilities whose development humans might learn to recognise and direct better.

In the history of western culture, natural philosophy bloomed in ancient Greece and at the time when modern natural science had its beginnings. Modern science was guided by the mechanistic-materialistic world-view which was long believed to correspond to reality, at least at the material level. The difficulties in interpreting quantum mechanics have now shown that the the basic ontological and epistemelogical presumptions that lie behind the mechanistic-deterministic paradigm are deficient or insufficient, with the result that natural philosophy can currently be said to be experiencing its third 'golden age'. This might lead to a fundamental renewal of the basic presuppositions of metaphysics and radical change in our concept of reality. In the future, scientific explanation may not mecessarily mean an attempt to reduce all events to the movement of particles in space-time.

History shows that in a period of profound cultural change, the material for new thinking is often drawn from antiquity. Since the road marked out by the Atomists now appears to have reached its end, not only Plato and Aristotle but also Heraclitus or Empedocles might offer sustenance for a way forward. Old ideas and different starting points may sound more understandable within a quantum framework. Also, in spite of the basic materialistic nature of our culture, the heritage of antiquity continues to prevail in many ways. In our thinking we still use many of the basic models and distinctions that were debated and pondered by the Greeks[130] and when one looks carefully enough beyond the surface, the ideals of Truth, Beauty and Virtue that were stressed by Plato can still be seen to influence the content of scientific research.[131]

2.2. The Middle Ages and transcendental reality

The ancient world-view and tradition continued to be influential in many ways in Roman times. To the Romans, who emphasised individual ethics and practical life skills, the traditional

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[129] The Aristotelian concept of teleology is still topical in the philosophy of science in connection with functional explanations, and continuous references to it are made within the philosophy of biology. Theslef and Sihvola 1994, 176-177.

[130] The concept of quanta can be seen as the first physical innovation which did not have any kind of counterpart in the thinking of ancient times. The only real predecessor for this concept born at the beginning of the 20th century is Newton's persistent claim concerning the particle nature of light. Hämäläinen 1999, 124, 127.

concepts of the Sceptics and Stoics were of particular interest. Epicurean atomism was also disseminated via the influential poem "*De rerum natura*", a work written by Lucretius (c. 97-55 BC) which has often later been regarded as a defence of both enlightenment and the scientific world-view. In the first and second centuries AD, both Pythagorism and Platonism strengthened at the same time as eastern influences, religion and occultism found increasing favour in upper-class circles.[132]

The new bloom of Platonism was initiated by Plotinus (c. 205-270 AD), whose subsequent influence on later antiquity, the Middle Ages, and the modern era right up to the 1800s was both remarkable and many-faceted. While Plotinus saw himself as returning to Plato's original and true doctrine, he very soon created a new synthesis of Plato's dialogues, Aristotleism, Stoicism and the Gnosticism of his own age.[133] In Plotinus' metaphysics, Plato's model of reality as two levels developed into a complicated hierarchy and all-embracing system which incorporated many levels, the hypostases. By becoming aware of these levels, the individual could gradually achieve perfection and freedom from the multiple distractions of material and temporal life. Plotinus, who laid special emphasis on the soul's mystic connection with unity, *unio mystica*, became the predecessor and exemplar for many later European mystics. Unity could be achieved by intuitive methods which closed everything else out of the mind. Plotinus is said to have experienced encounters with the One (i.e. the Good) several times in his life via the processes of mental exercise and meditation.

Plotinus laid extensive emphasis on the fact that matter could not be regarded as an independent element of reality, even though the soul could only become individual by connecting itself to matter. Following Aristotle, he considered matter to be something formless that could accept form, and that form could be derived from higher levels such as the Soul and Reason which emanated from the One. Reason was the medium required to make the One understandable. For its part, the Soul brought change and temporality to Reason's handling of reality. Even though change and time did not belong to the world of ideas, a temporal process was essential if ideas grasped by reason were to become manifest.[134]

Plotinus displayed a supreme indifference towarsd concrete natural facts, which after all were

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131 See Inga Gammel 2004.

132 Thesleff ja Sihvola 1994, 392-394, 432. Ketonen 1989, 75, 80.

133 Dijksterhuis 1986, 45-46.

134 Nordin 1995, 143-147. Thesleff and Sihvola 1994, 409-419.

nothing more than unreal manifestations of the spirit that operates in them. The spirit could be better approached using our rational powers or in ecstatic contemplation. According to his pupil Porphury, Plotinus appeared to be ashamed of having a body, and this resulted in an anti-empirical orientation as well as a fascination with the occult. The Neo-Platonists were apparently convinced that for every division or distinction that the human mind can make, there is a corresponding real division or distinction in the structure of the universe. This mystical and magical trend obstructed scientific thinking because it encouraged a reliance on magic and theurgic practices rather than learning to understand nature through one's own study and reflection: to control it by one's own actions.[135]

The Neo-Platonists' doctrine of different levels of reality, of a divine logos, unity, soul and love, was well suited to the Christian faith, which had been influenced by both Platonism and Gnosticism since the first century AD.[136] From the very beginning, the Christian gospels and the world of the early church did not have many points of contact with Greek philosophy, the Christian religion rather drew its power from Judaism.[137] When God's kingdom on earth was revealed as something whose coming had to be waited for, consolidation of the church as an institution required the defining of a position towards Greek and Roman culture as well. In part, this was also a question of the need to strengthen arguments against different Gnostic trends which were gaining an ever-increasing foothold.[138]

Through the influence of the early church fathers, the Jews' active, dynamic and willing God gradually replaced the Hellenic concept of an abstract intelligence working in the background that could only be accessed in an analytical manner. Plato's *logos* became flesh and joined the ranks of men. It was not just an impersonal mind, it was also the divine word, and belief in it meant salvation. It was believed that this one superior being had a historical plan to save mankind. The Greeks' cyclical concept of history was replaced by a linear development in which God's plan was gradually realised. At the same time, human history acquired some spiritual significance. The personal God of Christian teaching was interested in human activities and the

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[135] Dijksteerhuis 1986, 47-49.

[136] The first record in Christian religion appears around 100 A.D. when Emperor Nero accused Christians of causing the Great Fire of Rome. Around 250 A.D., some of Rome's noblest citizens were already Christians and in 392 A.D. when Christanity become a state religion, one tenth of the population were Christians. Thesleff ja Sihvola 1994, 365-366.

[137] The Hebrew conception of the fundamental nature of universe was quite different to that of the Greeks. Whereas the Greeks were interested in nature and human beings, the life of the Hebrews was more closely connected to supernatural powers. They were conscious of an almighty God whose laws could not be ignored. Ketonen 1989, 66-67.

[138] Thesleff and Sihvola 1994, 427-428.

salvation of every human soul. In front of Him, ordinary people, the simple and the sick, were of just as much importance as the powerful and the successful. Everyone was a part of God's creative plan, which gave clear meaning and purpose to mankind and its actions.[139]

Even though the Christian religion highlighted the value and freedom of the individual, its central significance was ethical and ecclesiastical. Most important was each individual's personal connection with transcendence. When trying to understand the deeper meaning of things, belief was the first factor. Proper knowledge required illumination coming from God and reason was not as important. This was also emphasised by Augustine (354-430 BC), who is widely accepted as being the most influential character in western theology and who gave the church an overall Christian perspective on all things human and divine. Born in Thagaste, a town in modern-day Algeria, Augustine renounced his earlier Manichaeian view of religious issues after he became acquanited with Neo-Platonist texts. He taught that the soul could lead the way to eternal truths. While Plotinos had changed Plato's eternal Ideas into the eternal thoughts of Nous, the godlike world order, Augustine went a step further. Eternal truths corresponded to eternal consciousness, absolute reason. The human spirit was part of the divine thinking which formed the foundation for the certainty of our knowledge. To Augustine, doubt, which Descartes later proposed as the path to certain knowledge, was the opposite of faith and knowledge. Correct knowledge required belief, i.e. that humans had a proper relationship with God. If this was not the case, investigations driven by reason would not lead in the right direction.[140]

In religious practice, individual personal knowledge and experience had anyway to yield in the face of doctrine, which was defined by an authority external to the individual. Religious positioning often began to mean the complete subjugation of one's own judgement to the requirements of revelation. With Christianity, the natural world became a stage for the drama of salvation. To Christians of the Middle Ages, God and the Devil, the Virgin Mary and the kingdom of heaven, sin and salvation were not merely abstract beliefs. They were more the world than just a world-view, they were self-evident, living and palpable reality in the same way as mythical reality was to the ancient Greeks or the self-determining, objective material world is

[139] Tarnas 1989, 104-105, 129. Greek philosophy was exclusive and elitist: equality between people was not recognized either in theory or practice. The fact that the Christian god was interested in saving all people was considered revolutionary by the ruling class. With Christianity, suffering, sacrifice, humility and universal anthropy - already Stoic virtues - attained increasing cultural influence. Thesleff and Sihvola 453.

[140] Nordin, 1995, 155-160. Aspelin 1995, 172. Thesleff and Sihvola 1994, 447. The thoughts of Augustine are still a living heritage in Christianity. See for example Augustine 1948. His *Confessions* is a classic text highlighting the problems of faith and doubt. See Augustine 1960.

considered reality by modern man.[141]

At the beginning of the second millennium, Europe's closed feudal society received new stimulation during what is termed the 'Little Renaissance'. Increasing trade and agriculture were boosted by new inventions such as the windmill and the water wheel which highlighted the significance of human reason and an understanding in collecting knowledge and harnessing the power of nature. In place of kingdom come and the human being's inner world, an increasing emphasis began to be placed on the visible world. The long-dominant orientation influenced by Platonism began to make room for Aristotleism. The advent of Aristotle's naturalistically-oriented way of thinking was made concrete when his works reached Europe by way of the Arab philosophers Averroës and Avicenna. Other ancient texts, long-forgotten but preserved by the Arabs, were also rediscovered. In monasteries, these texts were classified, copied and translated from Arabic to Latin. By 1240, all of Aristotle's works had been translated into Latin either directly from Greek or indirectly from the Arabic.[142]

Ancient knowledge in different fields clearly surpassed what had been thus far realised. In addition to philosophy and literature, scientific works including the texts of Euclides and Ptolemy also become available. Scholarship began to be respected and esteemed and the church began to establish schools and universities in which the early Scholastics studied the antique texts in the light of holy writings. Views which corresponded with the Patrician texts were accepted as belonging to the body of reliable knowledge. Using logic, attempts were made to form new tenable conclusions from this body of knowledge, but the premises on which it was based were not examined in a critical manner. It was believed that humans, who could easily be misled in their studies, were neither able to alter the Holy Scriptures nor independently reveal any fundamental truths concerning nature.[143]

The new Scholasticism and the revival of the Hellenistic inheritance brought, however, new currents and tensions to the surface. For example, the writings of Aristotle were initially received with considerable reservation as they appeared to prohibit the immortality of the individual soul.[144] Thomas Aquinas (1224-1274), who attempted to combine ancient natural philosophy with Christian beliefs, was however successful in pointing out that this interpretation was

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141 Tarnas 1989, 112-113, 170. Aspelin 1995, 299.
142 Nordin 1995, 174, 183. Tarnas 1998, 171-178.
143 Trusted 1991, 2-3. Nordin, 1995, 171.
144 Trusted 1991, 6.

incorrect. Aquinas took the view that understanding the order and beauty of the world of creation could not be in conflict with either the glory of God or his better comprehension. Nothing that reason could discover could in fact be in fundamental disagreement with either theological teachings or with religious faith, since both reason and belief were derived from the same source. Even though spirit and nature were separate from one another, they were at the same time intertwined aspects of a single homogeneous whole. The history of one affected the history of the other. In this way, freely-acting and self-realising human beings in no way reduced God's infinite creativity and omnipotence, they actually promoted His will.[145]

Thomas Aquinas shaped a comprehensive synthesis of the doctrines of Aristotle and Plato. In a similar manner to Aristotle, he saw the soul as the form of the human being and the body as its matter. Sensory experience and reason fed each other. Sensory experience was necessary to awaken reason's potential knowledge of the universals, since humans had no direct access to the realm of transcendental ideas. Aquinas did not, however, wish to interpret individuals as completely separate and distinct substance, nor did he wish to see the world of matter as separated from God. He linked created beings to each other and to God by using Plato's idea of participation. Individuals participated in God's existence, which was the foundation of all being.[146] Through his synthesis, Aquinas made Aristotle legitimate, and made it possible for Greek rationalism and naturalism to access the Christian culture which permeated the whole of Europe in the Middle Ages. From 1150 to 1650, Aristotle can be regarded as the most important philosopher influencing European thought. His *Physics* was widely read and discussed, and over the centuries, his natural philosophical concepts concerning teleological explanations, the elements and cosmology became an inviolable part of the Scholastics holistic conception of nature, a conception which related to not only the material world but also to the role played by human beings in the world and their relationship with God.[147]

Mediaeval science was clearly structured from the bottom upwards. It was based on Aristotle's physics and metaphysics, and the top of the pyramid consisted of theology as the highest form of intellectual knowledge. In contrast to opinions being voiced by historians of science even in the 1950s and 1960s, there is no good reason to regard mediaeval science as being undeveloped. Claims that the Middle Ages made no significant contribution to the advancement of science

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[145] Tarnas 1998, 175-190.

[146] Tarnas 1998, 182-188. Aquinas committed himself to the Herculean intellectual task of comprehensively uniting the Greek and the Christian world views in his *Summa Theologica*. See Aquinas 1947.

[147] Trusted 1991, 6-7. Tarnas 1998, 190.

were, in part, made on the basis of the Renaissance view of the Middle Ages as a dark intermediate stage between antiquity and the Renaissance itself. In the last few decades, research into the Middle Ages, a subject that has been pursued with considerable merit in Finland, has questioned the depiction of the Middle Ages as a dark and static time.[148] In the field of logic in particular, and also in attempts to define the relationship between science and faith, mediaeval science registered explicit achievements, while progress also took place in the fields of medicine, technology and physics.

Mediaeval science did not, however, strive, in the way that modern science does, to explain, predict and control different phenomena, it attempted to understand them by examining their significance to everything else and to God. The mediaeval view of the structure of the universe was both strict and hierarchical. Every being, from the smallest to the greatest, had its own place and observed its own laws, and these laws were considered to be more moral in their nature than mechanical. The earth was believed to occupy a unique position in the universe. It was distinct from the rest of the created order in both its location and in its metaphysics. The earth that was at rest was surrounded by the celestial spheres, whose state of perfection could only be illustrated by the employment of circles.

In the Thomistic conception of nature, the categories of explanation were *essentia*, quality, and potentiality. In Aristotle’s concept of causes, the stress was on the final cause and the formal cause. Causality was depicted with the help of a final cause (*causa finalis*) and a formal cause (*causa formalis*), not so much as the result of an action of a former event (*causa efficiens*) in a present situation (*causa materialis*). When attention was focused on the purpose rather than on the detailed process of change from one state to another, the Thomistic way of thinking did not generally pay much heed to the laws which regulated the movement of particles in space-time. It was not seen as problematical for every object to have its own natural place in a cosmic hierarchy which had been created in accordance with divine intention.

Natural philosophy and natural science, however, also moved forwards. Studies of nature carried out in universities using the thoughts of Aristotle as a foundation resulted in the creation of an empirical environment which fostered critical natural research based on mechanical and quantitative investigation, something that later assisted the adoption of a new natural-scientific

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[148] Professor Simo Knuuttila an his research group have carried out ground-breaking work in the field of Middle Ages studies. See for example Knuuttila 1998.

way of thinking.[149] Thought concerning the basic elements and structure of reality were connected to the central controversy in Scholastic philosophy, i.e. the nature and existence of the universals.[150] Aquinas had proposed that ideas had a threefold existence: firstly that they existed in the mind of God, secondly that they appeared in comprehensible form in real entities in nature, and thirdly that they existed in the minds of human beings. For ideas to reach their minds, humans had to abstract them from experiences with things in the material world, but in the mind of God, all the universals existed independently of any objects. God was both the foundation of all existence and its highest form. He was also an active order and the dynamism out of which everything unfolded.

The dispute between realism and nominalism concerning the nature and existence of universal concepts was connected to deep metaphysical questions. Are ideas basically something material or spiritual? The dispute which culminates in the names of John Duns Scotus (c. 1266-1308) and William of Occam (c. 1285-1347) became increasingly acute in the 1300s. The conceptual realists followed Plato. For example, they believed that the idea of red existed independently and timelessly beside red objects, independently of the awareness of a human mind. According to moderate Aristotlean realism, general concepts truly existed, but only when attached to individuals. The nominalists believed that it was only individuals that truly existed. According to some nominalists, reality existed exclusively in the mind since to assign it another existence outside the mind would amount to superfluous duplication, a violation of the principle of economy of thought. Conceptualism was a compromise position according to which general concepts did exist inside the human mind.[151]

Nowhere did the Middle Ages come so close to physics in the form into which it was to evolve in the 1500s and 1600s as in the work of a group of thinkers who taught or studied in the 1300s at the University of Paris where William of Occam was the central figure. Occam emphasized the role of empirical research in his epistemology. Empirical research was needed in discovering which, of many logical possibilities, truly existed in reality. [152] Anti-Aristotelian ideas were

[149] Tarnas 1998, 200-201.

[150] Universals are often called also general concepts, properties, attributes, characteristics, or qualities.

[151] Niiniluoto 1980, 124. Dijksterhuis 1986, 166. Platonists understood ideas as archetypes or prototypes which served as models for the individual things which somehow participated in them. Nordin, 1995, 167.

[152] Dijksterhuis 1986, 164. Nordin 1995, 207-215. Occam himself was more interested in logic than the natural sciences. In contrast to Aristotle, who saw the world as it was out of necessity, Occam stressed the contingency of the world, the countless possible realities. Occam’s razor, his famous methodical rule, emphasised economy and was counter to the real existence of universals.

further developed by, for example, Nicholas d'Autrecourt, John Buridan and Nichole Oresme. In their *Impetus* theory they proposed, as logical possibilities, concepts of motion that contradicted Aristotle. Oresme even criticised Aristotle's cosmology and presented a theoretical defence of the proposition by Aristarchus of Samos that the earth was spinning around its own axis. At a later date, Copernicus and Kepler were to use these ideas in justification of their heliocentric world-view.[153]

The systematic and careful synthesis produced by Aquinas left its stamp on western thought until the 1600s[154], even though it was not long after his death that the relationship between theology and philosophy or faith and wordly reason proved difficult to reconcile in practice. The strained condition of this relationship was influenced both by the internal development of the Catholic church and by broader cultural and societal factors. Following rediscovery of the ancient sources, Greek and Roman art and literature were at first the subject of admiration and were copied in accordance with the mediaeval tradition, but the Renaissance brought with it a questioning of the old standards. Artists, writers and philosophers liberated themselves from guidance by the authorities and started to search for originality. In just a single generation, Leonardo, Michelangelo and Raphael created their masterpieces, Columbus sailed to America, Luther brought about the reformation and Copernicus questioned earth-centred cosmology. Development of the natural sciences and religious wars – particularly the Thirty Years' War (1618-1648) – shook the foundations of the existing world-view and encouraged scepticism, while at the same time promoting the breakdown of the Aristotlean concept of science.[155]

These developments can be viewed as indicating that the development of European thought had reached a threshold over which the old paradigm could not be maintained. Within the Christian world-view, a many-sided process of development and maturing had taken place in the fields of religion, philosophy, science and politics, as well as in art. New ideas started to challenge the foundations of long-dominant ways of thinking. An increasing need for autonomy and independence gave birth to a spectacular cultural revolution, the result of which was a completely new understanding of the universe and man's place in it. To use a modern metaphor, a clear quantum leap in cultural development took place between the middle of the 1400s and the beginning of the 1600s, a spontaneous and irreversible revolution which, from a practical

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[153] Trusted 1991, 18.

[154] In his advanced years, Aquinas did not like to speak or write because he no longer believed that truth could not be expressed with words. In *Summa Theologiae* he had already written that we cannot say what God is but rather what he is not. De Mello 2000, 88.

viewpoint, touched all aspects of western culture.[156]

The first prominent renessance thinkers were humanists such as Marcilio Ficino (1433-1499) and Pico de la Mirandola (1463-1494), who concentrated on Plato's and Aristotle's ideas. They also promoted the belief in human capacity and uniqueness by interpreting the esoteric texts of Hermes Trismegistus[157], Orfeus, Pythagoras or Zoroaster. The absence of clear and generally-accepted criteria made it impossible to distinguish superstition from constructive speculation. During the Renaissance, interest in astrology, alchemy, numerology and different occult practices increased. These esoteric teachings and particularly the *Corpus Hermeticum*, Hermetic texts dating back to the fourth century BC in which the role of the sun was emphasised, also provided significant inspiration for the new cosmological way of thinking.[158]

2.3. Birth of the Modern Scientific-technical Paradigm

Long-neglected questions concerning natural philosophy once again became the centre of reflection at the beginning of the modern era. The well-defined period that began in 1543 with Copernicus' *De Revolutionibus Orbium Coele*stium and ended with Newton's *Philosophiae Naturalis Principia Mathematica* might be called the anni mirables, i.e. years that brought about an enormous advance in men's knowledge and technical skill, and in consequence, a radical change in their views of life and of the world. The events that took place during this period resulted in a revival of the various branches of natural science which ushered in the classical period, and was the opening phase of an era that witnessed the mechanisation of the generally-accepted world-view.[159]

One consequence of the new thinking was a re-evaluation of basic metaphysical presumptions concerning the nature of reality. Both in Greek philosophy and in the science of the Middle Ages, a basic tenet was that the universe was rational and intellectual. In general, it can be said that right up to the beginning of the modern age, God was regarded as the foundation for the

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155 Niiniluoto 1983, 43-45.

156 Nordin 1995, 230-236. Tarnas 1998, 191-224, 231.

157 Hermes Trismegistus was generally thought to have been an Egyptian priest who had inspired the Ancient Greeks and who had foreseen the coming of Christ on earth. Trusted 1991, 35-36. The fundamental principles of hermetic thought are the parallelism of microcosm and macrocosm, cosmic sympathy, and the conception of the universe as a living being. Dijksterhuis 1986, 280.

158 Trusted 1991, 20-21, 35-38, 40-41.

159 Dijksterhuis 1986, 287.

existence of both matter and life. The mind was viewed as a guiding element connected to all matter which brought order to the body to which it belonged as well as to its environment.[160] This way of thinking was turned on its head as a result of modern science. When Galileo ignored the question of purpose or final cause and concentrated on the relationships between observable phenomena, a new view of the world of matter unfolded: mechanistic and quantitative, ruled absolutely by laws, and completely without purpose.

Even though the development of natural science during the 1600s signified enormous and perhaps revolutionary change compared to earlier ways of thinking, this event was tied to both its time and the prevailing conditions. The revival of ancient philosophies and the Renaissance encouraged people to have confidence in their own reasoning and created the space for new thoughts. Research carried out at earlier times was of considerable importance to development of the new experimental method. Natural research based on experimentation had begun evolving in England in the 1200s under the influence of Robert Grosseteste (1175-1253) and Roger Bacon (1214-1294). The work of Jean Buridan and Nicholas Oresme, who developed the basic concepts of the new natural science at the University of Paris, had a strong impact on Galileo's mechanics. Also the non-Aristotlean modal theory proposed by Duns Scotus (1266-1308), which called for a basic differentiation between logical necessities and natural necessities, cleared the way for a new conception of natural laws and the objectives of natural research.[161]

The clear division between matter and the mind that was drawn by modern philosophy can be seen as a precondition for the mechanistic-deterministic world-view created at the beginning of the modern era. This division gave natural science a a clear area of application which was seen as independent. Natural science which concentrated on the world of matter did not have to take account of subjective states inside human beings, or pay heed to questions regarding the relationship between matter and the spirit. The difficult psycho-physical problem could be left to philosophers. The roots of this problem go back to the dispute between realists and nominalists on the nature and existence of universal concepts and on the metaphysical structure of the world. Against this background, Galileo represents a clearly-defined mathematical realism. Mathematically-approachable measurable properties really existed in objects, while subjective sensory qualities only existed in human mind.[162]

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[160] Collingwood 1960, 3, 111.
[161] Niiniluoto 1980, 42-43. See also Grant 1971.
[162] Niiniluoto 1980, 124.

In the following sections, the outlines of the formation of the development of the modern scientific-technical way of thinking is examined by concentrating on the ideas of the most influential natural philosophers. Many of them were not only philosophers, they were also first-class natural scientists and mathematicians.

2.3.1. The early pioneers of natural science

Copernicus

Polish-born Nicolaus Copernicus (1473-1543), who lived during the golden age of the Renaissance, is often regarded as symbolising the irreversible shift from the Middle Ages to the modern era even though his thoughts were incomprehensible to the majority of his educated European contemporaries.

Well known as a skilful mathematician and astronomer, Copernicus received a thorough Scholastic education in Krakov (Poland) and Italy. He embraced the academic ideals of his time and did not attach any value to originality, and his desire to be revolutionary was even less. However, when the Catholic Church asked him to review the calendar, whose accuracy had become inadequate for both administrative and liturgical purposes, he was not able to avoid concrete recognition of the inadequacy of Ptolemaic celestial mechanics. It is unlikely that the need for revision would have convinced Copernicus of the need for a radical change in the dominant geocentric way of thinking. It is apparent that he was influenced by the Neo-Platonism of the Renaissance and the resurgence of the ideas of Pythagoras – the idea that nature could be comprehended in simple and harmonic mathematical terms was an inspiration to him. He also knew that the sun occupied a central position in *Corpus Hermeticum*, and this perhaps led him to suspect that the whole of the dominant way of depicting cosmology was incorrect.[163]

To the Scholastics, correct knowledge had to be supported by holy scriptures or at least by an antique authority. Copernicus embarked on time-consuming research, working through all the ancient scientific texts he could lay his hands on. He realised that Aristotle's geocentric conception of the universe had not in fact been the only view taken by the Greeks, since several

[163] Trusted 1991, 24-30, 38. During the Renaissance, aesthetic and metaphysical views, neoplatonism and hermetism highlighting the position of the sun also affected some scientists, but their influence on Copernicus should not be exaggerated. See for example Lehti 1987, 186-196, 222.

philosophers, including Aristarchus of Samos (310-230 BC), had proposed that the earth was moving. No-one had developed this hypothesis to its ultimate astronomical and mathematical conclusion. When the Scholastics at the universities started to criticise Aristotle and antique tradition supported the position of the sun as advocated by the Neo-Platonists, Copernicus was emboldened to abandon the geocentric tradition which had dominated astronomy for almost 2000 years. Convinced that the earth was actually moving, he proposed a heliocentric universe and provided mathematical consequences of this hypothesis. Copernicus did not, however, rush to publicise his revolutionary ideas. He had written a brief manuscript on the subject in 1514, and circulated this among his acquaintances. Two decades later, in the presence of the Pope, Copernicus gave a lecture on his principles and received formal permission to publish a book. Despite the encouragement of his friends, he continued to delay matters and only agreed to the publication of *De Revolutionibus Orbium Coelestium*, a book dedicated to the Pope, shortly before his death.[164]

It is often thought that fear of the Inquisition was the cause of Copernicus' unwillingness to publish his thoughts.[165] In fact, he was never the personal target of persecution of any kind. In the preface to *De Revolutionibus Orbium Coelestium*, he explains that his unwillingness to publish his insights into the mysteries of nature derived from the Pythagorean tradition of keeping such things secret – since among the uninitiated they might only arouse mockery. After all, his proposition that the earth both turned on its own axis and moved around the sun was in such contrast to everyday observation that most people could not take them seriously in any way at all. To counter many apparent objections, Copernicus could plead only that his conception threw the facts of astronomy into a simpler and more harmonous mathematical order[166].

In 1543, in the very last days of his life, Copernicus was able however to handle a printed copy of *De Revolutionibus Orbium Coelestium*. This work consists of two parts which differ widely in their aim and character. The first part provides a lucid and simplified exposition of the new world system and is designed for the general reader, the second part is written for the professional astronomer. The second part provides the highly-complicated details of the system and constitutes a text of the same grade of difficulty as Ptolemy's *Almagest*. It has been claimed that apart for the application of the new methods of trigonometrical calculation, there is nothing in *De Revolutionibus Orbium Coelestium* that could not have been equally well written by a

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[164] Tarnas 1998, 218, 248-251.
[165] Esim. White 1998, 73.
[166] Burt 1980, 38.

follower of Ptolemy, so after a period of stagnation that lasted fourteen hundred years, the evolution of astronomy started again at Frauenberg from the point at which it had stopped in Alexandria.[167] In spite of its complication, *De Revolutionibus Orbium Coelestium* initiated a revolution whose practical consequences only became visible decades later.

In truth, astronomers immediately began using the tables and calculations offered by Copernicus, but the general opinion was that its heliocentricity was no more than a mathematical model which "saved the phenomena". When they gradually began to understand the propositions made by Copernicus as serious hypotheses concerning reality and his thoughts propagated outside the small circle of the educated, opposition also resulted.[168] Even though the initial reaction of the Pope to the heliocentric model had been benign, the Protestant reformists interpreted Copernicus' hypothesis as contradicting the Holy Scriptures. Under pressure from the Counter-Reformation, the Pope was no longer able to accept it and *De Revolutionibus Orbium Coelestium* was banned in 1616 – 73 years after its first publication.

Bruno

An ardent supporter of Copernicus, and in a sense also a successor, was Giordano Bruno, who was a learned Dominican monk, philosopher, and theologist. Bruno endorsed the Copernican heliocentric doctrine as part of his esoteric philosophy, but he did not exercise any appreciable influence on the development of science as by that time, science had already begun to emancipate itself from speculative philosophy.[169] Bruno's Pantheistic thinking, which emphasised the unity and boundless infinity of everything, was also strongly influenced by Neo-Platonism and Christian Hermeticism. In common with many other Renaissance philosophers, Bruno stood for an animistic interpretation of the world. His view of nature was that of the inspired poet. While Paracelsus saw spiritual qualities hidden behind a material veil, it was Bruno's opinion that the world's new creative and sustaining power became manifest in natural phenomena.[170]

To Bruno, matter was not dead material since the divine world-soul affected and animated nature from the inside and made it into a single organism. The same life which slumbered in an

[167] Dijksterhuis 1986, 288, 289.
[168] Trusted 1991, 25.
[169] Dijksterhuis 1986, 232.
[170] Nordin 1995, 258-261.

inorganic world was manifested in the countless different forms of the plant and animal world and was given shape in the spiritual activities of the human being. Bruno viewed the Christian faith as having become alienated from this divine unity and a direct connection with the sacred forces that influenced nature. People no longer understood that the Creator and Creation were a single entity and that divinity was also present in all particular things. They did not see the hidden connections between lifeless and living phenomena. Knowledge of this multiplicity of connections would have offered the possibility of influencing surrounding events.[171]

In his propagation for the understanding and exploitation of magical forces, Bruno did not consider himself to be a heretic but a reformer. He was, however, expelled from the Dominican order in 1576, and then travelled in Europe and in England giving lectures on a ‘purer’ Christian faith and the Copernican system. As well as not hesitating to turn the Thomistic method against itself by undermining the foundations of much Christian dogma, Bruno also expounded bold and far-reaching interpretations of the Copernican system. He understood that the new astronomy repudiated qualitative differences between earthly and celestial phenomena. The sun did not have to be the centre of the universe. It was just a normal star in the infinity of space, which was full of an innumerable quantity of worlds similar to our own. Intelligent life was present everywhere in the universe which was built up of atoms, physical and spiritual.[172]

Bruno’s concept of a single identical substance existing everywhere with no differences in its quality, only in its quantity and geometrical form, can be seen as a necessary prerequisite for Newton’s later being able to suppose that the same force kept the moon in the sky and made an apple fall to the ground. Bruno also saw, as Galileo did at a later date, that bodies did not require any kind of “first mover”, but that movement was part of their nature. He linked motion to God, who was immanent in each body and caused changes through them. Bruno returned to Italy in 1592. In the turmoil of the Counter-Reformation, he was soon in conflict with the Inquisition. Following years of interrogation for suspected theological heresy, he was burnt at the stake in 1600. At the same time, the heliocentric world-view that Bruno had so strongly supported was shown to be a dangerous one. [173]

Tycho Brahe and Johannes Kepler

[171] Aaltola 1999, 170. Kenny 1998, 183. For Bruno’s ideas about the implications of Copernicanism and concerning magic, see Bruno 1998.
[172] Kenny 1998, 183. Bruno’s idea of human being as a conscious immortal atom mirroring in itself the entire universe can be seen as a precursor to Leibniz’ monadology. Nordin 1995, 259.
[173] Collingwood 1960, 98-100. Trusted 1991, 37-41. Tarnas 1996, 253, 266.

Copernicus had adhered to Plato's conception that the planets orbited the sun in perfect circles. In consequence, his doctrine was not, from a mathematical point of view, much simpler or more accurate than Ptolemy's epicyclic theory. In itself, the introduction of a heliocentric world-view as such could not lead to greater accuracy in the planetary tables until more accurate observations of the positions of the planets were available. Since he had been convinced of the simplicity and harmony of the universe, Copernicus had been satisfied with the minimum number of observations required to determine the ideal system of motion.[174] Even supporters of the Copernican theory were not necessarily fascinated just by the scientific applicability of the model, they were also attracted by its aesthetic beauty and its harmonic symmetry. It is these factors which are thought to have attracted the attention of Johannes Kepler (1571-1630) and Galileo Galilei (1564-1642), who were fascinated by Neo-Platonism. Without their efforts to clarify and remove the internal contradictions in Copernicus's work, the Copernican revolution might not have taken place, at least in the way that it actually did.[175]

Kepler was strongly influenced by the mysticism of the Renaissance era. He believed in the transcendental power of numbers and geometric shapes and regarded the sun as the manifestation of divinity in nature. He continued wholeheartedly with the Pythaorean quest for harmonious numbers and geometrical excellence. He even went to the extent of writing down the tune for each planet in musical notation.[176] In 1595, he was inspired to propose that the planets must be connected with the fact that there are precisely five regular polyhedra, and that there must be a correlation between their distances from the sun. Even if there has perhaps never been another scientific investigator whose imagination soared as high as Kepler's, he at the same time took an enormously critical approach towards his inspirations, examining them both soberly and with great patience.[177] In spite of his mystical leanings, Kepler drew a clear line between uncontrolled speculation and mathematics based on observations. As part of the process of working out his inspirations, Kepler published *Mysterium Cosmographicum*, a work in which, at the age of 24, he

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[174] Dijksterhuis 1986, 300. In place of the some eighty epicycles of the Ptolemaic system, Copernicus was able to "save the phenomena" with only thirty-four. Before the days of the telescope, the testimony provided by the senses appeared perfectly plain on this matter. Burtt 1980, 36-38.

[175] Tarnas 1998, 255.

[176] Polanyi 1958, 6-7. The speculative nature of Kepler's views is not comparable to the hermetic natural philosophy of his "magical" contemporaries like Paracelsus who despised ordinary mathematics. Lehti 1987 222-226.

[177] Trusted 1991, 44. Dijksterhuis 1986, 303-304. Kepler has however been considered the foremost astrological theoretician of his era. Even Galileo routinely calculated astrological birth charts – as did most Renaissance astronomers. In *De Revolutionibus*, Copernicus made no distinction between astronomy and astrology. Tarnas 1998, 294-5.

defended Copernican theory and presented an early version of his own model of the solar system. He believed that Copernicus had grasped something of greater significance than the theory represented at that time. Cleansed of its remaining Ptolemaic characteristics, he believed it could open the way to a new scientific understanding of the cosmos as an astonishingly organised and harmonious entity which was a direct reflection of the glory of God. Impressed by Kepler's work, the well-known Danish astronomer Tycho Brahe invited him to become his assistant in Prague, where he worked in his later years as mathematician and astrologer to the court of Rudolf II.[178]

During the 20 years he spent at Uraniborg, his observatory on the island of Hveen, with the benefit of new or improved instruments and an unparalleled talent for observation, Tycho Brahe was able to raise observational astronomy to a level unprecedented before his time, and one which was not to be reached again before the invention of the telescope. Brahe's observations enabled Kepler to achieve the complete reform of astronomy by taking into account the eccentricities of the orbits of the planets.Cooperation between these two talented individuals was not, however, without human complications. While Kepler was a convinced Copernican, Brahe had a system of his own. He (Brahe) had recognised the considerable simplification that adoption of the heliocentric viewpoint would provide in the world-view, but he was still too much confined by the Aristotlean way of thinking to break away from the influence of arguments against the possibility that the earth was actually moving. Also, he, like the vast majority of his contemporaries, thought that the Copernican system was in conflict with the Christian faith. In his own theory, Brahe attempted to replace the Ptolemaic system with that of Copernicus while maintaining the central position of the earth.[179]

Kepler strongly objected to the minor position assigned to the sun in *Tychonics*. To Kepler, the sun was not only the source of light for the world, it was also the world's source of power. Using mystical language, he compared the sun to the Father in the Trinity and conceived the idea that it caused the motion of the planets. Alchemistic and astrological ideas are also not without importance in understanding Brahe's achievements as an astronomer. He presumed an essential relationship between the study of the properties of sublunary matter and that of the stars. At Uraniborg, he had both an astronomical observatory and a chemical laboratory. He was convinced of an essential affinity between celestial phenomena and terrestrial events, and he had a deeply-rooted cosmological belief in the intrinsic relationship of everything that exists. Brahe's

[178] White 1998, 75. Tarnas 1998, 255-256

beliefs are symbolised in a vignette on the title page of one of his works. Translated into modern terms, it means that astronomy is able to help us in developing atomic theory, and that atomic theory will help us to understand the processes taking place in the stars.[180] The same ethos has been a source of inspiration for many great scientists. If the theory of relativity, which enables us to describe cosmic phenomena, can at some point be combined with quantum theory, which dominates events at atomic level, these two theories might feed each other in a way which further strengthens the belief that everything has a common foundation.

A year after Kepler arrived in Prague, Tycho Brahe died. Kepler, appointed to be his successor, was now able to become acquainted with his vast store of astronomic observations. Inspired by his Pythagorean beliefs, Kepler worked for almost ten years searching for a simple mathematical law that would describe the observed motion of the planets. Circular motion was not able to explain the orbit of Mars because of slight discrepancy which Tycho had observed. After having tried all possible types of circular motion, Kepler finally began looking for another type of orbit. After he became familiar with antique studies of conic sections by Euler and Apollonius, Kepler finally realised that the planets followed elliptical orbits.[181] The sun was one of the ellipse's foci and the speed of the planet changed in relation to its distance from the sun in a way that a straight line drawn between the planet and the sun transcribed a surface of the same size in any chosen time interval. A little later, in 1619, Kepler discovered his third law, according to which the square of a planet's orbital period was equivalent to the cube of its average distance from the sun. Even though the planets did not move along circular orbits at a constant speed as he had expected, he was satisfied with the mathematical harmony he had found in the heavens. The mathematical solution to the planetary problem also produced a graphic physical description of celestial motion. For Kepler the simplicity and unity of nature was a commonplace. Through his work, he believed that he had proved the Pythagorean view that mathematics was the key to understanding the cosmos.[182]

In his youth, Kepler had adhered to the Stoic conception that a planet possesses an intelligence or spirit which enables it conciously to find its way through celestial space. In *Astronomia Nova*, the work which contained his first two laws, he very reluctantly abandoned this idea. In 1623, he added the following note to the second edition of *Mysterium Cosmographicum*: "If the word soul

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179 Dijksterhuis 1986, 300-301, 305.
180 Dijksterhuis 1986, 302-303, 305.
181 For an extensive survey of the development of Kepler's ideas, see Lehti 1987.
182 Trusted 1991, 46, Tarnas 1998, 256-257, White 1998, 76. Burtt 1980, 56-62.

(*anima*) is replaced by force (*vis*), we have the very principle on which celestial physics in *Astronomica Nova* is based". To substitute the word *vis* for the earlier *anima* is an abandoning of the animistic in favour of a mechanistic conception. Elsewhere, Kepler expressed the opinion that he no longer wished to regard nature as a divinely-animated being but as clockwork. Neither of these two words, however, tells us very much. Soul is an unknown *agens*, and so is force. The only thing established with certainty in both cases is the behaviour of the body. Giving a name to the unknown cause of a particular mode of behaviour does not result in the gaining of a deeper understanding of that behaviour. Kepler did however take the first step in the right direction because his use of the word *vis* heralded the move to determine what could be learned about planetary motion with the aid of mechanics. Kepler was the individual who, more than anyone else, inaugurated the new era by gradually discarding the ideas of antique and mediaeval science and evolving the new concepts that would open the door to classical science.[183]

The new elements in Kepler's work are not, in the first place, his results which greatly deviate from those achieved using the old system, his main achievement is a method which is very clearly different. The principal features of this method are:
(1) The rejection of all arguments solely based on tradition or authority.
(2) Scientific enquiry independent of all philosophical and theological tenets.
(3) Constant application of the mathematical mode of thinking in the formulation and elaboration of hypotheses.
(4) Rigorous verification of the results thus deduced by means of empiricism raised to the highest degree of accuracy.[184]

As a scientific philosopher, Kepler's solid and forward-looking achievement was his insistence that valid mathematical hypotheses must be exactly verifiable in the observed world. His metaphysics shows strong similarities to the early Pythagorean speculations. Kepler believed that he he had shown the necessary and rational ground of the world by penetrating to the mathematical structure which connected facts formerly held to be distinct. For him, the real world was the mathematical harmony discoverable in things and his new conception of causality was essentially the Aristotelian formal cause reinterpreted in terms of precise mathematics. The underlying mathematical harmony discoverable in observed facts was the cause of these facts, i.e. why things are as they are. The real qualities of things were what was caught up in the mathematical harmony underlying the world of the senses, and thus all certain knowledge must

[183] Dijksterhuis 1986, 310, 312, 314, 321.

be mathematical knowledge of quantitative characteristics.[185]

Galileo Galilei

With the benefit of Kepler's laws, the Copernican scientific revolution might have taken place as a result of its mathematical superiority and its predictive power. Coincidentally, in the same year (1619) that Kepler published *Astronomica Nova*, which contained his first two laws, Galileo Galilei pointed the telescope he had just constructed towards the heavens. With its help, celestial phenomena could be observed at completely new levels of accuracy, and the new observations supported the heliocentric theory. Our galaxy turned out to consist of innumerable stars, and this indicated that the universe was much larger than had been believed. Craters were seen on the moon's surface and moving spots were observed on the sun, which indicated that the celestial bodies were not the perfect spheres that Aristotle had supposed. Also, moons were found which orbited Jupiter in the manner that our moon orbited the earth. This provided the basis for the assumption that systems consisting of a planet and a moon could be part of a much wider conception.

Galileo recorded his observations in *Siderus Nuncius*[186], a work in which he attempted to convince his readers that the heliocentric system was not a mere mathematical fiction that simplified astronomic calculations, but that it embodied full physical truth about the structure of the world. The text created a sensation in Europe's educated circles. Astronomy started to become of interest to people who were not experts in its disciplines. The Copernican theory was considered not only believable but also liberating. When, in the later Renaissance, all traditional doctrines and absolute authorities were gradually called into question, no matter whether they had their source in antiquity or church teachings, Galileo's work reinforced people's confidence in their own capacity to obtain new knowledge about the world.[187] He also achieved a large audience for *Diagolo*, a work published in 1632 in his mature years, which was no more than a thinly-veiled, dialogue-form defence of the heliocentric world-view.[188]

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[184] Dijksterhuis 1986, 322.
[185] Burtt 1980, 63-71.
[186] Galilei 1999.
[187] Tarnas 1998, 258-259. White 1998, 77.
[188] Galilei 1953. Many of the ideas that Galilei expressed, and particularly the arguments he uses to attack Aristotelean theory are closely akin to those of the Paris Terminists. Albert of Saxony, Leonardo da Vinci and Oresme had already supposed that the instantaneous velocity of a falling body was proportional to the distance covered. Dijksterhuis 1986, 334, 339.

Like Kepler, Galileo had established a reputation as a mathematician at an early stage in his academic career. At the age of 25, he was appointed to the position of professor of mathematics at Pisa, and three years later, in 1592, he moved to Padova. There he studied falling bodies and developed his epoch-making laws of motion, which proved that Aristotle's ideas concerning the motion of bodies were incorrect. With the help of observations and accurate measurements, Galileo concentrated on studying how objects actually moved in reality. Others before Galileo had asked *why* heavy bodies fall, but he also subjected terrestial motion to precise mathematical study. His first concern was not to explain, but to describe. Even more than to Kepler, nature presented herself to Galileo as a simple orderly system. He was continually astonished at the marvellous manner in which natural happenings folloved the principles of geometry. Aristotle, like the preceding traditions of natural philosophy, was concerned with searching for the cause or purpose of motion. He believed that objects were seeking their natural positions from which they could not be removed except by an external force, but Galileo now concluded that while objects could indeed be at rest if nothing was forcing them to move, they could also be moving at constant velocity.[189]

In contrast to everyday observation, no force was required to maintain uniform motion, force was only required to change the state of motion. The change in the concept of inertia which Newton later formulated more precisely probably constitutes the most important element in the transition from antique and mediaeval science to classical science. It is one of the foundations which underlie the most essential parts of the new world-view, and it is beyond dispute that this change was largely brought about by Galileo. When he is talking about the phenomena of inertia, Galileo often, however, more-or-less lapses into the modes of expression and thought employed by the Scholastics of the 1300s and also by modern schoolchildren: everything that moves is moved by something else. This should not be a surprise, because Copernicus, Kepler and Galileo continued to view the universe as a sphere with a finite radius, even if they believed that radius to be much large than their predecessors had done.[190]

Galileo, like Kepler made a clear distinction between the world which is absolute, objective, immutable and mathematical, and that which is relative, subjective, fluctuating and sensible.

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[189] Dijksterhuis 1986, 380. Tarnas 1998, 264. Burtt 1980, 73-5. Galileo's speculations about inertia, relativity and the composition of motions were largely directed at refuting the physical objections that had previously been raised to the idea that the earth was in motion. Using his new concept of inertia, Galileo was able, for example, to explain why a body thrown vertically upwards into the air fell back on its starting position even though the earth was moving. It was indeed moving - like all other things on earth - forwards at the same velocity as the earth. This common motion of all things could not however be observed via any experiments carried out on the earth.

Democritus' atomic doctrine, which had been rediscovered during sudies of antique literature, was a source of inspiration to Galileo 30 years before it began to gain currency with other thinkers. Galileo did not, however, regard the movement of atoms as random, since to him all parts of the universe were ruled by laws. In some of his writings, Galileo employed expressions used by Epicurus, and from Democritus he adopted the concept of primary and secondary qualities. The primary properties of things such as size, shape, number and motion had their source in the properties of atoms and could be measured. The secondary, qualitative properties such as colour, taste and odour were considered to be subjective phenomena of secondary importance that arose in the human sense organs and were dependent on the primary qualities. When the real world was simply a succession of atomic motions in mathematical continuity, man was in a way eliminated from it. Only the primary qualities were real and our knowledge of objects was mediated by the secondary qualities arising in the senses.[191]

Galileo is generally regarded as the father of natural science. In his time, Galileo's proposition that the behaviour of material objects could be explained by referring only to physical and mechanistic factors represented a completely new way of thinking: quantitative relationships did not occupy a predominant position in peripatetic philosophy. In contrast to Plato and Pythagoras, who also highlighted the role of mathematics, the object of research for natural scientists of the modern time has clearly been, as it was for Aristotle, the visible world and the changes observable in it.[192] By analysing the quantitative and measurable changes taking place in space and time, natural science has truly been able to discover general laws which control phenomena. In a brief period Galileo was able to refute experimentally many of the aspects of Aristotle's physics which had been criticised but not empirically disproved by many philosophers. Observations and repeatable experiments revealed laws of nature which could be stated in exact mathematical form. When portraying the epoch-making characteristics of the Galilean method, it has been repeatedly pointed out that as a consequence of the new natural science, 'natural laws' no longer meant "*qualitates occultae*" which were derived from the hidden qualities of things, but dependent relationships governed by laws which could be stated as mathematical

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190 Dijksterhuis 1986, 348-352.

191 White 1998, 38-39. Trusted 1991, 52. Collingwood 1960, 94-102. Burtt 1980, 83-84, 98-99. Although Galileo's thou ghts are reconciliable with the fundamental principle of the mechanistic interpretation of nature his conceptions of the void form a curious blend of ideas originating from medieval physics. His idea of the cosmos as a beautifully and efficiently-organized whole was perhaps too vivid for him to be satisfied by the notion of atoms in an infinite void. Dijksterhuis 1986, 419-424.

192 Trusted 1991, 61-62.

functions.[193]

Galileo believed that for a change or property to be handled in a mathematical manner, it must be directly measurable. This approach led him to abandon Aristotle's concept of potential being from which something could anyway come, since potential entities did not appear directly in space-time as measurable objects possessing properties.[194] By abandoning inner qualities, Galileo's descriptions of motion and change differed radically from those employed previously. Aristotle and the Scholastics had regarded change as "becoming", i.e. the actualisation of something that was potential. The Renaissance philosphers had viewed motion in the same light. To them, change was an expression of the inner tendencies of nature: a child developed into an adult and an acorn developed into a huge tree. For two thousand years, both animate and inanimate nature had been viewed as a struggle about the realisation of possibilities and purposes. The new mechanical natural science believed that everything occurring in the world could be traced back to the motion of bodies in space-time. Galileo was not satisfied with Kepler's idea of formal mathematical cause. He was primarily concerned with accelerated motion and he expressed the cause in terms of force.[195]

Galileo's notorious conflict with the Inquisition means that he occupies an exceptional position not only in the history of natural science, but also in the history of civilisation.[196] Galileo was living in the fervent atmosphere prevailing in Italy and he did not wisk to risk his own future by opposing the authority of the church.[197] Within the religious establishment itself, there had long been opposing views on how the church should react to the new Copernican doctrine. In 1616, Cardinal Bellarmine, the chief theologian of the Catholic church, declared them to be false and contrary to the Holy Scriptures. Earlier, the very same Bellarmine had written that this should not be the course of action if there was evidence that the earth moved around the sun and not vice versa. In such a case, his opinion had been that the church should proceed with caution and admit that those parts of the doctrine that appeared to be in conflict with the heliocentric view

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193 Kaila1939, 71-72. 76-77.

194 From the modern point of view, Galileo's conception is limited. All the theoretical terms that belong to a theory describing reality do not need to have an observable correlative. An important example of this kind of term is the wave function in quantum theory. In its interpretation, some similarities to Aristotle's thinking can be observed. See sections 4.3.1. ja 5.2.

195 Burtt 1980, 98.

196 Dijksterhuis 1986, 381.

197 For example Galileo did not react when Kepler, being made aware of Galileo's private support for both the Copernican doctrine and Kepler's own thoughts, sent Galileo a letter requesting him to publish his views by appealing to "Plato and Pythagoras, our true teachers". Galileo's letters have also been published in Finnish, see Galilei 1999, 90-94.

had simply not been understood correctly earlier. Despite his prudence and his willingness to cooperate, Galileo was placed under house arrest in his final years and had to publicly deny the heliocentric teachings in front of the Inquisition in 1633. In the conviction of Galileo, those university professors who strongly opposed his views – which contradicted those of Aristotle – played their part.[198]

Galileo consolidated the status of empirical natural science by his research, by his writings, which were available to a wide audience, and to some extent through his martyrdom. The denunciation of Galileo resulted in a profound conflict between science and the church. It would of course have been possible to find a *modus* for settling the conflict in a conciliatory manner, but instead of this, an old man was forced to deny everything he had professed with all the vigour of his brilliant mind and his ardent soul.[199] By holding to its view that the authority of its dogmas overruled all the accomplishments of rational common sense, the church lost an increasing degree of credibility with each step forward made by natural science. Galileo himself did not, however, see any contradiction between the Bible and natural phenomena, he believed that both were based on the divine word. With naïve confidence, he almost to the very end wanted to be able to convince the church authorities that the true significance of the word of God might be more easily understood by studying and interpreting the book of nature rather than the Bible.[200]

2.3.2. Bacon and Descartes as shapers of the modern world-view

Francis Bacon and René Descartes were philosophers who made a strong and constructive contribution to the shaping of the modern scientific-technical era. Without their influence, it is unlikely that natural science would have become such a powerful influence on the shaping of culture. Bacon was a powerful rhetorician and visionary who modified the cultural climate so that it became receptive to new ideas, while Descartes created a new and clear conception of reality within which the newly-observed natural phenomena could be located and explained.

Francis Bacon (1561-1626) was a contemporary of Galileo. He was the most distinguished

[198] Trusted 1991, 48. Tarnas 1998, 260. White 1998, 77-78.
[199] Dijksterhuis 1986, 384.

philosopher of science during the Renaissance period and in England, he proclaimed the birth of a new era. Bacon was quite convinced that by observing the facts of nature accurately, humans could obtain an abundance of information that would enable people to control and benefit from nature. With clear insight and brilliant exposition, Bacon vigorously engaged in propagandising man's power over nature. He was the source of classical utterances such as 'Nature to be commanded must be obeyed', 'True knowledge is knowledge by causes' and 'Knowledge is power'.[201] By *knowledge*, he did not mean the Scholastics' useless hairsplitting definitions, but new empirical knowledge about the natural world. By learning to know causal chains in nature, he believed that the new empirical natural sciences could bring human beings unprecendented material well-being and technical inventions. [202]

The advance of science, however, required reformation of the scientific method. In his *Novum Organum* (1620), Bacon combined a vigorous criticism of Aristotle's vague teleological explanations with a more precise presentation of the emerging experimental method.[203] He emphasised both the causal links between natural phenomena and the search for efficient causes. He believed that these causes could be deduced without problems from the collected factual evidence through the use of inductive methods. By induction, Bacon did not mean hasty generalizations from inadequate sampling of nature, but a carefully-structured procedure, mounting gradually from particular instances to axioms and laws of increasing generality. Induction was a search for the hidden forms of things, and must begin with a precise and regular record of observations. By applying the systematic tabulation and categorisation techniques associated with the inductive technique, researchers would be unable to avoid reaching the correct results, unimpeded by their own subjective influences.[204]

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200 Trusted 1991, 55. In spite of the difficulties Galileo wanted to publish his books in Italy. The church authorities gave official permission for the publication of all his volumes except the last one, which was printed in The Netherlands in 1638.

201 Bacon also made the striking comparision of the empiricist to an ant which merely collects and uses things, of the rationalist to a spider spinning cobwebs out of its own substance, and of a true man of science to a bee which, steering a middle course, collects material from the flowers of the gardens and fields and digests and transforms it using its own powers. Bacon did not think that passive observation was enough. Through experiments, nature was forced provide answers. Nordin 1995, 272.

202 Dijksteerhuis 1986, 396-398. Kenny 1998, 184. In *Nova Atlantis*, his posthumuous future vision, Bacon described organized research in the coming age of science in a surprisingly realistic manner. Research on the fictious island of Atlantis led to plant development and promoted the human age by new implants, not to mention the various kinds of vehicle moving through the air and under the water. Tamminen 1994, 61-64.

203 Bacon 1952. Bacon wanted to abandon old superstitions and the metaphysics he linked with it, but this did not prevent him from believing that lifeless things could be inhabited by spirits or that other metals could be transformed to gold.

204 Kenny 1998, 186-187. Bacon also introduced four different kinds of factor that can introduce bias into our observation. He called these 'the idols'. For more about Baconian inductivism see, for example, Niiniluoto 1883, 119-123 or Dijksterhuis 1986, 399-401.

The logic of inductive thought based on the principles expounded by Bacon became a tradition in English philosophy which has survived until the present day, even though Bacon without doubt over-estimated the the significance of induction as a scientific method.[205] In his enthusiasm for inductive empiricism, Bacon forgot the importance of theory and deductive inferences when building up knowledge. He did not see the researcher's role in the creation of hypotheses, he simply believed that the facts somehow spoke on their own behalf and that scientific propositions could be derived without difficulty from observations with the assistance of eliminative induction. Since the number of facts is potentially infinite, it is however necessary for a researcher to be able to estimate which of them are actually relevant to the problem being studied. In the marriage of empiricism and rationalism that Bacon dreamt of, rationalism was very much the loser.

Only at a later date did philosophers of science acknowledge the significance of theoretical presuppositions and hypotheses in the process of generating knowledge. The research problem selected for investigation and its associated hypotheses ilfluence and direct the search for, and selection of, relevant facts, the design of scientific experiments and the analysis of the resulting observations.[206] Also, the shift from observed material to hypotheses normally requires, in addition to generalisations, both the enrichment of terminology and the utilisation of new concepts, neither of which can be achieved through the application of mechanical rules. It was on this basis that in 1860, William Whewell (1794-1866), one of the most important pioneers of the philosophy and history of science, criticised Bacon's inductivism by stating that he had not recognised the degree of creative ingenuity required for the generation of hypotheses. In a similar manner one hundred years later, Hempel, like Whewell, stated that "Scientific hypotheses and theories are not derived from observed facts, they are invented to explain them".[207]

It is not difficult to identify defects in Bacon's controversial approach and figure. Experimental science has never actually been studied in the manner Bacon had in his mind. Bacon actually did very little to further the advancement of science and made unfair judgments about the achievements of others. As an example of this, he did not attach much value to the work of either Copernicus or Galilei. He did not fully understand the value of measurement and mathematics in the formation of hypothetic-deductive theories, since he did not have a deeper knowledge of

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[205] von Wright 1987, 49-50.
[206] Cohen ja Nagel 1934, 201, Hempel 166, 13.
[207] Niiniluoto 1983, 124.

either ancien or contemporary natural science.[208] Bacon's ignorance of the significance of speculative reason in natural research did not, however, prevent him from offering the scientific era a new utopia, something which was a source of great inspiration to future generations.[209] Employing biblical metaphors and rhetoric, he convinced people of the opportunities that progress offered.[210] For Bacon, the ultimate aim of science was a practical one: reform of the scientific method could lead to technological applications which would make possible a better future and an unprecedented degree of happiness for the whole of humanity. Through Bacon, Jewish-Christian eschatological anticipation was reshaped, in a way, into the modern world-view. It became a worldly belief and confidence that historical progress and a better future are actually attainable.[211]

The essential philosophical foundation for modern times was, however, created by René Descartes (1596-1650), who left an indelible stamp on the whole of the modern era by constructing a general framework in which there was a proper place for the new science as well as for religion. Descartes greatly admired Bacon, and felt akin to him in both his rejection of Aristotleism and in his all-encompassing faith in a fixed method. Descartes, however, while realising the one-sided nature of Bacon's exclusively empirical viewpoint, emphased reason and mathematics along the mechanistic conception of nature. He carried Kepler's and Galilei's confidence in mathematics to its extreme by virtually combaining mathematics and natural science. From his early youth, Descartes was fascinated by the clarity of the insights offered by mathematical argumentation, and throughout his life he retained a fanatical admiration for its formal methodological value: there was actually something that one could know in the absolute sense. The aim of the Cartesian method is indeed to cause all scientific thinking to take place in a mathematical manner, which for him meant deduction from axioms and algebraic calculation.[212]

Descartes considered the multi-faceted classical education that he had received at the hands of the Jesuits insufficient to handle the new challenges of the age. At the dawn of the new era, old and established institutions and authorities were losing control, while at the same time, new thinking and inventions were rapidly changing the world. The resulting turmoil undermined the

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[208] Dijksterhuis 1986, 397,400, 402. Trusted 1991, 71-78.

[209] Dijksterhuis 1986, 402-403. Bacons conception's and guiding principles of experimental philosophy led to the formation of influential scientific associations in England and in other countries.

[210] Niiniluoto 1994, 146-148. Bacon believed that by employing science and technology, man was able to retrieve part of his power over creation which he had lost in the Fall.

[211] White 1997, 42. Tamminen 1994.

[212] Dijksterhuis 1986, 403-405.

confidence of Europe's educated classes in the possibility of any knowledge actually being certain. The epistemological doubts of the antique Sceptics became known, for example through essays written by Michel de Montaigne in the 1570s and 1580s. In these texts, he mounted a vigorous defence of classical scepticism as a way of avoiding arrogant and pompous dogmatism.[213] For his part, Descartes also did not want to defend unfounded beliefs, but in a manner similar to Plato in his time, he considered it essential to crush sceptical relativism and its epitemological doubts. In his opinion, the best way to accomplish this was to present tenable arguments for certain knowledge.[214]

Descartes consciously strove to create a new and clear description of the world while restricting himself to those observations about which opinion was unanimous. Using his method of doubt he believed he could get rid of the Scholastics' qualities, elements and other old-fashioned explanations of natural phenomena.[215] In contrast to Bacon's approach, which was content with plain empiricism and the glorification of the practical application of science, Descartes targeted the description of reality in a more holistic manner. In addition to the material dimension, he paid attention to human beings, emphasising reason as a precondition for mathematical rationalism. As Plato did in his time, Descartes believed that reason roamed its own territory, and that its clear ideas could provide certainty in situations where the senses, feelings and imagination led in the wrong direction. By accentuating rationalism, mathematical methods and the clear ideas of reason, he viewed physics as just another branch of mathematics. Just like geometry, physics could be deduced from axioms that had been established *a priori*. The human mind was a precondition not only for mathematics, but for physics as well.[216]

Descartes positioned the new laws of natural science firmly in the material world, while at the same time leaving the spirit free. He regarded the difference between man's rational freedom and the unavoidable mechanical processes of nature as so deep that he considered it correct to speak of two substances. The dimension of the material world, *res extensa*, and the spiritual or mental world, *res cogitans*, coalesced only in humans, and their common source was God. The attribute of the mental substance was thought, all the phenomena of consciousness and awareness such as feelings, desires, impressions and deductive acts were different modes of this same basic substance in the same way that shape, motion and rest were different modes or extensions of the

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[213] Tarnas 1991, 275-276.

[214] Descartes 1994, 11. At the beginning of his Discourse on Method, Descartes gives a lengthy and vivid description of the process he went through in order to renew the basis for thought and knowledge.

[215] Descartes 1999, 87, 97, 102.

material dimension.[217] This world-view did not restrict the development of natural science, since it left the spirit free, and people tied to the Christian faith could also accept it. The concept of the rational mind and causal matter was soon considered “common sense”, universally accepted, and in fact considered to be almost self-evident. At the beginning of the 1700s, primary geometric-mechanical qualities were considered to be truly an inherent part of a physical body, while the secondary qualities were mere names for the perceptive sensations and feelings experienced in consequence of, or in connection with, physical processes taking place in the external world.[218]

For Descartes, the material world which obeyed natural laws was a completely mechanical entity. While the motion of bodies was the consequence of direct collisions, these collisions were not random or chaotic events as they were ruled by unconditional laws.[219] Descartes did not, however, maintain an Atomist view of matter. The ultimate nature of material was determined by the purely geometric characterisation of extension: matter is that which has extension in space and nothing more. Although material bodies appear to have physical qualities such as hardness, colour and taste, all these words merely designate states of consciousness. They are subjective reactions which the presence or contact with particular parts of space generate in us and which acnnot therefore be the subject of scientific knowledge. Apart from the geometric characteristics of bodies, i.e. their form and size, only the kinematic magnitudes which determine their relative state of motion can be known in the scientific sense. The identity of matter and space, the metaphysical foundation of the Cartesian system, leads to the inevitable conclusion that the world has infinite extension and consists of the same matter throughout. Also, while matter is infinitely divisible, a vacuum, i.e. a space that contains no matter, is a contradiction and consequently impossible.[220]

The Cartesian system for interpreting nature equalled that of Aristotle in its universality. Even though his dualism demolished Aristotle’s view of the ultimate unity of form and matter,

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216 Dijksterhuis 1986, 406-407. Descartes 1999, 60, 65.

217 Aspelin 1995, 286-287. Tarnas 1991, 277-278. To a considerable extent, so-called “Cartesian dualism” is a myth created by his followers and modern commentators which does not wholly respect his ideas. Strictly speaking, both thinking and extension are for Descartes attributes of a substance, not substances. Alanen 1997, 41,43.

218 Toulmin 1998, 212. Dijksterhuis 1986, 431.

219 Descartes 1999, 98,99, 107. In 1637, Descartes developed analytical geometry, which was needed in the subsequent development of dynamics.

220 Dijksterhuis 1986, 405, 409. When the concept of body consists solely of extension, there is of necessity but one matter in the whole universe, and we know this by the simple fact of its being extended. All variations in matter or diversity in form are dependent on motion, i.e. the transference of one part of matter or one body from the vicinity of those bodies that are in immediate contact with it, and which we regard as being in response, into the vicinity of others. Nagel 1961, 171-172. Nagel refers to René Descartes, ”The Principles of Philosophy,” Part 2 Principles 4, 23 and 24 in The Philosophical Works of Descartes, Cambridge, England, 1931, Vol 1, pp. 255, 265, 266.

Descartes employed many Aristotlean concepts in his thinking and in a way simply poured new wine into old bottles. Descartes wanted to give the spirit what belonged to the spirit and matter what belonged to matter. He did not accept the principles of form outlined by Aristotle and the Scholastics which defined the passive and formless matter, any more than he accepted the the concept of a world soul as defined by the natural philosophers of the Renaissance. For Descartes, matter was absolutely without soul, and the soul was absolutely immaterial. He believed that physiology could function by using general mechanical principles without the need for any souls or vital energy. Plants, animals and the human body were to be regarded as machines constructed with incomparable skill by an infinite intelligence. However, mechanical interpretation of the universe had its limits. Human beings were not simply an organised body, they also had a soul, i.e. thinking substance. Human understanding and will did not belong to the physical domain, they were states of spiritual reality. It was Descartes' assumption that the interaction between the soul and the body took place in the pineal gland.[221]

The two realms of reality, the material and the mental, were represented by two fundamental sciences, mechanics and psychology. The first of these employs concepts of extension and motion, the second studies thinking i.e. different modifications of consciousness. In his search for transparent and precise basic concepts, Descartes did not deal with the emotions in the traditional way employed by moralists or preachers, his position as a natural scientist meant that in his psychology, he attempted to find a regular coherence of law-observing emotions in the precise manner that would be employed by a physicist or a physician. Compared with Descartes' universality, Galileo had confined himself to the investigation of a small number of special fundamental phenomena, something that Descartes accordingly charged to his account as a defect. Descartes was also critical of Galilei's excessive confidence in empirical observation, believing that he should have deduced the laws controlling falling bodies from clear and indisputable first principles or primary axioms. In his attempts to find these, Descartes actually formulated the law of inertia in a clearer manner than Galilei: bodies remain at rest or continue in their straight motion at a constant velocity, provided that they are not interfered with. In his interpretations of nature, it is however a fact that Descartes hardly ever conducts a mathematical argument and is always very vague when expressing functional dependencies. The first thoroughgoing Cartesian who did full justice to the mathematical treatment was Christian

[221] Alanen 1997, 42. Aspelin 1995, 287-189.

Huygens (1629-1695), who continued the mechanistic direction suggested by Descartes.[222]

The Cartesian formulation of the mechanistic interpretation of nature[223] lacks the word "force", which in later times appeared to express its quintessence. To Descartes, there was no doubt that forces which bodies were able to exert on each other from a distance, such as weight, were not explanatory principles but required a mechanistic explanation. In the history of science, however, the influence of Descartes has often become combined with that of revived ancient Atomism.[224] This may appear strange because Descartes in principle rejects the void, which is a prerequisite for Atomism.[225] He also denies the existence of indivisible particles, since for him matter is infinitely divisible. As Descartes did not accept the concept of the void, he could not, as Newton did, contemplate absolute time and space or the possibility of forces operating through space.[226]

In the Europe of the 1600s, Descartes' philosophy developed into a role reminiscent of the role played by Aristotleism in the 1200s. It was the "new philosophy" of the time, which clearly opposed traditional ways of thinking and was confident that it would succeed in solving all problems via its compelling mathematic-scientific method. Natural scientists and physicians in particular, who opposed the customary Scholastic and Humanist cultural ideals, accepted it rapidly, but in both university and theological circles, this reforming project was viewed as dangerous and bitter battles were fought with the old Aristotlean philosophy. Descartes was always anxious to avoid coming into conflict with the Catholic faith on the subject of his propositions. It is known that the denunciation of Galilei prevented him from publishing his *Le Monde*, a work in which he adopted the Copernican view. In this respect, Descartes possessed an ability typical of scholars in the 1600s – keeping the new science separated from religion. Reason was not to be applied to religious questions, as for example, Blaise Pascal (1623-1662), a contemporary of Descartes, had learned from his father.[227]

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[222] Aspelin 1995, 290-291. Dijksterhuis 1986, 408-409, 414. Tarnas 1991, 267. Seventeenth-century mechanistic science, which assumed no other explanatory principles besides matter and motion, and no other way in which material bodies influenced each other in addition to contact, reached its culmination in the work of Christiaan Huygens. Dijksterhuis 1986, 457.

[223] The content of the term mechanistic was not fixed once and for all, but it was to vary over the course of time. The concept of mechanism is defined in Section 3.1.1..

[224] The clear revival of Democritean-Epicurean atomism was a result of the activities of the French philosopher Pierre Gassend (1592-1655) Dijksterhuis 1986, 419, 425-431.

[225] By confusing space and extended matter, Descartes was able to exclude spirit from the realm of science. Spirit was fundamentally different from matter because it did not have extension in space.

[226] Dijksterhuis 1986, 414-415, 417. In practice, the differences are not as great as they may appear. We can only mentally divide the parts into which God originally divided space. Even if, in actual fact, he can do this with reference to science, the parts behave like Democitean atoms.

[227] Trusted 1991, 68-71. Dijksterhuis 1986, 417-418. Aspelin 1995, 191-192.

2.3.3. Isaac Newton's synthesis

On the basis of Kepler's and Galilei's laws, it was not yet possible to conclude why the planets and bodies moved in the way they did. Isaac Newton (1642-1727) collected together and systematised the traditional mechanistic explanations influenced by ancient thinking and put them into a uniform axiomatic form. He took vague terms like force and mass and inertia and found them a precise meaning in mathematical terms, so that by their use the major phenomena of physics became amenable to mathematical treatment. Newton also gave new meanings to the old terms space, time and motion which were now becoming the fundamental categories in men's thinking.[228]

With his concept of the attraction between masses, Newton succeeded in uniting Kepler's planetary laws and Galilei's research on motion. His monumental work *Philosophiae naturalis principia mathematica*[229], published in 1687, came to justify belief in the adequacy of the mechanistic description of natural phenomena. In the background of *Principia*, it is possible to distinguish both Descartes' idea of mathematics as a universal science and Galilei's cosmology of the world as a machine made by God that is coloured with secondary properties by man. In his synthesis, Newton united these ideas with the hypothesis by the English physician and physicist William Gilbert (1540-1603) of a universal attraction between bodies that was in inverse proportion to the distance between them that was already known at that time. The seamless combining of all these elements by Newton was an achievement that would nowadays be considered as significant as unifying the theory of relativity and quantum mechanics.[230]

It was generally believed that Newton had revealed the true structure of the world, and nature began to be regarded as a perfectly organised machine ruled by mathematical laws. His achievement was celebrated as a victory which surpassed those of both antique and mediaeval times. Voltaire, for example, regarded Newton as the greatest man that had ever lived. Newtonian mechanics became a paradigmatic ideal and model for scientific theory, and even though Newton himself regarded simple mechanistic philosophy as inadequate to explain the active and living phenomena of nature, the mechanical conception of the world was to wield its

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[228] Burtt 1980, 32-33.
[229] Newton 1972.
[230] Collingwood 1960, 107.White 1998, 216. Burtt 1980. 31-32.

influence both inside the world of physics, and extensively outside it, for more than two hundred years.[231]

Newton, who studied and worked at the University of Cambridge in England, was both an experimenter and a mathematical genius. In Newton's time, university teaching focused on the masters of antiquity, above all Aristotle. Instruction in mathematicians and the thoughts of modern philosophers such as Descartes, Bacon and Galilei was inadequate, but Newton became acquainted with their writings independently. He also studied higher mathematics on his own for a period of two years and developed differential and integral calculus at the same time.[232] In this work he was influenced by the analytical geometry of Descartes, which revealed the link between algebraic equations and geometry. In his younger days, Newton was also interested in Descartes' philosophy, but he later began to regard it as overly atheistic. Deeply religious, Newton conducted a dialogue with Henry More, the leading light of the Cambridge Platonists, who was attempting to unite Atomism with Platonism in his mystic natural philosophy and who was convinced that matter was guided by the mind.[233]

The new understanding of the motion of bodies made a new concept of force essential. Changes in the state of motion were evidence of the influence of a force, even though neither a state of rest or motion in a straight line required the assumption of any force. In his synthesis, Newton postulated the concepts of absolute time and space and differentiated them from relative time and space. Absolute time and space were infinite and independent of matter, and they provide the foundation for the mathematical description of the motions of material bodies.[234] Bodies in empty space were under the influence of gravitational force, i.e. every piece of matter in the universe attracted every other body with a force proprotional to the square of the distance between them. This interaction defined the orbits of bodies with absolute inevitability. If the location and state of motion of bodies in this system are known at a specific point in time in relation to a stable system of reference, Newtonian dynamics provide a basis for the accurate prediction of their behaviour.

Verification of the idea of gravitation was not simple, even though Newton was able to

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231 Dijksterhuis 1986, 463-464. Tarnas 1998, 269-271.

232 Newton and Leibniz were in dispute over who was the first to invent differential and integral calculus. The notation used nowadays actually originates from Leibniz.

233 White 1998, 53-62, 233.

234 Newton appeared to be ignorant about the philosophical problems related to these basic differentiations. Motion and space had been considered to be relative for a long time. Collingwood, 1960, 108.

demonstrate mathematically that such an attraction between masses would lead to the elliptical motions of the planets observed by Kepler. The pieces of the jigsaw puzzle came together when, at the beginning of the 1680s, a bright, rapidly-moving comet was observed of a type similar to one concerning which observations had also been recorded in 1666. Newton was able to demonstrate that this phenomenon could be explained by making the assumption that the comet was orbiting along a specific elliptical path within the gravitational field of the sun. Newton's proposition, according to which gravitational attraction could operate across empty space, could not be accepted within the dominant Cartesian mechanical theory, since this required direct contact between interacting bodies. Among others, the philosopher Leibniz was fiercely critical of Newton's gravitational theory since it required "occult forces" with which bodies attracted one another and which remained beyond both rational explanation and human cognition.[235] Newton absolutely rejected the charge that gravity was an occult quality. For him, it was not a hypothesis, it was an empirically established fact whose cause would be revealed in time.[236]

Newton's three axioms or laws of motion, which form the foundation for mechanical explanation, were stated by him as follows:

Law I. Every body preserves its state of rest, or of uniform motion in a right line, unless it is compelled to change that state by forces impressed thereon.
Law II. The alteration of motion is ever proportional to the motive force impressed; and is made in the direction of the right line in which that force is impressed.
Law III. To every action there is always opposed and equal reaction: or the mutual actions of two bodies upon each other are always equal, and directed to contrary parts.

The axioms of motion are theorethical statements that must be assumed to be formulated for so-called ”point-masses” i.e. for bodies whose masses are, in theory, concentrated at a ”point”. This fact makes it evident that the axioms of motion cannot be regarded as statements about relationships between experimentally specified properties, but are postulates which implicitly define a number of fundamental notions otherwise left unspecified by the postulates of the theory.[237]

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[235] Leibniz 1981, 65.
[236] Lehti 1988, 218. White 1998, 303. Dijksterhuis 1986, 489.
[237] Nagel 1961, 158-160. Nagel also presents these basic axioms by using modern language and mathematics, and examines them in order to elicit the essential features of mechanical explanation. See also Section 2.4.1.

In addition to *Principia*, Newton also produced his treatise *Opticks*, another great scientific work which was published in 1703. As a great synthesist, Newton envisioned that gravitation and light would follow the same principles, and he also anticipated that other forces in addition to gravitation would exist in microphysics.[238] In parallel with his well-known scientific activity, Newton was also deeply interested in alchemy, numerology and mythology. He had 167 works on alchemy in his library, and his posthumous papers contain a wealth of of notes and unpublished texts concerning such matters which cover a period of 27 years. Newton also carried out many experiments related to alchemy, and as later analysis of his hair demonstrated, these led to him being poisoned.[239] Since he spent the majority of his time engaged in the comprehensive study of religion and alchemy, it is reasonable to assume that Newton was searching for an even greater synthesis, a principle that would have united the whole cosmos. His contemplations on an overall unification theory were apparently inspired by his belief that a general rational frame of reference had been known in the antique golden age when humans had been in possession of all knowledge.[240]

In spite of the fact that Newton is generally regarded as having reduced the world to the workings of a simple machine which can be described through deterministic interactions, he did not himself draw this type of conclusion from his work. He did not even believe that his theory implied unconditional determinism, but thought of God as being able to sometimes interfere in the course of the world, an illogicality for which Leibniz criticised him.[241] If the omnipotent Creator had not created an imperfect mechanism, why should he need to also function as the Preserver of the material universe – it operated perfectly well by itself on the basis of fixed and immutable laws. In his final years, Newton attempted to unite science and religion by regarding absolute time and space as aspects and manifestations of God. Although, in public, he avoided the “fabrication of hypotheses”, he pondered what caused the gravitational force until the very end. One explanation was the idea of Christ as the incorporeal ether who made gravitation

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238 White 1998, 225-6, 287-8.

239 White 1998, 105, 119-132. The alchemistic side of Newton was revealed to the general public in 1936, when the economist John Maynard Keynes began studying personal papers by Newton that had been donated to the University of Cambridge. In a lecture to the Royal Society in 1942, Keynes said that he no longer considered Newton to be the first genius of the rationalistic age, but rather as the last of the great Babylonic-Sumeric magicians who began building the intellectual heritage of our culture some 10,000 years ago. White 1998, 3.

240 Ahonen 1988, 75-84. Holton 1978, 123. White 1998, 106-7. Newton was a member of the Cambridge Platonists and believed he belonged to an age-old Pythagorean tradition. The curious co-operation between science and esoteric beliefs was almost the norm in Renaissance times and was an important part of the birth of modern science. Descartes also belonged to a Rosenchrist society. Tarnas 1998, 295. White 1998, 190-207.

241 The reasons why Newton believed God would sometimes interfere in the course of the world were mainly empirical. An additional explanation was required to prevent gravitational collapse as well as observed inconsistencies in the motion of the planets Jupiter and Saturn. The deceleration of Saturn which was compensated

possible.[242]

3. The Mechanistic-deterministic Conception of Reality

Among the numerous modifications that human understanding and scientific thought concerning nature have undergone over the centuries, it would be difficult to point to one that has had a more profound and far-reaching effect than the conception of the world that is usually called ’mechanical’ or ’mechanistic’. Instead of treating things in Aristotelian terms such as substance, accident, essence, form and potentiality, we now treat them in terms of forces, motions, laws, changes of mass in space and time and the like. The mechanisation of physical science has become much more than an internal question of method in natural science, since the modes of thought inherent in the conception have also penetrated philosophical thought about man and his place in the universe.[243] The mechanical and deterministic conception of the structure of the universe and the natural laws that direct natural events have formed a new scientific world-view which has, over the centuries, left its mark in educated humans concerning their conception of their surroundings.[244]

Newton’s *Principia* was understood as the foundation of physics before the end of the 1600s in British Isles, and in the European continent had replaced the Cartesian way of thinking by the middle of the 1700s. Modern people following Francis Bacon’s doctrine believed they had found the keys to knowledge that would enable them to exploit the power of nature. Newton’s great synthesis gave science a mandate to lead society into a new epoch. As a consequence of the new natural science, humans now lived in a world whose laws they had learned to understand. Metaphysics lost its hegemony as modern knowledge and world-view were trustworthy constructed in the laboratory of natural science. In Newton’s work, classical science attained an independent role that has affected both human society and the history of culture in many ways: the whole conception of reality was changed.[245]

Empirical observations confirming Newton’s laws legitimised the widely-held confidence that nature could be investigated as an lawful object independent of human subject. After *Principia*,

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for by the accelation of Jupiter was explained by Laplace in 1786. See Enqvist 2003, 80-82.

242 Trusted 1991, 101-105. White 1998, 351-352. Dijksterhuis 1986, 491.

243 Dijksterhuis 1986, 3, 463. Burtt 1980, 26, 303.

244 von Wright, 1987, 9-10.

the appropriate organized structures found in the world system were no longer interpreted as being part of nature's own intelligence and it become customary to explain all qualitative phenomena as secondary phenomena arising in the mind. Matter was no longer understood in the Aristotlean manner, it became a totality of quantitatively organised moving bodies, whose behavior could in some cases be controlled by humans. Another result of the new way of thinking was that *anima*, a quality of vital energy previously thought to be part of reality which could bring about qualitative change, was now replaced by mechanical energy which caused quantitative change. Matter was subject to mechanical laws, while mind was not bound to time and place in a similar way. *Res extensa* and *res cogitas* worked independently in accordance with their own laws. This strict dualism was reflected in a new view of the relationship between humans and nature: no dialogue was possible with the inanimate material which made up the world.

Nobody could regard the new concept of matter as a trivial fancy when events on the world were seen to observe the mathematical formulae of natural science. The precise predictions of the Newtonian model yielded a basis for describing reality which could be used to explain countless natural phenomena and to develop technical innovations which changed both culture and lifestyles in many ways. The Newtonian conception of the material world was generally believed to be 'truth', and this placed serious limitations on the options open to philosophy.[246] As new knowledge of the material world was seen as a real and reliable result produced by human reason, critical philosophy was also forced to operate within this firmly espoused mechanistic-deteministic paradigm. Philosophy had no option but to take physics seriously and to recognise that its achievements represented true knowledge. New science strongly affected the problems studied in philosophy. The question was no longer whether the quantitative and material world of natural science could be perceived, only why it could be perceived.[247]

In the same way as it affected philosophy, the direction of cultural development pushed theology into a minor role: both disciplines were forced to more or less reconcile their operations to the new reality of deterministic science. Scientific research was regarded as essentially different to philosophical speculation. During the 1700s, natural philosophy changed into science, employing methods which remain largely unchanged today. Nature, believed to be ruled by absolute laws and deterministic causality, was investigated by proposing hypotheses and conducting

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245 Trusted 1991, 107. Aspelin 1995, 470.
246 Trusted 1991, 58, 78, 107.
247 Tarnas 1998, 280-281.

experiments. Physical events were observed and measured and attempts were made to describe them using mathematical terms. The empirical thesis of natural science, that knowledge should be based on observation, was only strengthened as research advanced. The mechanistic-deterministic approach of classical physics began to have an increasing effect on the development of other disciplines. In the 1800s, it was generally believed that an observation was objective and independent of theory, and that all phenomena could, in principle, be explained by natural laws which were just as reliable and fundamental as Newton's laws of motion. A result of the new level of certainty achieved by explanation was the common belief that science could be totally free of metaphysics.[248]

In the 1700s, Newton's discovery of a cosmos controlled by mathematical laws was still generally interpreted as evidence for the existence of God, even though he was no longer believed to initiate action to change the natural course of the world he had created. As there was no doubt about the validity of the deterministic laws controlling matter and the only criterion for an acceptable scientific explanation was the discovery of an effective material cause, the new method of explanation provided material for both secularism and materialism.[249] The latent secularism of natural philosophy became explicit in France in the 1700s, where the philosophy of enlightenment, which resisted religious authority, popularised Newton's ideas. Laplace (1749-1827) rejected God as an unnecessary hypothesis, while Paul Henrik d'Holbach (1723-1789) employed Newtonian philosophy as a tool in both Atheism and Materialism.[250]

By the middle of the 1800s, mechanics was widely acknowledged as the most perfect physical science, embodying the ideal toward which all other branches of enquiry ought to aspire. It was in fact the common assumption of outstanding thinkers, both physicists and philosophers, that mechanics was the basic and ultimate science, in terms of whose fundamental notions the phenomena studied by all other natural sciences could and should be explained.[251]
The particle-mechanistic conception of reality that was born as a result can be regarded as a mathematically sophisticated version of the forgotten two thousand year old materialistic world-view proposed by Democritus and Epicurus, in which the world consists of atoms and empty

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[248] Trusted 1991, 127-128.
[249] Trusted 1991, 78,108
[250] Toulmin 1998, 268-9. Trusted 1991, 110-111. On the other hand, the thought that mind is material is not very far from Pantheism. When postulating matter as the only reality, many of the materialists of the 1700s and 1800s used Christian phraseology, but referred to matter instead of to God. d´Hollbach even ended his major work *Du systéme de la Nature* with a prayer for matter. Collingwood 1960, 104.
[251] Nagel 1961, 154.

space. In the new way of thinking, this antique mechanistic way of thinking has also been integrated with the Pythagorean tradition. Modern science is built on the Platonic belief of a rational system which can be revealed by intelligence. Development of the new way of thinking left however very little room for Plato's mystical metaphysics. Even though a mathematical law may perhaps be timeless, its usefulness is not taken as addressing deeper meaning, no more than as nature's mechanical tendency to produce regular forms. In physics, the mechanistic-deterministic way of thinking and world-view ruled from Newton's death until the end of the 1800s.[252]

3.1. Fundamental ontological and epistemological presuppositions

The frequent comparison of the material world to an ingeniously contrived clockwork mechanism which was embraced by several thinkers in natural philosophy in the 1600s[253] made it easy for a layman to understand the basic principles of the mechanical material world. For several centuries, the common conception of reality was strictly deterministic. The attempt was made to reduce all the intricate phenomena of nature to a few basic phenomena which could be carefully measured, analysed and predicted. Even though the universe was constantly in motion, it was believed that no qualitative development or change took place in its material basis. Atoms, the fundamental components of matter, were always considered to exist at some point in space and the causes of every event were to be found in some previous event. Explaining a particular phenomenon meant the precise identification of an effective cause. In the last resort, it was believed that all the phenomena observed in nature could be reduced to the motion of atomic particles which moved from place to place in accordance with Newton's laws of motion.

Essential concepts in the scientific thinking of the modern age were the terms mechanism, determinism and atomism, which were seamlessly combined in classical physics and which define the material foundation for the widely adopted world-view. The precise content and significance of these concepts will be examined more closely in this chapter. It is important to examine the terms as precisely as possible to understand the change that took place both in scientific development and in the ideal of mechanical explanation at the beginning of the modern era, as well as to understand the subsequent changes that took place in the by then familiar

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[252] March 1957, 30-32. Tarnas 1998, 292-3.
[253] Dijksterhuis 1986, 442, 495. In particular, the comparision to the large and extremely-complicated clock in Strasbourg Cathedral recurs frequently.

mechanical and deterministic ideals as a result of quantum mechanics. Despite the great changes that have taken place in physical science since the turn of the 20th century, classical mechanics continues to be both a fundamental part of modern physics and to illustrate an important type of physical explanation.[254]

3.1.1. Mechanism

As a beginning, it is by no means superfluous to examine the meaning of the words mechanic and mechanical, the most common qualifications of classical science. These words sound familiar to most people and are often employed without any further explanation even in technical discussions. But what do we precisely understand by the ”mechanisation” of the picture that scientists form of the physical world, and what is the meaning of the word ”mechanical” that it is linked with so many scientific terms such as problem, model, fact, law, conception or explanation? For Descartes, these terms implied that no other explanatory principles are used other than the concepts employed in mechanics: geometric concepts such as shape, size and quantity which are used by mechanics as a department of mathematics and motion which forms its specific subject. According to him, only things that can be described and explained using these concepts can be recognised as actually existing in nature. This approach not only excludes all notions of animation, internal spontaneity and purpose, it also, since it views them as the ultimate building blocks of perceivable bodies, prohibits all internal changes in the particles of matter, and banishes from physics all the secondary qualities of matter, which it considers to be states of consciousness.[255]

From an etymological point of view, the word ”mechanistic” can be viewed as the opposite of ”animistic”. When thought of in this way, the essence of the replacement of Aristotlean by classical physics can be seen as a rejection of any internal principle of change and the attribution of all forms of motion to external causes. The word ”mechanical” also carries the connotation of automatic or thoughtless in addition to the idea of being capable of imitation by a mechanical model. There is no essential difference between a clockwork mechanism and a growing tree.[256] Even if such associations may not add very much to a correct understanding of the character of classical science, they may have had a quite profound effect on the commonly accepted world-

[254] Nagel 1961, 153.
[255] Dijksterhuis 1986, 414-415, 495. Nagel 1961, 155.
[256] Dijksterhuis 1986, 415, 498.

view.

In one broad use of the word ”mechanical”, any answer to questions such as ”How does it work? or ”How is it done? is apparently a mechanical explanation, whatever the determining factors of the process under discussion may be. Accordingly, in this broad sense of the term, all sciences of nature always provide mechanical explanations, to the extent that all the special sciences seek to discover the conditions under which things and events occur and to formulate the laws that express such relations of dependence.[257] Typical of the classical science of mechanics, the first of the natural sciences to achieve a unified system of explanation for the phenomena it claims fall within its provenance, was a profound trust in mathematics. Viewed in a quite general manner, mechanics can be seen as a set of equations that formalise the dependence of certain traits exhibited by bodies on other physical properties. A more restricted definition of the ”mechanistic” characteristic of classical science could be to answer the questions posed above in accordance with Newton’s system, ’with the aid of the concepts of Newtonian mechanics’.[258]

The customary definitions of ”mechanics” are variations of Maxwell’s definition (1877) of the term as the science of matter and motion. This is not very revealing without further analysis. For example, the definition does not tell us anything about the limits of the science of mechanics, and the word ”matter” is far too imprecise to define anything clearly. The content of the science of classical mechanics is best examined within the framework of ideas provided by Newton’s fundamental ’axioms’ or ’laws’ of motion which constitute the ultimate premises for explanations in accordance with the science of mechanics.[259] The axioms have been carefully studied by various philosophers of science. In his thoroughgoing style, and in consideration of the ways that theory has actually been used in science, Ernest Nagel examined the distinctive features of the axioms with respect to their mathematical *form*, and with respect to the kinds of *terms* to which they relate.[260]

After completing a lengthy investigation, Nagel concludes that it is not in consequence of their mathematical form that the axioms of motion are to be viewed as the premises of a mechanical science. In order to ascertain the characteristic features of mechanical explanations, he considers

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[257] Nagel 1961, 153, 156.
[258] Dijksterhuis 1986, 498.
[259] Nagel 1961, 157-162. The axioms of motion when asserted with strict universality are not experimental laws, on the contrary they are theorethical postulates for which the rules of correspondence must be supplied before they can be said to have any definite empirical content.
[260] Nagel 1961, 153-202.

it is more important to examine the kinds of terms to which the axioms of motion relate. The axioms state the general character of some of these terms in an explicit manner. While they involve references to at least three kinds of magnitude, namely measures of space, of time, and of mass, they do not do this for all the terms. A more difficult task is to clarify what sort of characteristics are involved in the concept of force.[261] Newton provided no indication of what limitations, if any, should be imposed on the force function. Different types of force function are employed in different areas of mechanics such as the mechanics of rigid bodies, the mechanics of elastic or deformable bodies, and the mechanics of liquids and gases. Even if the mechanics of point masses is the foundation for all of these, the second axiom cannot contribute anything to the analysis of actual motion if something additional is not stated about the force involved.[262]

A survey of actual physical practice shows that a large variety of problems can be successfully handled in terms of the Newtonian equations of motion, and that a considerable number of distinct factors may enter into specification of the force function. The force functions employed in mechanics are specified in terms of some or all of a set of ”parameters” which are either *variables* or *constant coefficients*.[263] This makes it difficult to provide a straightforward answer to the question ”What is a mechanical explanation? The labels ”mechanics” and ”mechanical explanation” have a wide but by no means precise scope. Nevertheless, there is a core of common meaning in all the senses of ”mechanical explanation”, and they can be given a narrower or a more-inclusive connotation according to the various restrictions that may be imposed on the composition of force functions, if these are to count as ”mechanical” force functions.[264]

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[261] The notion of force has been the source of much difficulty in the foundations for mechanics. The Cartesians at first did not consider it appropriate for mechanics. The concept doubtless originated in familiar experiences of human effort and much of the critical work concerning the foundations of science has been directed towards the elimination from physics of such anthropomorphic notions. Nagel 1961,186.

[262] Nagel 1961, 166-167. Two main types of force-functions are employed in the mechanics of point-masses: positional and motional forces. Motional forces are functions not only of relative positions, masses and such coefficients but also of the relative velocities of the point-masses and of certain temporal periods. Central forces like gravitation and damped and forced vibrations are positional forces. Newton’s analysis of motion is usable also in cases where the force-function contains term referring to the magnitudes of electrical charge, magnetic moment and several other items.

[263] In all cases, the variables are spatiotemporal magnitudes: distances, angles, time intervals, velocities and the like. The constant coefficients are of three main types: universal constants such as the gravitational constant; constants having different values in different problems, but which can in principle be calculated from the universal constants and the geometry of the physical system under consideration; and coefficients such as those of mass, elasticity, viscosity, electric charge and magnetic moment, which have different values for different bodies or materials but whose magnitudes cannot in general be evaluated from such geometrical considerations and must be ascertained in some independent manner. Nagel 1961,169-170.

[264] Nagel 1961, 169,173.

In the most inclusive sense of the phrase, Nagel defines a ”mechanical explanation” to be one that satisfies the following three conditions:

a) Its ultimate premise asserts that the time-rate-of-change in the momentum of a physical system is a function of the magnitude and direction of the forces acting on it.

b) The direction of the change in momentum of a body is along the direction of the impressed force; and the direction of such a change associated with several forces is along the direction of the vectorial sum of the component forces.

c) The forces are specified exclusively in terms of the spatio-temporal magnitudes and relations of bodies, a universal constant, and a number of constant coefficients (assumed to be listed exhaustively) whose values depend on the individual properties of a given system of bodies.[265]

More-restrictive definitions can be applied to mechanical explanations. The Newtonian theory of gravitation actually provides a more-demanding requirement for a mechanical explanation. While it satisfies the first two conditions, the force function is specified exclusively in terms of spatio-temporal variables, the universal constant of gravitation, and coefficients of mass. Explanations of this type employ force functions which have an identical form in every problem and they must postulate sub-microscopic particles and processes. What historians of ideas call the ”mechanical conception of nature” appears to be the once widely entertained view that phenomena of physical, if not animate, nature can eventually be explained by a unitary mechanical theory. The theory satisfying Nagel’s requirements above does not necessarily have to employ force functions having an identical form in every problem.[266]

Descartes related the inertia of bodies to their size and Leibnitz related it to their weight. Newton wished to distinguish between weight and mass because the latter did not vary with motion, and related inertia to a body’s mass. Classical mechanics adopted Newtonian mass as a kind of constant, ’the quantity of matter in a body’, and ”intrinsic” property of a body which did not

[265] Nagel 170. This account of the nature of mechanical explanation does not differ in substance from the traditional definition of mechanics as the science of matter and motion, or from the frequent characterizations of mechanics as the science that deals with those properties of things that are ”definable” in terms of mass, length, and time.

depend on that body's velocity. Newton's account of mass in his third law is, however, notoriously unsatisfactory. His definition of mass as the product of a body's density and volume is quite useless since the density of a body is commonly defined in terms of its mass and volume. Newton's third axiom is not a literal definition of 'mass', and Ernst Mach was the first to propose the definition which has been widely adopted. Mach equated the 'relative masses' of bodies with the 'negative inverse ratio of their mutually induced accelerations'. As has been repeatedly emphasised, the constancy of this ratio is not actually a matter of definition, and it is in the affirmation of this constancy that the main burden of the third axiom lies.[267]

3.1.2. Determinism

Closely associated with the study of mechanism, the concept of determinism traditionally refers to such lawful order on the basis of which later events are predestined or "determined" by what has gone before. Classical mechanics is the generally acknowledged paradigm of a deterministic theory. Viewed in a quite general way, a scientific theory is deterministic if it describes a certain type of system behaviour against time with the assistance of deterministic laws.[268] In their Newtonian form, the equations of motion assert that the time rate of change in the momentum of each mass point belonging to a given physical system is dependent on a definite set of other factors. In relation to time, the basic laws of classical mechanics are deterministic both forwards and backwards. Even though the word "cause" does not appear in these equations, they are sometimes said to express "causal relationships" simply because they assert such a functional dependence of the time rate of- hange in one magnitude (i.e. momentum) upon other

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266 Nagel 172, 173. Cartesian physics is the expression of an ideal that can even be termed "extreme". It restricts genuine mechanical explanations solely to explanations in terms of action through contact. The various specific differences between substances must themselves be ultimately explained exlusively in terms of spatiotemporal differences in the microscopic structures of those substances. Althought it was Newton who propounded the theory of gravitation, he did not regard it as completely satisfactory because it involved the notion of "action at a distance". Apparently Newton also desired, something that was made quite explicit by Descartes and his followers, a theory of mechanics which employs only force-functions that correspond to action through contact. Nagel 1961, 171.

267 Trusted 1991, 94-95. Nagel 1961, 167, 170, 192-193.

268 In physics, determinism refers to circumstances in which a certain precondition (as given by certain boundary conditions) always leads to the same dynamic state.

magnitudes.[269]

The position and momentum of a point mass at any given time are said to constitute the ”mechanical state” of that point-mass at that time, and the variables – the coordinates of position and momentum – which define the mechanical state are called the ”state variables”. Given the force-function for a physical system, the mechanical state of the system at any time is completely and uniquely determined by the mechanical state of the system at some arbitrary initial time. [270] When, in principle, the whole of the universe is thought of as a closed system in which mechanically interacting particles of matter always exist at some point in space, the laws of classical mechanics should make it possible to calculate the state of the world both before and after any specific point in time, provided only that the position and motion of all the particles is known at one particular moment.

The French mathematician and natural scientist Laplace crystallised the extreme determinism of this material world into a celebrated thesis in which a supreme intelligence completely aware of the state of the world at any specific moment could calculate both its future and its past.[271] In classical physics, the student of nature was, in principle, considered to occupy a similar position to that of Laplace’s demon. He (or she) was an external subject to whose consciousness the world appeared exactly how it actually was. If the demon were to provide the student of nature with knowledge of the position and motion of all particles at any particular moment in time, he would also, in principle, have been able to calculate both the whole history of the world and its

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[269] Niiniluoto 1983, 246. Nagel 1961, 278. When the equations of motion are stated quite generally they contain, as we have seen, an unspecified function, the force-function. If the equations are to serve as means for analysing concrete physical problems, a special structure must be assigned to this function and definite values must be given to any arbitrary constants that may appear in it. Moreover, the equations of motion are linear second-order differential equations, and must therefore be integrated in order to obtain the solution to a given problem. Accordingly, two constants of integration finally appear for each equation that is employed: the components of position and momentum of the point-mass under consideration at some indicated initial time when positions and velocities are assumed to be specifiable with respect to some appropriate frame of reference. Nagel 1961, 278-9.

[270] Nagel 1961, 279.

[271] In a frequently-quoted passage, Laplace declared: ”We ought to regard the present state of the universe as the effect of its antecedent state and as the cause of the state that is to follow. An intelligence knowing all the forces acting in nature at a given instant, as well as the momentary positions of all things in the universe, would be able to comprehend in one single formula the motions of the largest bodies as well as of the lightest atoms in the world, provided that its intellect were sufficiently powerfull to subject all data to analysis: to it nothing would be uncertain, the future as well as the past would be present to its eyes. The perfection that the human mind has been able to give to astronomy affords a feeble outline of such an intelligence. Discoveries in mechanics and geometry, coupled with those in universal gravitation, have brought the mind within reach of comprehending in teh same analytical formula the past and the future state of the system of the world. All the mind’s efforts in the search for truth tend to approximate to the intelligence we have just imagined, although it will forever remain infinitely remote from such an intelligence.” *Théorie analytique des probabilités*, Paris 1820, Preface. Nagel 1961, 281-282.

future development.[272]

It is, however, evident that Laplace was here simply expounding the feature of mechanics that makes it a deterministic theory. He was guilty of a serious *non sequitur* when he declared that ”nothing would be uncertain” even if he did not know whether the divine intelligence was able to analyse *all* the traits of physical objects in terms of the variables that constitute the mechanical state of the system. Moreover, when physicists of the 1800s subscribed to determinism as an article of scientific faith, most of them took as their ideal of a deterministic theory one which defines the state of a physical system in the manner employed by particle mechanics. In considerable measure, this ideal continues to control current discussions of causality and determinism in physics. Even if the identification of determinism with mechanism is a mistaken one, it is frequently assumed that the mark of a deterministic theory is its use of mechanical definitions of state. If the determinism were to be severely limited just to determinism with respect to mechanical states, all the possible traits of physical objects – such as their optical, thermal and electromagnetic properties – would be definable in terms of the variables that constitute the mechanical state of the system.[273]

Mechanics does not rest on the assumption that such an analysis is in fact possible in terms of particle mechanics. Nor does the determinism of mechanics exclude the possibility that alterations in the mechanical state of the system may be consequences of changes in the properties of a system that cannot be analysed in this way. It is evident that classical mechanics is not the only deterministic theory in modern physics. For example, electromagnetic field theory, statistical mechanics and general relativity theory, and more recently quantum theory, involve modes of state description that diverge from the canonical one. A theory is properly labelled as deterministic if analysis of its internal structure shows that the theoretical state of a system at a single instant logically determines a unique state of that system at any other instant. Given the values of the state variables for some initial period, the theory should logically determine a unique set of values for those variables for any other period. If a causal theory is characterised as being in some sense ”indeterministic”, the alleged indeterminism must be explicated in terms of some special features distinguishing the state-description which the theory

[272] In practical terms, the calculations soon become very complicated. Chaos theory also implied difficulties with the predictability of a deterministic system, since a minute change in the initial figures may result in huge variations in the results.

employs.[274]

3.1.3. Atomism and reductionism

Adopted from Democritus, Galilean atomic theory, according to which physical particles are formed out of complexes of atoms, has been an essential part of the world-view of modern physics. The conception embraced by natural science that the whole can be reduced to its parts, and that it can be handled via these, represented a new view of the mutual relationship between whole and its constituents. According to the Aristotlean tradition, all beings had an internal nature, essence, which they attempted to fulfil to the maximum extent possible. Throughout the Middle Ages, the formal or final causes which targeted the internal nature things or their possibility of becoming something were believed to have the power to shape the development of material phenomena. The wholesale adoption of Atomism meant that there was no longer any room for these actors as they could not interact with particles in a mechanical fashion.

Reduction means ”a return to the point of departure” and the method is the opposite of a holistic view, in which the whole takes precedence over the parts which constitute it, and understanding of the properties and activities of those parts is approached via the whole and its controlling qualities. Atomism offers a fruitful starting point for detailed research into the structure of matter and it has shaped the foundation for Meristic methodology, which was connected to the new scientific way of thinking. It was believed that both particles of matter and natural events can, in principle, be genuinely analysed and divided into their constituent parts so that their properties and modes of operation can be defined in accurate manner without difficulty. While the alchemy and occultism of the Middle Ages were largely holistic, Meristic methodology is regarded as a huge intellectual breakthrough in the historical development of science.[275]

Even in antiquity, Epicurus linked the atomic viewpoint with a materialistic world-view. The particle-mechanics way of thinking in classical physics is generally associated with a materialistic conception of the world. It is believed that every one of the multiplicity of beings

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273 Nagel 1961, 282-283, 286. As a result of this mistake, the innovations in physical theories - such as electromagnetic field theory, statistical mechanics, general relativity theory and more recently quantum theory - that involve modes of state-description diverging from the canonical one in the mechanics of point-masses have often been straightforwardly taken as signals of the ”bankruptcy” of ”deterministic” physics.

274 Nagel 1961, 292-293.

and events observed in the world can be derived from matter and material events, i.e. atoms moving in space and interacting in accordance with absolute laws. On the basis of atomistic reductionism, both Vitalist and Dualist ways of thinking are usually rejected in science, even though, on the other hand, attempts have also been made in scientific circles to defend so-called ”anti-reductionist emergence” in situations where it is thought that within physical systems of sufficiently complexity, there could exist regularities that cannot be derived directly from physical or chemical laws.[276]

Subjects for reduction can include things, scientific theories or complete scientific disciplines. Ontological reduction attempts to implement the principle of ”Occam’s razor”, according to which the number of postulated objects should not be more than is absolutely necessary. According to mechanistic reductionism, living beings are nothing more than material bodies which obey physical and chemical laws. In this way, final causes can also be eliminated from biology as it is believed that this science can be reduced to physics and chemistry. In psychology, the attempt to eliminate teleological methods of study has been pursued by employing a behaviourist programme.[277]

3.1.4. The objective nature of theoretical description

Science cleaned out of the universe all earlier projections of human and spiritual attributes. When matter and mind began to be understood as belonging to completely separate categories and the internal subjective and external objective worlds were seen as strictly separate, nature became the object and humans the subject. Classical physics is generally associated with the opinion that Newton’s theory was 'complete' as it corresponded to reality in a proper way so that all the relevant elements of nature are represented. Physicists had no doubt that the language they were using accurately described the elements of reality, or that the attributes being employed (such as mass, speed, acceleration, size or position) correctly described an object’s properties.

When investigating and manipulating nature, humans have assumed that they are engaged in a

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[275] von Wright 1987, 46-48.
[276] Niiniluoto 1983, 292.

detached examination of reality, a fact that is illustrated, among other things, by the natural scientist's normal presumption that science and morality have no connection.[278] Knowledge was largely regarded as an unproblematic human ability. The Subjectivist conception of human knowledge was a natural consequence of the tendency to strip the physical world of all subjective qualities and deeper meanings. Meaning, intention or value no longer had a basis in natural facts. The absolute laws of nature were not believed to provide any indications about good and correct ways of living. The clear separation between facts and values resulted in values becoming nothing more than subjective reality.[279]

In mechanistic-deterministic reality, the source of knowledge is no longer regarded as divine revelation. Once this highest authority has been abandoned, the possibility of certain knowledge was not, however, questioned. Its source becomes human. By being independent external observers, it is believed that people can construct an objective view of the whole operation of the cosmos. According to the Rationalists, the certainty of knowledge has its foundations in human intelligence. For their part, Empiricists put their faith in human observation and experience. As will be presented more fully in Sections 3.2.1. and 3.2.2. of this thesis, the epistemological tension between empiricism and rationalism has not settled on a satisfactory solution within the mechanistic-deterministic framework, any more than has the ontological question of the relationship between matter and the mind. It has not been shown that it is possible to produce unequivocal and undisputed knowledge about reality by using either pure reason and logic, or by empirical trial. The hypothetical-deductive methods of research used in natural science are based on both observations and the use of reason . With the benefit of these, empirically tested mathematical theories have become increasingly comprehensive with the passage of time.

Drawing a line between description and reality is closely connected with the question of the position that the human being occupies in the world. Descartes explicitly stated that miracles do not take place in the world, and that people cannot ever disturb the course of nature in any way.[280] Even though humans have carried out experiments and manipulated the world in many ways, they have at the same time believed that they can, in the manner of Laplace's demon,

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277 Niiniluoto 1983, 255, 289-291. Aristotle believed that the purpose of explanation is to locate phenomena in their proper place in the lawful order of reality. This idea remains in the subsumption theory of explanation. Individual phenomena are explained by immersing they into general laws and general laws are explained by immersing them into laws which are even more general.

278 For example Feynman 1998, 45.

279 von Wright 1987, 44. Hooker 1972, 70.

280 Descartes 1999, 112. "God or no rational soul that are present in World will never disturb the ordinary course of nature in any way."

independently examine all the world's objective processes without either changing them of disturbing them. As will be presented later in Section 4.4.1. of this thesis, the Copenhagen interpretation repudiates this ideal of objectivity which has been maintained in physics through the whole of the modern era. In addition, the measurement problem, which is handled in Section 4.4.6., clearly indicates that humans must be thought of as both observers *and* actors in the theatre of reality.

3.2. The Position of Humans in Mechanistic-deterministic Reality

Man's relationship with nature can, in principle, be figured out in two ways. In one, nature can be viewed as a larger whole to which humans belong and according to whose guiding principles he must arrange his life. In the other, nature is seen as an opponent which humans must conquer, tame and make into a servant.[281] In antique times, humans were viewed as a microcosm of an obviously greater organised whole. In the Christian religion, people were also seen as part of a cosmic order created by God, even though they were at the same time related to the rest of creation and also seen as its rulers. This tendency to view nature as something that must be controlled and made into a servant was reinforced by the new natural science and Cartesian dualism.

In a certain way, the new image of humans indicated a belief in the omnipotence of human capabilities. Humans were considered to be conscious thinking subjects, capable of measuring and manipulating nature and responsible only to themselves independently of both nature and God. By using intelligence, they were free to develop to ever higher levels, unfettered by original sin or blind belief. On the other hand, the influence of the revolution in the image of reality which occurred at the beginning of the modern era in connection with man's understanding of his own position resulted in a significant dichotomy. The more that man struggled to free himself from nature by understanding and controlling its principles, the more he became conscious that nature's inevitable processes tied him to his earthly existence. As a result of the advance of science, man's belief in freedom was reduced, and in a way, he became imprisoned within the mechanical image of nature he had created. Concurrent with the stripping away of all significance and spirtiual dimensions of the world was the loss of humanity's belief in its own unique status. The "climax of creation" became nothing more than an animal resulting

[281] von Wright 1987, 56-57.

from evolution on which consciousness had been bestowed by capricious fortune and whose uncertain fate was constrained by a small fraction of the cosmos.[282]

3.2.1. The rise of materialism

Published in 1859, Darwin's *Origin of Species* made the study of evolution the central focus of scientific discussion. From the philosophical point of view, Darwinism signified adoption of the same way of thinking which, according to both Galilei and Descartes, was considered appropriate in connection with inorganic nature. "Final causes" were no longer required even in the world of organisms now that the development of species in nature could be explained by natural selection. The adoption of a mechanistic-deterministic way of thinking in natural science had a powerful influence not only on biology but also on people's thoughts and research into cultural phenomena. As a result of mechanism-determinism, "fitness for purpose" began to be adopted in the field of psychology when experimental psychology embarked on scientific research into mental phenomena in the 1800s.

Human civilisation was no longer seen as an isolated domain, but as just a province of the world ruled by laws which was investigated by physicists and biologists. In sociology, for example, Auguste Comte and Herbert Spencer enforced strictly scientific ways of thinking.[283] Subjective appraisals by researchers also began to be avoided in the humanities. Even though, for example, Wilhelm Dilthey and Heinrich Rickert stressed the fundamental differences between the humanities and natural science, language, art and religious phenomena were generally considered to be facts resulting from a chain of causality and they were investigated accordingly.[284]

The feeling that it was possible to achieve extensive knowledge by mathematical and mechanical methods while retaining the support of adequate evidence inevitably resulted in these sciences being assigned a unique status. By emphasising the objective facts of nature, man's subjective side essentially became forgotten: neither his internal state nor changes in it could be directly

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[282] Tarnas 1998, 280, 327-332.
[283] Following the natural sciences, Comte divided sociology into statistics and dynamisc.

measured. Even if some people continued to maintain that humans also had either a soul or a spirit, the influence of these was excluded from the areas investigated by natural science. In place of Dualism, natural scientists generally adopted Monistic Materialism, according to which deterministic and mechanical nature was the only reality. As a result of this alteration in world-view, people's conception of the meaning of life and the possibilities it offered became increasingly secular. As nature was no longer viewed as a live vessel of the spirit, a source of mystery and revelation, romantics such as Pope, Blake and Coleridge viewed Newton's *Principia* and his *Opticks* as diminishing the value of humanity.[285]

The Englishman Thomas Hobbes (1588-1679), who travelled the continent of Europe in his youth was fascinated by the new conquests of natural science. He made the "matter-in-motion" the basis of his natural philosophy believing that also psychic phenomena were the result of deterministic external influences. For example, the experience of colour was identical with events taking place in the central nervous system, and the whole of psychology could be be embedded within physiology, which in for its part was just a branch of general kinematics.[286] Hobbes is thought of as the classical Materialist whose extreme thinking affected the paths taken by subsequent philosophers. From Materialist point of view, there was no justification for human responsibility, free will or the division between people and animals pointed out by Aristotle and Descartes.

In common with Epicurus in his time, Materialists have believed that in the last resort, thoughts and knowledge should be described as the causal interaction of material particles: a structure made up of specific materialistic elements should produce both the activity of mind and subjective experiences. While a requirement of Epicurus' conception of free will was that atoms could, now and then, deviate from the direction in which they were travelling, Newton's deterministic laws of motion prohibited such exceptions. In Materialism, the traditional idea of nature as a self-regulating system was in a way united to the new mechanical conception of nature, in which events could be explained only in terms of physical bodies and the forces between them. Within the mechanistic-deterministic framework, Materialistic Monism can be viewed as an almost hopeless attempt to connect people with nature.

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[284] Aspelin 1995, 473-476, 504. All humanists did not approve of the scientific method. For example, the German philosopher Wilhelm Windelband (1848-1915) did not equate the scientific method with the methods used in the natural sciences. While natural science was based on generalisations, the purpose in history was to understand unique and individual phenomena. These thoughts were further developed by Heinrich Rickert and Wilhelm Dilthey. Aspelin 1995, 532-537.

[285] White 1998, 291. Dijksterhuis1986, 431. Tarnas 1991, 367.

The true rise of the Materialistic way of thinking took place in the 1700s, when enlightenment as a result of new developments in science and philosophy had a powerful influence on the whole of human culture. The tradition of enlightenment laid particular emphasis on the position taken by natural science, which was increasingly applied to both human life and to the problems of society. The philosophers of enlightenment were not so much systematic thinkers as quick-witted debaters who participated enthusiastically in dealing with the problems of their time. As Epicurus had done in his time, they attempted to free people from supernatural explanations, superstitions, and despotic rulers with the help of natural science and philosophy. The French philosophers of enlightenment d'Holbach, Voltaire (1694-1778) and La Mettrie (1709-1751) stood strongly for the idea that consciousness should revert to material substance. They wanted to explain the phenomena of the life of the soul and its laws with the same degree of precision that Newton had achieved in explaining the material world. In the name of consistency, they rejected the special position awarded to humans by Descartes: in the manner of animals, people could not, in fundamental terms, be anything more than complex mechanisms.[287]

The optimism which accompanied the forward march of enlightenment signified a never-before-experienced confidence in human intelligence and science. It was believed that in the light of reason, humans would be able to see things as they really were. By the beginning of the 1700s, educated people in the west knew that the universe was a complex mechanical system composed of material particles moving in infinite space according to a smalll number of basic principles, such as inertia and gravity, that could be analysed using mathematics. By conceiving the material world as an ingeniously contrived clockwork mechanism, people believed they could free themselves from dogmatic beliefs and superstition while at the same time obtaining knowledge about the real structure of the universe. As autonomous and self-confident subjects, humans no longer wanted to submit to the power of either religious or secular authority.[288]

Materialism also rose to a significant position in Germany in the 1800s, when following Hegel, the most important trend in the field of philosophy became the flow of ideas from materialists and natural scientists. Via Dialectical Materialism, Ludvig Feuerbach, Karl Marx (1818-1883) and Friedrich Engels (1820-1895) provided Hegel's dialectic with a materialistic interpretation

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[286] Aspelin 1995, 174-178.
[287] Trusted 1991, 113-118. Aspelin 1995, 355, 358-360.
[288] Aspelin 1995, 354. In spite of his optimism concerning progress, Rousseau(1712-1778), for example, doubted whether progress in the arts and sciences resulted in an increase in people's virtue and happiness.

and adapted it to both political and economic science and the scrutiny of natural research.[289] More universal attention in the Europe of the second half of the 1800s was awakened by Classical Materialism, for example that which arose from the Mechanistic Materialism promoted by Ludwig Büchner (1824-1899), according to which all knowledge concerning objective reality could be derived from the mechanical laws of movement concerning material particles. It was believed that correct knowledge could be obtained without engaging in philosophical speculation by using strictly empirical methods of research based on the procedures employed in natural science.[290]

Certain researchers, such as Ernst von Haeckel (1834-1919), and Wilhelm Ostwald presented this doctrine as a “natural-scientific world-view” deduced from scientific results, and their clarity and authority attracted a wide audience. In the early years of his writings, Eino Kaila, a notable representative of Finnish analytical philosophy and defender of science was fiercely critical of the spiritual poverty of such teachings. He viewed the “natural-scientific world-view” as a collection of narrow-minded and superficial science. Haeckel’s statement that “the whole of the universe has developed out of indestructable energy-forms of an substance according to the eternal laws of nature” was capable of being a clear and adequate view of primitive “common sense”, but if, from the philosophical point of view, it was the final word, no serious critical philosophy could then be undertaken. It was Kaila’s view that “This bottomless reality vibrating with thousands of colours, light and sound could never be built from material elements in such a simple way”.[291]

Even though the idea that the whole of reality could be reduced to the mechanical interaction of material elements appeared rather too simple, the new natural-scientific way of thinking signified a clear response to the fundamental disagreement between Nominalists and Realists about general concepts and the nature of being. The distinction might be defined as objective treatment of the primary qualities and subjective treatment of the secondary qualities, i.e. the former are considered as being objectively present, independent of a perceiving subject and observed in a physical body, while the latter only exist in the consciousness of the perceiving person. It was, however, imagined that a mental perception, such as the sensation that a body is warm, is caused by the state of that body, which by means of the sense organs creates in us the sensation that we denote by the word warm, and that this state had to be characterised by geometric-mechanical

[289] Ketonen 1989, 129-130.
[290] Niiniluoto 1980, 48, Ketonen 1989, 144-145.
[291] Kaila 1990, 68-73. Poroporvari ja kamarifilosofi, Valitut teokset 1 ed. Ilkka Niiniluoto, Otava 1990.

features, for example the shape and motion of special atoms. In this sense, i.e. on the part of the object, the secondary qualities are mechanised, the primary qualities are mechanical in character from the outset, and the secondary qualities reduce to them. The important fact that the primary qualities (size, shape, motion) are, after all, also presented to us only via sense perception, so that the drawing of any distinction is really futile, was very seldom realised.[292]

3.2.2. Freedom and free will

Physicists rarely bothered with the fact that completely deterministic laws turned them into automatons. Since physical determinism implied a completely self-contained physical world, there was no room for any external intervention. As the atoms in our bodies followed physical laws as immutable as the motions of the planets, our "own" efforts could make no difference. Everything that happens, including all our movements and all our actions, is thus physically predetermined, and all our thoughts, feelings and efforts can have no practical influence on what happens in the physical world: they are, if not mere illusions, at best superfluous by-products or the epiphenomena of physical events.[293] Within the mechanistic-deterministic framework, scientific thinking seemed to imply rejection of the self-evident presumption of everyday reasoning that humans had free will, autonomy and the right to self-determination. The description of reality based on classical physics offered no natural place for human responsibility or beings with feelings or free will. Physical law could be used as evidence contradicting human freedom.

In medieval thought, man occupied a significant place as the entire world of nature existed for his sake. The main current in modern thought holds nature to be more independent and determinative, and in this kind of context it is difficult to see man as a free agent: both the fundamental question of morality and a difficult problem in religion turned out to be more or less illusory. The problem of free will and physical determinism become a philosophical puzzle that resulted in a debate between Compatibilists and Incompatibilists that is still continuing.[294] Questions asked include 'Are we free and self-determining agents?', 'What is it to act or choose freely?', and 'What is it to be morally responsible for one's actions or choices?' More than two

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[292] Dijksterhuis 1986, 431.

[293] Popper 1972, 217-218, 226. Popper refers to *The Freedom of Man*, a book by the physicist Arthur Compton.

[294] For compatibilists, freedom is just a matter of being being able to choose and act in the way one prefers and thinks, they declare it to be combatible with determinism. Incompatibilists see all compatibilist theories of freedom as patently inadequate. They do not even touch the real problem of free will.

hundred senses of the word ‘free’ have so far been identified.[295] Many thinkers have distinguished between positive and negative freedom. ‘Positive’ liberty is something else than just the absence of restraint or impediment to our actions. Our personal autonomy or self-government cannot thus be guaranteed even if physical laws were indeterministic. From the framework of natural science, however, lack of determinism may be viewed as a necessary condition for allowing the real possibility of human intervention and choice.

One result of the abandonment of the concept of final cause is that even the effect of human goals in influencing the shaping of objective processes of the world has not been clearly represented. The anticipation of determinism in all events has led to a tendency to ignore the fact that a person usually has the ability to act in many different ways in any given set of circumstances. We feel that we are able to make decisions and direct our actions. Ignoring this impression may be a deficiency that has affected not only physicists, but also biologists, behavioural psychologists and computer engineers. Even though no-one has disputed the fact that humans operate within the natural world and that our collective actions change the face of the world, viewing nature as an objective process has meant that the significance of human activity in bringing about changes in reality could be minimised for an extended period.

Indeterministic quantum mechanics forces us to address the question of whether the actions of an individual carrying out experiments can truly be excluded from the world studied by physics. As will be presented in more detail in sections 4.3. and 4.4.1. of this thesis, it appears that certain natural phenomena are only observable in specific experimental conditions, so that the form of the questions we ask of nature essentially defines the answers that it is possible to obtain. This as such is nothing new. Natural scientists conducting experiments had to interfere with nature even when observing the deterministic phenomena of classical physics. Experimental situations had to be simplified and isolated from the surrounding environment in order for it to be possible to control and modify the factors which it was known would affect the results obtained. The future behaviour of a mechanical system cannot be predicted before a suitable experimental setup has been constructed and the system’s free parameters have been assigned the required values. Even though the deterministic laws of the macroscopic world guaranteed that the same set of preconditions always yielded the same set of results, it was only conscious action by human beings that made it possible to repeat experiments and exploit natural phenomena.[296]

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[295] Galen Strawson, Routledge Encyclopedia of Philosophy, 743-752.

[296] Petersen 1968, 150-154. In astronomy, the ideal of external objectivity has been achieved best in cases where it is difficult to carry out proper experiments.

Classical physics is not directly associated with particular values or ethics, but a mechanistic world-view diminishes any belief in its objective significance: the possibility of making responsible choices is not seen as having any basis in natural facts. This narrowing-down of the representation of reality is not however generally seen as a problem by natural scientists, or viewed as any kind of defect. Their confidence in the new scientific method and the universality of the manner of explanation it employs was shaken neither by the fact that living phenomena are difficult to understand on the basis of a mechanistic conception of nature, nor by the fact that human creativity and other ‘human’ characteristics cannot be depicted within such a deterministic framework. It is not surprising that within the generally-accepted mechanical context, the paths taken by natural science and humanist culture began to diverge. The natural sciences started to follow a course of their own choosing, without much apparent concern about the philosophical legitimacy of what they were doing, while philosophy, on the other hand, proved increasingly incapable of fulfilling, with regard to the study of nature, the leading role it should have played in an ideal cooperation of all the mental faculties.[297]

3.3. Philosophy in the Mechanical and Deterministic Era

Once the sincere belief of the Middle Ages in God had disappeared, Europeans were unable to construct a generally accepted, monistic, i.e. completely coherent, world-view that was based on a single fundamental principle. [298] The qualitative and teleological conception of nature was substituted by a quantitative and mechanical one and a penetrating study of the post-Newtonian philosophers quickly reveals the fact that they were philosophising in the light cast by achievements of natural science.. The new science acted as a stimulus to philosophy and generated metaphysical speculation on a great scale.[300] As a generalisation, it can be said that both the philosophers’ work and the reception given to their thinking was conditioned by the mechanistic-deterministic conception of reality employed by natural science.

Although the mechanistic view of nature was a source of great stimulation for science, it confronted philosophy with the difficult problem of the real relationship between the subjective

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[297] Dijksterhuis 1986, 432. Burt 1980, 34, 25. Burt thinks that modern metaphysics is in large part a series of unsuccessful protests against the new view of the relationship between man and nature.

[298] Ketonen 1989, 100.

[299] Ketonen 1989, 100.

world of our perceptions and feelings, and the external world of mechanical processes which is so different in character. Most philosophers sought a place where to locate immaterial reality, God and the human soul in a world of facts that seemed indifferent to man man and his affairs. The way of thinking adopted by science could not satisfy critical philosophers of the modern age, who had to face the hopeless problem of deriving psychic phenomena from physical ones in a way which could preserve the idea of free will and moral responsibility. In attempting to provide more precise explanations of the basis of both reality and knowledge, thinkers have not, however, been able to mount a credible challenge to the basic ontological presumptions of a mechanistic material world that were employed in physics. Philosophy as such lost a significant amount of its cabability to explain as it had to take seriously into consideration the presuppositions and facts of natural science. In some respects, the situation can be seen as analogous to the age of Scholastic philosophy, when thinkers were forced to work within the confines of Christian dogma.

Even though materialism had a powerful effect on both scientific culture and public opinion, Dualism was a more popular viewpoint among philosophers. Dualism can be taken as an auxiliary hypothesis which people leaning on the Christian dogma were infected by when they wanted to assign themselves some freedom to speculate in the world of matter and time independent of religious concepts. The development of natural science can in some way be seen as requiring the ontology of Cartesian dualism, in which the authority of reason could be defended in relation to the whole of nature, whose laws it investigated and tried to command.[301] Many philosophers actually challenged Dualism even during Descartes' lifetime. Since humans were neither simply soul or spirit, but had a material body that was subject to natural laws, the problem was the question of the relationship between these two substances, i.e. how human mind could have any influence in a completely deterministic material world.

When philosophers paid serious attention to the spiritual side of human beings, their reason and mental abilities, only a small number of them accepted Materialism. In particular, it was difficult to explain knowledge, meaning or intention by employing the concept of matter consisting of separate particles. The birth of knowledge or the spontaneous workings of the mind simply did not appear to be describable in quantitative and materialistic terms; as changes concerning particles which moved in space and time. The feeling of free will had to be viewed as an illusion, based, for example, on each individual’s ability to be aware of their own self. Even though in the

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[300] Jones 1969,114-117.

causal theories of action, each individual's mental states such as desire, purpose and beliefs could be regarded as causes for their action, free will was lost. Attempts to "rescue" the principle of free will were often the motivation for the production of non-causal theories of action , which in their turn found it difficult to explain how free will, released from causal links, could influence events in a world of deterministic matter.[302]

The basic ontological framework born out of Cartesian dualism has remained unchanged through the centuries. Those who have not accepted Descartes' dichotomy have however been bound to it in their representation. Materialists have typically attempted to reduce mental phenomena to matter while Idealists have wished to restore material to the spirit.[303] When stressing the importance of the mind Idealists realized that it could not have any links with a factor so completely alien as matter. Through idealism, the whole of the material world can be seen as nothing more than a by-product of the spontaneously active and autonomous mind. Combining the viewpoints of Materialism and Idealism is presumably impossible without significant alterations in the concepts of material or knowledge. For Dualism, the problem is interaction or lawful parallelism between two completely different substances.

In a similar way to the basic ontological setup, the starting point for epistemology, i.e. that humans are subjective observers of an objective world, has also now remained almost unchanged for several hundred years. Regardless of whether observers are considered to be immaterial or material, it is believed that they are able to form a truthful description of the reality of the world by using their reason or experience.

3.3.1. Materialism versus Idealism

In philosophy, the term substance has traditionally signified something that exists by itself. Descartes tried to save the sense of human freedom and to the claims of universal mechanism by his concepts of *res cogitans* and *res extensa*. If they are understood as substance, the relationship

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301 Ketonen 1989, 87. Aspelin 1995, 192.

302 Niiniluoto 1983, 162-3. the doctrine of Compatibilism is located between these stances, asserting that it is possible to give reasonable content to the concept of free will even when human actions are determined by deterministic or probabilistic laws.

303 In materialism, attempts have been made to solve the psycho-physical problem through elimination, reduction or emergence, which aim to either eliminate mind, reduce it to matter or somehow make it emerge from complex material systems. In dualistic interactionalism, mind and matter are assumed to somehow interact, while in parallelism, both obey their own laws which are synchronized in time.

between them becomes a problem. How can matter and mind appear to be connected to each other in many ways if they do not have a common source, why would a hand rise when its owner wanted it to rise? Some supporters of Descartes attempted to resolve the problem through a doctrine called Occasionalism, in which the human soul and the finite events of the world reverted to the infinite founder of the universe, i.e. God. The mainstream of western philosophy travelled from Descartes to Spinoza, Leibniz and Kant. They all considered mind and matter to be separate things, with God in some way as the source of both.[304] The great system builders of philosophy did not, however, achieve a common view of the nature of reality.

Benedict Spinoza (1632-1677) like Descartes was impressed by the achievements of science and mathematics and he tried to strengthen Descartes' teachings by the doctrine of Pantheism, which was both more systematic and more coherent that Giordiano Bruno's way of thinking. In his *Ethics*, Spinoza applied geometry and the axiomatic method systematically to metaphysics and mental entities employing one of the most beautiful philosophical systems ever created. In his vision, the universe is seen as an ordered unified whole – not as a lifeless world of innumerable separate things.[305] Spinoza founded his naturalism on God, not the personal God of Christianity but the pantheistic totality of nature. This eternal substance, which had an infinite number of properties or attributes, existed by itself. It was a being of both infinite dimensions and infinite rationality, both nature and God. In this wholeness, mind and matter were two different attributes which humans could perceive. As they were nothing more than two different ways of viewing the same substance, material particles and mental thoughts inevitably acted in harmony. The organisation of beings and ideas was the same, and the nature of both was preordained. Spinoza was not, however, able to say why something that had extension should also think, or vice versa.[306]

Spinoza's view of God as the only substance, with everything being different forms of manifestation or aspects of him, was well suited to the idea that the universe worked in the manner of a perfect clockwork mechanism. Since it was logically impossible for God to be otherwise than he actually was, the laws of the cosmos could not be changed, nor could the world be other than it was. While Descartes saw the human soul as free, in Spinoza's doctrine the body was a specific mode of dimensional attribute and the soul was a specific mode of

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[304] Aspelin 1995, 194. Collingwood 1960, 104-105. As Descartes appealed to God who guaranteed the psycho-physical parallelism, it can be thought that he also actually only had one substance, God.

[305] Spinoza 1997.

cognitive attribute. With their mental and bodily activity, humans belonged to the world of predermined beings. In contrast to the general understanding, humans were not to be seen as a ”state within a state”, they did not have free will or absolute power in connection with their acts. Human behaviour and emotions were belonging to the consistent system of nature and characteristics of mental life could be deduced from the nature of mind and be investigated using ”geometrical methods” in the same way as lines, surfaces and particles.[307]

In the last part of his *Ethics*, Spinoza attempted to define the nature and role of emotions more precisely, and to point out the path which humans should follow to gain control of their affections. At the level of confused thought man sees himself as a unique self with a private good but when man raises to a level of the true state of affairs, his nature and inner and outer behaviour change as he is able to act in accordance with his own nature and the universal order. Spinoza meant his psychology concerning emotional development was meant to be strictly scientific; correct insight and intuition could lead humans to inner freedom and increased happiness. At the same time, the workings of the body would expand, since every bodily state corresponded to a specific state of consciousness, and every act of the soul was paralleled by some physiological event. In developing oneself to the fullest extent, intuition, the highest form of thought, could clearly understand the nature of all entities. The rational road of knowledge could finally free humans from the deceptions of experience, and lead to an awareness of eternal substance and the affinity of all beings. In the end, perfect science became religion. Spinoza’s doctrine offered an internally-coherent world-view based on a single basic principle, in the same way as Materialism. Many people could not accept his teachings because of his critique of the Bible. Deeply religious Spinoza was said to be a man with the mark of damnation on his forehead.[308]

Gottfried Leibniz (1646-1716) did not accept Spinoza’s monism, naturalism and pantheism even though he also attempted to achieve a sound Cartesian kind of compromise by showing that new scientific world view was compatible with orthodox conception of God and the notion of teleological universe. He considered extension, the reality of which both Descartes and Spinoza took for granted, to be the source of problems. Extension was *an* ultimate, but not *the* ultimate physical concept. To unite metaphysical laws and laws of extension, metaphysical axioms like cause and effect and activity and passivity was needed, which meant that the really basic concept

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[306] Trusted 1991, 112-113. Collingwood 1960, 106.
[307] Jones 1969, 210-212. Aspelin 1995, 312-315.
[308] Ketonen 1989, 100. Aspelin 1995, 305, 314, 316-317.

in physics is a psychic concept. The fundamental indivisible units or elements of things out of which Being consists are monads which exist beyond “a purely geometrical concept of matter” and “purely geometric laws of motion. The monads do not have extension and thus they have to be spiritual i.e. immaterial units. Everything that was material could be seen as phenomena related to these spiritual realities which able to develop and understand their environment[309]

As a mathematician and natural researcher, Leibniz did not doubt that nature’s physical processes should take place in accordance with physical laws, but he wanted to link the new doctrine of natural science to the traditional metaphysical system. For Leibniz, the world was – more or less – our experiences, but at the level of phenomena, he considered it quite in order to speak of bodies acting upon one another and of causal relationships. He agreed with most of the ancient philosophers that ”Every spirit, every created simple substance is always united with a body and no soul is ever entirely without one”.[310] Leibniz considered that every part of the world was somehow connected to every other part and the coalesce of matter and spirit was possible, since bodies were aggregates of monads and the mental laws governing the mind were clearly differed from physical laws. Physics was adequate to represent deductive systems, such as mechanics. It is able to tell *what* is happening, but not *why* it is happening. Physics is useful and reliable, but it is also limited.

In his *New Essays on Human Understanding*, Leibniz commented widely on the thoughts of the English philosopher John Locke (1632-1704). In his philosophy, Locke had attempted to chart the nature of human understanding and mental laws by using scientific approach. He believed it was possible to explain the capabilities and limits of reason by empirical method.[311] Leibniz admitted that knowledge begins in experience but was critical of Locke’s concept that the soul is a blank writing tablet on which nothing has yet been written – a tabula rasa – and that everything inscribed there comes solely from the senses and from experience. As a rationalist, Leibniz believed, like Plato and the Scholastics, that only reason was capable of establishing reliable rules. Although the senses are necessary for the acquisition of knowledge, they are not capable of providing all of it. Leibniz was critical of Locke for not being able to see that we have something potential within us. We have reason and acquired dispositions of which we are not always

[309] Jones 1969, 220-226. As a monad was not a body it must be a mind. Reasoning follows from the Cartesian dualistic principle that everything that is not a body is mind

[310] Aspelin 1995, 319, 324. Leibniz 1981, 58.

[311] Ketonen 1998, 90-95.

actually aware.[313]

In the style of ancient thinkers, Leibniz also paid attention to problems connected with the division of matter. In his youth, he had been strongly influenced by atomic theory via Gassend, and he considered Descartes' concept of extended matter to be contradictory and inadequate as a way of explaining the whole of reality. Leibniz viewed the atomic hypothesis as valuable natural science, but insufficient for metaphysics, in which the search was for ultimate principles. If it is presumed that matter is continuous and infinitely divisible, there can be no true parts, only arbitrary division. On the other hand, if matter is presumed to consist of different indivisible parts, a whole formed from these parts cannot be a real whole, only a arbitrary collection. This kind of metaphysical theorising about the relationship between parts and wholes has received new impetus as a result of modern physics, since in some specific situations matter appears as localised particles, while in others it appears to be continuous waves.[314]

As an idealist monist, Leibniz did not have a fundamental belief in the absolute existence of space and time, he thought that we conceived the idea of them via our natural disposition to fix and relate phenomena. As the world was an organism which consisted of countless minute perceivable spiritual organisms (i.e. monads) no substance ever lacks activity. There is never a body without movement and at every moment in time, there is within us an infinity of perceptions which are alterations in the soul itself.[315] Like Spinoza, Leibniz rejected Descartes' interactive doctrine and adopted the idea of parallelism. States consisting of monadic complexes which we called living bodies and states of conscious monads which we called souls corresponded perfectly to one another. Leibniz was not however viewed as having been able to provide a more satisfactory explanation of the relationship between mind and matter than either Spinoza or Descartes. The orderliness in the sequences of well-founded phenomena was a consequence of the pre-established harmony ordained by God.[316] The connection between mental and material aspects was evidently impossible to understand from a dualistic standpoint, in which the mind could only be aware of its own state and the material world was just a mechanical machine obeying absolute laws.

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312 At the same time, Leibniz realised that the study of probabilities might lead to valuable theoretical and practical results if this mathematical method could define the statistical probabilities of possible events. Aspelin 1995, 321-322.

313 Leibniz 1981, 48-49, 51-52.

314 Aspelin 1995, 325.

315 Leibniz 1981, 53.

316 Trusted 1991, 88-92. Aspelin 1995, 326. Collingwood 1960, 110-112

George Berkeley (1685-1753) Berkeley was a sincerely religious man who was deeply concerned about the conflict between scientific and religious views. For him the root of the trouble was the supposed independent existence of matter which he aimed to deny, without denying the validity of scientific enterprise. Berkeley leaned towards Idealism pointing out that both the primary and secondary qualities are relative to the perceiver. Even though the physical world was said to contain only quantitative properties, the world of which people had explicit experience consisted of secondary qualitative things and phenomena. Nowhere could quantity be found without quality. Quantity without quality was therefore merely an abstraction, a formal view of specific aspects of reality. Consequently, the physicist's material world was no actual reality, it was a pure abstraction derived from the world of the mind. To be means to-be-perceived, to be an object for mind. Since substance was something that depended only on itself, only the mind could be substance and nature as we saw it was a product of the mind. [317]

Berkeley did not ask exactly which mind carried out the creation of the physical world. He was however satisfied that it was not created by the finite human mind but by the infinite mind of God, since the latter guaranteed the existence of physical bodies even when no-one observed them. In this way, Berkeley rejected the pantheism of Renaissance thinkers in which the world was the body of God. To Berkeley, as to Plato of the Christian theologists, God was a transcendental concept whose thinking created the world , and to him (i.e. Berkeley), minds which created the secondary qualities were human.[318] More cautious than Berkeley, Immanual Kant postulated that the mind which created the world was also human. Kant did not however believe that Copernicus had created the heliocentric world, that Kepler had created the elliptical orbits of the planets, or that Newton had created the law of gravity. The world was not made by an individual mind but by pure reason, a transcendental ego immanent in all of human thought. As a consequence of the structure of human understanding, the world inevitably appeared to humans just as it appeared.

Since the categories of the human mind influenced our conception of the world, our knowledge, according to Kant, applied only to that world of phenomena which to Plato had been fit for nothing more than beliefs and sources of opinion. Both the foundations of mind and things themselves therefore remained obscure to us. The scientific method could not attain them, nor

[317] Jones 1969, 281-289. Collingwood 1960, 113-114. Berkeley's position is compatible with the existence of scientific laws, which are considered to be generalisations about the relations of certain ideas to certain other ideas
[318] Collingwood 1960, 115-116.

could we even prove that they existed. Kant left metaphysics to philosophers and theologians who were better able than scientists to deal with things as such.[319] In making such a division, Kant restricted the domain of scientific knowledge. If the division were to be taken as truth, science would have lost contact with the foundation of experimentally approachable reality. It was not possible to obtain deeper knowledge via scientific methods, and no statements could be made about the metaphysical essence of nature - even though improved understanding of reality has always been an important source of motivation for natural research.

3.3.2. Empiricism versus rationalism

Just as, in their ontological view, philosophers were not able to completely free themselves of the classical mechanistic-deterministic conception of reality, the idea of the detached external observer that was favoured by physicists has for centuries guided modern-age thinking in epistemology. When searching for theory of knowledge, philosophers have predominantly asked how humans can obtain certain knowledge that is connected to reality. The answers have been Rationalism and Empiricism, whose foundations have then been the subject of critical examination. In this critical process, both the reliability of human representation and reality's absolute conformity to laws have been called into question. Of the great philosophers, only Hegel and the Marxian dialectic stimulated by his thinking have paid significant attention to the active role played by humans in the obtaining of knowledge and the shaping of reality.

Continental advocates of rationalism emphasised reason and strove to justify the possibility of natural science that was independent of experience. They believed that the initial premises of science, from which other statements must logically follow, could be recognised as true *a priori*, without being dependent on sense experiences. Descartes, an advocate of ontological dualism, was a strict rationalist in regard to epistemology. He believed that in principle, like in geometry absolutely certain knowledge had to be based on some self-evident and indubitable truth from which true theorems can then be deduced by clear and accurate reasoning. In this way, genuine knowledge was independent of the fallible senses, and its correctness could not be doubted.[320]

Both Leibniz and Spinoza also considered information collected by the senses to be of only

[319] Collingwood 1960, 117-119. Descartes already restricted the area of knowledge since he excluded history, poetry and divinity from his universal science.

secondary value when compared to knowledge obtained via reason. For its part, the mainstream of British Empiricism believed, like Galilei, that information about the world could not be obtained by logical analysis alone, and that observation and experience were the source of all knowledge: scientific statements resulted from the generalisation of experiences through the process of induction. It was not entirely necessary for Empiricism to be connected to Materialism or for Rationalism to be connected to Dualism. Stepping over the obvious counterparts of the ontological and epistemological approaches, the mainstream of British Empiricism rejected Materialism and adopted Cartesian dualism.[321]

Descartes had no doubts about the absolute perfection of natural laws. They reflected the immutability of God's construction of universe, and therefore consequence could always be deduced from a cause in a rational manner. Locke and Berkeley paid attention to the fact that laws could not be obtained without experience. These empiricists realized that humans could not be certain that their ideas really corresponded to objects in the external world. In the act of representation, primary and secondary qualities were separated from one another and it was doubtful whether people could ever truly consider the sense-impressions and the workings of the human mind from an external viewpoint. A real challenge to Logical Rationalism was mounted however by David Hume (1711-1776), who respected logic and was dissatisfied with the "abstruse speculations" that for rationalists passed for philosophy.

Hume did not consider reasonable the earlier practice of appealing to God as guarantor of the perfection and constancy of natural laws. From his empirical and nominalistic starting points Hume concluded that there are no substances or selves and there is no evidence to believe in the existence of outside world or causal relationship. When pondering the problem of the human mind, Hume abandoned the fruitless reflection concerning the essence of the soul. He found no more evidence to believe in the existence of mental substance, which Berkeley took to be indisputable reality, than for the existence of physical substance and outside world.[322] The certainty of natural sciences was also completely without basis as there was no logical reason why previously observed regularities should continue in the same manner. On the basis of empirical observations, people could never verify claims about the unquestionable certainty of natural facts, and it was not possible for them to prove that natural laws and any resulting

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[320] Jones 1969, 156-162.
[321] Niiniluoto 1980, 45-46. Trusted 1991, 80-82.
[322] Hume concluded that the soul was nothing more than a series of changing states of mind which succeeded one another in an endless forward-sweeping stream. Aspelin 1995, 373-375.

consequences would remain absolutely the same in the future.

Since causality or induction could not be justified by appealing to experience, Hume's critical analysis also undermined the foundations of the objective certainty of empirical science. One had to accept that even the highest levels of scientific knowledge were subject to error.[323] Starting with Bacon, the British Empiricists have relied on induction, assuming that it produce the fundamental statements of science. Hume also relied on empirical evidence within the natural limits of such knowledge. Even if inductive inferences were not justified by evidence, the method was applicable by its practical success. Hume's radical conclusions however highlighted the problem of justifying induction, i.e. the question of how can we justify reasoning that extends knowledge.[325]

The German philosopher Immanuel Kant (1724-1804) attempted to find a solution to the conflict between rationalism and empiricism. He was one of the very few of Hume's contemporaries who understood that the Englishman's primary desire was not to deny the existence of causal relationships, but that his criticism was an attack on the reliability of empirical knowledge. On the other hand, Kant greatly respected Newtonian science and its victories and did not doubt that humans could obtain certain knowledge concerning the material world. In his *Kritik der reinen Vernunft* (1781) (*The Critique of Pure Reason*), Kant attempted to explain how Newton could have obtained certain knowledge of the world even though Hume had judged this to be impossible. In his solution, Kant build on the absolute structure of the human mind, saying that our empirical knowledge is a combination of what we receive via sense-experiences and that which is added by the categories of the mind. Human knowledge arises from the combined operation of the senses and the understanding. "Without sensibility no object could be given to us, without understanding no object could be thought. Thoughts without content are empty, intuitions without concepts are blind."[326]

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[323] Trusted 1991, 119-121. Tarnas 1996, 334-339. Jones 1969. 311-320. When defending rationalism, Leibniz already wrote: "The senses never give us anything but instances, that is particular or singular truths. But however many instances confirm a general truth, they do not suffice to establish its universal necessity; for it does not happen that what has happened will always happen in the same way." Leibniz 1981, 49.

[324] Hume concluded that the soul was nothing more than a series of changing states of mind which succeeded one another in an endless forward-sweeping stream. Aspelin 1995, 373-375.

[325] Niiniluoto 1983, 33-49. Inductive reasoning proceeds from special cases to general conclusions and it extends knowledge, since the conclusion is not included in the premises but, in a certain way, says more than they do. Inductive reasoning cannot be reduced to deduction without unfounded presuppositions. Inductive argument which employs experience leads to a vicious circle, and no other attempts to provide answers to the problem of induction are generally accepted.

Order observed in the world is not followed through passive reception by the mind, but mind imposes its own order on the world. Human experience of the world is not an objective portrayal of external reality, but to essential measure it is a product of our cognitive apparatus. Since the world of phenomena as constructed by the mind inevitably appears to us such as it appears, all knowledge which results from experience is accompanied by an inseparable conceptual component. Knowledge is born when the forms of perception and categories of understanding which belong to a person's cognitive apparatus are combined with the phenomena arising from the senses.[327] Categories of understanding such as causality, substance or time make the rational examination of observed data possible. Since causality is also something that our understanding locates in the world, it was Kant's belief, like Hume's, that causal relationships were not linked to any degree of inevitability to ”reality” or ”beings as such” level. From the viewpoint of the realists, Kant simply circumvented Hume's problem in this way, he did not solve it.[328]

Kant attached considerable importance to metaphysics. He saw that the initial presumptions of metaphysics such as the *a priori* requirements for understanding and knowledge could not be abandoned because factual propositions always required, and were based on, some more fundamental premise: we need some type of metaphysical framework within which we are to be able to interpret our experiences. On the other hand, Kant understood the significance of Hume's criticism for metaphysics: logical argument was no better than experience in judging whether metaphysical propositions were true or false. Metaphysical speculation could be nonsensical and often was, but could also lead to the discovery of new connections. Metaphysical theses were reminiscent of empirical propositions in that they told us something new about the nature of reality. At the same time, metaphysical propositions resembled logical assertions in that they were not based on sense-experience. To Hume, propositions founded on pure reason were tautological and those founded on observations were factual but not necessary. Kant needed a third category which combined these factors. The fundamental question posed by his epistemology was whether besides both analytical-*a priori* knowledge (i.e. logical and analytical truths) and synthetic-*a posteriori* knowledge based on experience, there could also be synthetic-*a priori* knowledge.[329]

Kant could have judged Hume's criticism unfounded if he had been able to show that the

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326 Kant 1929, 93.

327 Kant took the notion of 'category' from Aristotle, while at the same time rejecting his list as unsystematic. Kenny 1998, 257.

328 Trusted 1991, 120-123, Niiniluoto 1980, 46, 144, Niiniluoto 1983, 37.

essential prerequisites of experimental knowledge such as the law of causality and mathematical truths were by their nature synthetic-*a priori*. He is anyway seen as having been unsuccessful in achieving this purpose.[330] To a considerable degree, Kant's problems can be thought of as resulting from his attempt to keep the field of metaphysics outside the field of science. Science only contacted the world of phenomena, while metaphysics was left to philosophers and theologists. According to Kant, all questions to which empirical answers could not be obtained within the scientific framework also remained outside the dimension of human reason. On this fundamental question, Kant's viewpoint was the opposite of Plato's, who considered knowledge concerning the sense-world to be nothing more than beliefs and opinions, while the employment of reason made it possible to address the eternal truths of the world of Ideas in complete purity. The limitation imposed by Kant no doubt resulted from his acceptance that the presuppositions by classical physics about the nature of the world of phenomena were essentially correct.

Since, in Kant's view, only knowledge about the phenomenal world was attainable, humans could not come to metaphysical conclusions about the true nature of the world: both the basis for consciousness and things as such remained unknown to them.[331] People were prisoners of their mental structure, and scientific research was not able to lead to a more-complete and fundamental knowledge of reality. The field of metaphysics also became narrower since only things in themselves, the foundations of the mind, and theological questions remained within its domain. Metaphysics matters could be subjects of reflection, but obtaining proper knowledge concerning them was not possible. Religious matters became internal personal experience for each individual. Via his synthesis, Kant is said to have saved both religion from scientific determinism and science from radical scepticism, but he was only able to do this by separating them from one another. In his heart of hearts, Kant no doubt felt that the laws of the external world and internal morality were connected to each other, but he was not able to prove their relationship. With Kant, the Cartesian schism between the human mind and the material world continued in a new and even deeper form.[332]

Gradually, the space that Kant had made for religion with his postulates of practical reason began to resemble a vacuum, since neither the external world nor pure reason offered any support to

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329 Niiniluoto 1980, 145.

330 Trusted 1991, 123.

331 Kant's critical idealism does not mean the empirical or psychological idealism which holds that knowledge concerning our internal subjective states is immediate and certain. Aspelin 1995, 396.

332 Tarnas 1991, 341, 349-50. There are different opinions. J.G. Fichte believed that Kant liberated man from the slavery of strict determinism and nature. Aspelin 1995, 417.

either religion or ethics. Also science, whose reliability Kant had relegated to dependence on the human cognitive structure, lost its foundations in twentieth-century physics when the absolute categories of Newton and Euclid, on which Kant based his *a prioris* such as time, space, substance and causality, were no longer deemed to be necessary foundations for the scientific approach.[333] On the other hand, two points made by Kant still stand. Firstly, that we need to have some metaphysical framework: humans cannot obtain knowledge of nature's universal laws by simply waiting for the correct answers, they must present nature with questions which are based on hypotheses. An approach to the world requires an *a priori* hypothesis in order for it to be observable and testable. Secondly, that our sensations can only provide us with intelligible experiences if they conform to our framework. Quantum mechanics bestows credibility on Kant's thesis that physics does not address nature as it actually is, only via our relationship to it – nature as if presents itself to human questioning.[334]

3.3.3. Romantic natural philosophy in Germany

Kant conceded that, in metaphysics, it is possible to think of things ”as such”, but left his followers to answer the question of what to think about. In German philosophy, after Kant's demise, his Critical idealism quite rapidly became genuine Idealism with the elimination of the ”things as such”, with the consequence that no reality independent of the conceiving subject remained. In his objective idealism, G.F.W. Hegel (1770-1831), Kant's most important successor, attempted to combine man and nature, mind and matter, as well as time and eternity into an all-embracing multi-dimensional and developing dialectic process. Hegel viewed the whole of world history as a process of development of an ”absolute spirit”. Investigation of the laws of this “self-movement” he called a dialectic.

In his extreme Rationalism, which in experimental terms was difficult to distinguish from Irrationalism, Hegel attempted to show that all the features of existence were necessary. He considered philosophy to be ”an objective science of truth, a science of its necessity, of conceptual knowing, it is no opining and no web spinning of opinions”.[335] Hegel abandoned the

[333] Even though the general statement of causality is synthetic *a priori*, general and necessary, all the specific causal laws are empirical. They are no more certain in Kant's doctrine than they are in empiristic epistemology. Aspelin 1995, 379.

[334] Trusted 1991, 125, Tarnas 1991, 351, 358-359.

[335] Hegel 1985, 17. In his *Phenomenology of Mind*, Hegel expressed an extended and trenchant critisism of Newton. Burtt 1980, 35.

previous use of cause and effect as a basis for explanation since, following Hume, it was not logically necessary. In place of observation and experience, he appealed to nothing more than the logical relationship between cause and consequence. Thinking and reality were completely combined, and it was therefore possible to achieve certain knowledge of reality through the sheer activity of thinking. To Hegel, the target of knowledge was not the ”substantial invariances”, but more the internal relationships between things that were in constant movement because of the dialectical laws that governed them.[336]

For Hegel, the “thing as such” was pure being, being as such. It could be said to be reminiscent of a quantum field in that it appeared to be unknown - there was nothing specific to portray, no features distinguishing it from everything else. Since western philosophy from the time of Aristotle had defined opposites as logically contradictory and mutually exclusive, Hegel viewed all differences as necessary and complementary components of some greater truth. All partial perspectives could be harmonized into a one all-inclusive perspective. Even though such a reality was radically paradoxical, the human mind was, according to Hegel, fully capable of addressing it. To Hegel, the structure of human knowledge was not fixed and timeless in the way that Kant proposed, it was historically determined and progressed through defined phases. Each preceding phase was overthrown when the subject become aware of the forms of thought he had previously, in an uncritical manner, taken for granted. That which had once appeared fixed was abandoned in the subsequent phase as new possibilities and greater freedom beckoned. Where Kant’s human could not intrude on the causes of phenomena without encountering contradiction, Hegel saw the human mind as capable of achieving a higher synthesis. In love, for example, all discord was overcome.[337]

Hegel’s doctrine was reminiscent of Pantheism, but differed from it in that now God as a creative concept surpassed the material world and was its cause. The ultimate truth could be expressed not only as Substance but as Subject as well. Behind all the battling combatant powers and things was hidden a living foundation which was an boundless and homogeneous harmony comprehending all beings. Oneness was developed in plurality and difference. The infinite had to become finite to reveal and realize its being. After becoming conscious of its own essence, it could rejoin itself. Hegel’s fundamental motive: primary unity, the fall, the return of lost

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[336] Aspelin 1995, 433. Niiniluoto 1980, 46, Ketonen 1989, 110.

[337] Tarnas 1991, 379. Hegel solved the relationship between the minds of God and individuals by saying that the human being is a form or vessel in which the self-realisation of God and the process of creation was developing. God is not beyond the creation but is the creative process itself and man is not the passive spectator of reality, but its active co-creator in which the universal essence finally comes to consciousness of itself. Tarnas 1991, 380-381.

harmony, was reminiscent of Christian neo-Platonism. In the manner of Plato, Hegel also considered ideas to be real. They did not depend on the mind which thought about them. According to Hegel, the misconception that concepts belonged to the subject or were just the contents of the mind was a consequence of Cartesian mind-body dualism. He also contested the generally accepted thinking that anything which was not matter must be mind. Concepts created a logical process in reality and generated new concepts through contrasts. This process did not advance in time or in space but as the consequence of a logical necessity, which was God. [338]

Hegel attempted to unite the natural science of his time with the concept of reality as a process. He saw the activities of living beings as a manifestation of a new principle of organisation which produced qualitative differences, something that dead material did not have the capability to do. The world was real, but not 'ready'. Even though Hegel presupposed the existence of space and time in which everything was manifested, it was permeated by a fundamental logical process which was nature turning into mind. In one way, Hegel thought of nature as a machine, in another it was an active process of development which advanced as a consequence of logical necessity.[339] He thought that although until now (i.e. his present) the world-spirit had been busy with the objective world, in his time the flow of activity had been interrupted, and that alongside the kingdom of the world the Kingdom of God might be thought again as meaning a sense for a higher inner life and purer spirituality.[340]

Hegel's philosophy aroused huge interest, but on the other hand, since he was evaluated within the generally accepted mechanistic-deterministic paradigm, the speculative nature of his propositions could not be defended. In his analysis, Collingwood stated that even though some type of synthesis was required to make evolution understandable, Hegel had been in too much of a hurry. He valued ancient thinking and understood both Plato and Aristotle, but through this contact he had lost his connection to the practical life of his own time. Dead matter and evolution were simply not compatible. Hegel's doctrine did not work in a particle-mechanistic physical world which was believed to obey deterministic laws. Natural science had to resolve its problems by employing its own empirical methods.[341]

Even though, in his own philosophy, Hegel radically rejected a world-view which was founded

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[338] Aspelin 1995, 431, 437. Collingwood 1960, 121,122.
[339] Collingwood 1960, 128 -130.
[340] Hegel 1985, 1.
[341] Collingwood 1961, 121,129,132.

on nothing more than natural science, his influence strengthened the position of Materialism when Marx employed Hegel's thinking in his Dialectical materialism. On the other hand, Hegel also provided inspiration for the counter-current of Romantic humanism that was then influencing culture. While natural science was searching for efficient causes in the world of dead matter, the natural philosophers of the Romantic Age sought a deeper interpretation of the world. In the place of calculus and experiment, they stressed the importance of teleological explanations, and did not consider it reasonable to impose a strict division between living and inanimate nature. German romantic natural philosophy, in which nature was examined from a teleological viewpoint as an essentially purposeful organism, was also strongly influenced by Kant's teachings.[342].

The German natural philosophers such as Johan Wolfgang von Goethe (1747-1832) and Friedrich Schelling (1775-1854) reacted strongly to the mechanistic-materialistic viewpoint taken by the philosophy of enlightenment. According to their view, thinking about the world as a machine was not so much wrong as it was irrelevant. It did not take account of the deeply organic aspect of nature, its internal vitality which was manifested in humans as mind and spirit.[343] Goethe attempted to incorporate empirical observation into spiritual intuition. He did not believe that humans could achieve a deeper understanding of nature if they separated themselves from it – being satisfied with recording natural events as the workings of a machine and chopping out anaemic abstractions in order to understand it. Such a strategy produced an illusory picture out of which the profundities had been unconsciously filtered. Goethe viewed the constructive role of the human mind in the same manner as Kant, but also believed that people were truly part of nature. The human spirit did not simply impose its order on nature, nature incorporated everything, including humans and their imaginings. Truth about nature was not autonomous and independent, it was revealed in the very act of human cognition. Nature brought its own order out through humans. It was a spirit as indivisible from humans as it was from God.[344]

Human sensitivity to natural experiences and our creativity in discovering new approaches were given particular emphasis by artists of the Romantic period such as Blake, Wordsworth, Keats and Baudelaire. They valued human emotions and creativity more than rational intelligence: i.e. the ability to penetrate nature's spiritual essence. More important than universal laws was

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342 Niiniluoto 1980, 46. Aspelin 423-424.
343 Trusted 1991, 153.
344 Tarnas 1991, 378.

subjective consciousness about each object's complex uniqueness. The changing and manifold contents and meanings revealed in these different individual events were, in the opinion of the Romantics, of greater interest than the unambiguous view of reality offered by empirical science. Even though Romantic natural philosophy attempted to unite humans with nature, the delicate internal culture, art and literature inspired by Romanticism was generally considered to be subjective. The humanistic way of thinking was even further detached from the external cosmological world of natural science, whose objective and absolute character offered no natural place for unique individual events. Self-conscious and delicately sentient humans were left to weave their own internal webs in a world on which their subjective understanding had no effect.. Since science did not accept the existence of any deeper truths in parallel with conventional scientific reality, to the Romantics it represented a new form of Monotheism.[345]

While the Romantics highlighted intuition and emotions, in neo-Kantian philosophical circles in Germany from the 1860s "vulgar materialism" was opposed by rational arguments. Ideas concerning natural science were were especially developed by Ernst Cassirer (1874-1945), who took the view that scientific knowledge also included material which was not dependent on experience.[346] At the beginning of the 1900s, metaphysically inclined natural researchers and philosophers such as Henry Bergson, A.N.Whitehead, P.T. de Chardin and C.S.Pierce also attempted to combine the scientific conception of evolution with the Hegelian idea about reality as a spiritually-driven process. In their 'process' philosophy, they criticised the basic assumptions of classical physics, and did not, for example, accept its naïve epistelmological premise that theoretical description automatically corresponded to real objects in reality. They were also critical of the view taken by classical physics that the world was made up of discrete localised objects existing in space-time, because this view could not take account of internal interactions between things, i.e. how they were connected with each other.

Bergson viewed the concepts of natural science as constructions that were well-suited to practical tasks, but not capable of providing us with any information about the reality which lay behind surface phenomena. In his philosophy, he relied on his own observations and paid particular attention to the fact that a person's internal world of experience consisted of a continuing becoming – an unstoppable process. Observations and thoughts followed each other in an unbroken flow. Each new thought contained the previous one and provided content for

345 Tarnas 1991, 367-369, 375-378.
346 Niiniluoto 1980, 48-49.

what followed. He considered attempts to divide thoughts into different ’atoms’ to be as artificial as trying to understand a complete musical work by examining the series of different individual notes at any specific moment. In a corresponding way, all other phenomena could be understood as being processes which took shape in time, they constituted it, and did not need to be visualised. Talking about the life of the soul in mechanical or chemical terms was something Bergson considered to defy common sense. Spiritual manifestations of life could not be reflected with physical terms, they were manifestations of reality, which was essentially different from the world of matter. The world of the soul was revealed in creative work, which defied all calculation and strict prediction. The dynamic continuity of events also belonged to the physical world. It shut out categorical Atomism, because parts could only retain their identity by their being embedded in an interactive cosmic web. According to Bergson, for example, the constant influence exerted by atoms was a consequence of the fact that their internal processes, i.e. vibration, took place in what was for humans an infinitely short interval of time.[347]

Since no empirical foundation could be found to support the thoughts of these ’process’ philosophers, whose ideas aroused great interest, their fate in an academic context was similar to those of Hegel in previous time. Speculative metaphysical overviews were rejected as unfounded in both natural scientific and many philosophical circles. At the same time, however, both a climate critical of science gained an increased footing in human culture and more radical doctrines were developed. Friedrich Nietzsche (1844-1900) had already said that truth could not be copied, it had to be created. In the 1900s, Irrationalism, Existentialism, Sceptical relativism and the complex post-modern way of thinking began to attract an increasing number of people. Influential philosophers such as William James, Edmund Husserl and Martin Heidegger rejected the approach taken by natural science and emphasised the authentic character of people’s phenomenal world and its many nuances in their writings.[348] This change in the centre of gravity of ways of thinking can be seen as having similarities with the ending of the pre-Socratic era in ancient times, or the Renaissance period in the 1500s.

3.3.4. Positivism and the analytical theory of science

Positivist outlook, which from the middle of the 1800s, has been popular with many scientists

347 Bergson 1964. Aspelin 1995, 520, 524.
348 Tarnas 1991, 174, 383.
349 Trusted 1991, 131.

and philosophers, signified the antithesis of all metaphysical speculation. It can be seen as the final attempt to hold on to way of thinking which aims to factual certainty. Even though authentic Cartesian certainty and trust in human reason had little by little lost its credibility, so that by the 1900s, belief in the reliability of reason had largely been abandoned, factual certainty was and still is believed to exist. It is to be presumed that, in spite of post-modern philosophy, the mechanistic-deterministic way of thinking, in accordance with technological applications based on natural science, still offers a common man the most credible portrayal of the world – even though the its reductionist programme ran into serious difficulties at the beginning of the twentieth century.[350]

Positivists believed that science is able to produce results without recourse to metaphysics as it investigates *how* phenomena occurred instead of asking *why* they occur. The trend can to some extent be taken as a continuation of traditional empiricism and the tradition of Enlightenment. Auguste Comte (1798-1857), the founder of Positivism, wanted to demonstrate that human thought traversed three main phases which he called the Theological, the Metaphysical and the Positive. It was his firm belief that in the Positive phase, all problems could be resolved via the scientific method. Scientific knowledge could be gained simply by inferring facts from objective data. Psychology had to be reduced to physiology and sociology, since objective science could not be founded on internal subjective observations.[351] In describing phenomena, Positivists attempted to avoid all forms of abstract speculation. In principle, all questions which could not be answered by empirically-observed facts were classified as being meaningless. To the Positivists, even such metaphysical terms as causality and substance represented Primitivist thinking.[352]

During the 1800s, philosophy of science was engaged in a heated debate between Realists and Antirealists about the justification for atomic theory. As atoms could not be observed, the Instrumentalists did not believe in their real existence. According to methodological instrumentalism, theories and theoretical terms did not refer to reality that is not observable by the senses, they were just logical and conceptual instruments for parsing our experiences and

[350] Trusted 1991, 131. This will be further discussed in Chapter 4.
[351] Aspelin 1995, 479-481. Comte also criticized introspection because it often destroys the phenomena one is trying to observe. David Bohm later used the same example when arguing for the usefulness of quantum mechanics in consciousness studies.
[352] Trusted 1991, 133-137. The philosopher John Stuart Mill, who was influential in the first half of the 19th century, abandoned the problem concerning the foundation of reality to metaphysicians when he defined it as a 'permanent possibility of sensation'. Positivists went even further in diminishing the constructive role of science and Mill criticized Comte that he did not differentiate empirical generalisations from fundamental natural laws such as

observations. Since theory was merely a symbolic device for systematising observations, the essence of the task it performs is not to present and explain reality. In the interests of scientific realism, ”models” are considered as steps towards theories which are representative of reality and ”model building” is the first phase in a search for a truthful theory. The antagonism between these positions is as old as systematic science. In his time, Plato set astronomers the task of discovering a group of geometric assumptions which would reduce the motions of heavenly bodies to circular movements. For 2000 years, this Instrumentalist principle for rescuing phenomena became an ideal for the formation of astronomical theories. In general terms, the birth of modern-era natural science signified the triumphal march of Realism.[353]

Instrumentalism has also appeared in the modern era in different forms in the philosophy of, among others, George Berkeley, John Stuart Mill, Ernst Mach, Pierre Duhem and Henri Poincaré.[354] Duhem refused to accept that scientific theories are able to explain anything, since it was his view that explanation inextricably connected science with the metaphysics. Also, Descriptivists such as Hume and Mach restricted the task of science to the portrayal of observed phenomena, science was only for providing descriptive answers to questions of ”How?”, never answers to questions such as ”Why?” which sought explanations. In science, descriptions of phenomena were to be attempted in the most economical way possible. Pierre Duhem’s scientific ideals were closely akin to Conventionalism, which Henri Poincaré formulated in the first decade of the 1900s. According to this doctrine, scientific theories were, in the last resort, agreements whose truth or falcity it was not meaningful to discuss. Observations were always compatible with competing theories, so choices between different theories were based on a search for appropriateness. For example, Copernicus’ heliocentric system was not better than the Ptolemaic earth-centred system because it was either true or closer to reality, only because it was mathematically less complicated.[356]

The Austrian physicist and philosopher Ernst Mach (1838-1915) accepted neither atomic theory or Mechanistic materialism. His response was Phenomenalism, according to which sense-perceptions were the ”elements” of reality. Physical objects were nothing more than ”collections of sense-experiences”. As a Positivist, Mach believed that ”scientific theory must not go beyond

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the theory of gravitation. See further J.S. Mill, *Auguste Comte and Positivism*. Trubner, London 1865, 57-58.

[353] Niiniluoto 11980, 228-229.

[354] Niiniluoto 1980, 230-231. In recent times, philosophers such as John Dewey, Moritz Schlick, Gilbert Ryle and Stephen Toulmin have made representations in favour of Instrumentalism, and some scientists, especially in the fields of physics and economics, have also adopted the doctrine.

experience by affirming anything that cannot be tested by experience”. The task of natural science was to do no more than disclose the relationships between the elements of observation as ”economically” as possible.[357] According to Michael Polanyi, a philosopher of science, the massive modern absurdity of this viewpoint, which can be traced back to Locke and Hume, has almost entirely dominated twentieth-century thinking concerning science. Polanyi sees the trend as an inevitable consequence of separating, in principle, mathematical and empirical knowledge. In spite of the beliefs of the Positivists, science cannot be considered to be nothing but classification, the natural history of sense-experiences. It is also not acceptable to reduce the significance of mathematics to science to nothing more than pure calculation. In the second half of the 1900s, the premises of Positivism become a target of increasingly-critical examination within the domain of philosophy of science.[358]

Deeming metaphysics to be primitive superstition, the Positivists connected it to several outmoded theories such as Vitalism. As not all of those who defended the scientific world-view were not as critical as Mach, they did not appear to notice that the foundations of accepted guesswork in the science of their own time, such as the hypothetical ether or force field and the postulates that material and energy were conserved, also lay in metaphysical presuppositions. Mach argued that Newton’s postulates concerning the existence of absolute space and time were meaningless, but the Positivists did not, in general, question Newton’s Principle of Relativity, which presupposes that laws are the same in all inertial systems. Also, the Positivists expressed no concerns about whether measurements of time or the length of objects should be independent of the state of movement of the observer that was making measurements, or whether distances remained constant, or whether clocks moved at the same speed in different systems. Only Einstein questioned the justification for these metaphysical presumptions, and it was only through his theory of relativity that they were seen to be nothing more than presuppositions.[359]

In the 1920s, the Austrian Moriz Schlick collected around him a group of philosophers and scientists which included Rudolf Carnap, Otto Neurath, Hans Reichenbach and Carl C. Hempel

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[356] Niiniluoto 1980, 232. Niiniluoto 1983, 272.

[357] Trusted 1991, 139-140. Niiniluoto 1980, 23. Niiniluoto 1983, 290. Mach’s critique of the concepts of absolute time and space employed in Newtonian mechanics later affected Albert Einstein in a significant manner. Niiniluoto 1980, 46-47.

[358] Polanyi 1958, 9.Trusted 1991, 143-144.

[359] Trusted 1991, 138-139, 165. Einstein’s theory substituted four-dimensional space-time for Newton’s absolute space and time. At the same time as it questioned some of the old metaphysical presuppositions, the theory of relativity also postulated new ones such as the constancy of the velocity of light or the view that mass is a form of energy. The nature of metaphysics is further discussed in Section 3.2.

who combined the Empiricist viewpoint of science, the idea of unity of all disciplines, the rejection of traditional philosophical metaphysics, the restriction of the task of philosophy to that of criticising scientific language, and a belief that modern philosophical logic was the most important analytical tool. Through Mach's Phenomenalism , the Vienna Group was influenced by the Positivism of the 1800s, and affected to a lesser extent by both Conventionalism and Pragmatism. The group attempted to formulate Positivist philosophical principles by exploiting precise conceptual tools that had been developed in the study of logic. For this reason, the philosophy of the Vienna Group was usually known as ”Logical Positivism” or ”Logical Empiricism”. The influence of the group on Anglo-American scientific culture in particular was great, since it was disbanded following the Nazi invasion in 1936, and many of its most important members settled in the United States.[360]

Logical empiricism, in which a great deal of attention is paid to scientific language, the logical analysis of conceptual tools, and the problems of formulating and drawing conclusions of scientific theories, had a powerful influence on the analytical theory of science.[361] It has also been attracted by questions concerning the evaluation of the presuppositions and research methods of special sciences, as well as with problems concerning the character of development and growth of knowledge. The ”dynamics” of science have been considered in, among others, influential works by Karl Popper and Thomas Kuhn. Popper's *The Logic of Scientific Discovery* was published in 1959 and Kuhn's *The Structure of Scientific Revolutions*, which caused considerable debate, was published in 1962.[362] The discussion concerning the growth of knowledge has brought the philosophy of science and the history of science closer, and has resulted in research that was carried out in the 1800s by W.Whewell and C.Pierce becoming topical once again.[363]

In the manner of Kant, the analytical theory of science has aimed to create a synthesis between the Empiricist and Rationalist traditions in science. While the Rationalist tradition from Plato to Leibniz viewed humans as having some inborn ideas and Empiricists emphasised that concepts and ideas were born in the human mind as a consequence of associations and abstractions

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[360] Niiniluoto 1080, 51.

[361] The analytical theory of science has had a strong effect on philosophy in Finland as Eino Kaila, an influential Finnish philosopher, was in contact with the Vienna Circle. Kaila's students are, for example, Georg Henrik von Wright and Jaakko Hintikka.

[362] Kuhn 1970 ja 1974. Kuhn's ideas concerning the growth of scientific knowledge are more closely examined in Section 3.5.

[363] Niiniluoto 1980, 51-54. Critical realism highlights the interrelation of concept and theory formation in a way that is fairly similar to that of Whewell in his *The Philosophy of Inductive Sciences*, a book published in 1847.

resulting from experience, so-called Critical Realism found the idea of conceptual preconditions for empirical knowledge acceptable. At the same time, these conceptual systems are seen as historically-developing and being consciously changeable, something which makes it possible to relinquish Kant’s agnosticism. Humans are not imprisoned by their fixed cognitive apparatus, they can, through scientific investigation, attempt to gain more perfect and more accurate knowledge of reality from “things as such”.[364]

As a result of the criticism of Positivism and the development of new tools, modern analytic tradition has been freed from many of the traditional restraints and obligations and many advocates of scientific realism have adopted a radical ”Anti-Positivist” view of the general nature of scientific theories. The Empiricist and Descriptivist view of scientific language turned out to be too confining when, for example, dispositional concepts could not be directly converted into observational terms. Claims of this type were alleviated by stating that scientific language could also accept terms which could be reduced to observational terms via explicit definitions and reductive statements. Hempel and Carnap liberalised this thinking to the dual-level theory of scientific language, according to which it was sufficient that some theoretical terms were connected to observationals term in a logical manner via a general proposition. In this way, scientific theory was understood to be a partly-interpreted formal system. This way of thinking did, however, result in problems since unambiguous criteria that could be used to separate theoretical terms from observational terminology did not exist. That which was observed depended on the experimental equipment being used by the observer, the conceptual system they were using, and their background knowledge. Observations were seen as theory-laden and proving the correctness of theories became problematical.[365]

Empiricism is no longer necessarily accepted, even in the modified form that Hempel and Carnap developed in the 1950s. Giving up the thesis of Semantic empiricism does, however, create new challenges when explicating problems concerning the interpretation of theoretical terms. According to Scientific Realism, theories are attempts to obtain knowledge concerning reality, and as such, they are true or untrue propositions whose truth must somehow be established. Via Descriptivism or Instrumentalism, problems connected with the interpretation of theoretical terms can be eliminated by concentrating only on their ”function” or their operation in science. If the task of science is viewed in a unilateral manner as the control of practical operations, the simple conclusion is Methodological instrumentalism. There is no need to take

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[364] Niiniluoto 1980, 144.

extra trouble with the interpretation of theoretical terms – or their truth values – if they work well, i.e. if sufficiently reliable and precise predictions concerning observation can be made with their assistance. If, once again, the primary target of science is taken to be information about reality, the task of formulating theories will naturally be seen as pursuing realism.[366]

According to Scientific Realism, the theoretical entities postulated by theories, i.e. the things or properties to which the theoretical terms make reference, exist regardless of whether they can be observed by the human senses or not. Scientific Realists thus accept the realistic theory of knowledge (epistemology) according to which reality conforming to laws exists independent of consciousness, and in contrast to Kant's agnosticism, they also consider it possible to obtain knowledge concerning this reality, even though this happens little by little and by trial and error. The theories of empirical sciences can be thought of as a hypothetical-deductive systems whose basic statements can be indirectly supported by investigating the truthfulness of their experimental consequences. Even though only a small part of external reality falls within the circle of human observational ability, scientific research either yields or approaches true knowledge of reality. By inventing laws, scientists are attempting to discover and pin down the conformities that pertain in the world. At least in the long term, the scientific image of the world is a deeper and, from an ontological viewpoint, a more primary one than the manifest image that is provided by everyday experience and expressible within the frame of natural language.[367] In the 1900s, advocates of Scientific Realism included Charles Pierce, Karl Popper, Carl Hempel and Ilkka Niiniluoto.

In spite of the less-extreme attitude adopted in analytical philosophy, it was not generally believed in twentieth-century philosophy that obtaining objective knowledge concerning the structure of the cosmos is possible.[368] Philosophy was directed at the investigation of language and logic, and physics was left to solve practical questions rather than those concerning ontology or natural philosophy. On the other hand, it was in the 1900s that it generally began to be appreciated that exhaustive descriptions, not to speak of explanations, of phenomena concerning the natural world cannot be achieved only through empirical experience. Even though the quest

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[365] Niiniluoto 1980, 217-224.
[366] Niiniluoto 1980, 52, 238.
[367] Niiniluoto 1980, 211, 229-230. The presupposition of scientific realism that the things and characteristics referred to in theorethical terms really exist is too strong in comparison to the idea presented in Section 5.2. that is based on Bohr's complementarity. One should rather say that something exists which has until now been best described by using these terms and theories.
[368] Trusted 1991, 78-80.

for scientific certainty was the usual reason for a fear of metaphysics, Kant had already noted, when reacting to Hume's criticism, that we cannot understand our experiences if we do not have a wider set of assumptions we can use as a foundation for interpreting them. Metaphysical presuppositions cannot be evaded when absolutely certain sources of knowledge do not exist. In the light of the analytical theory of science, these initial metaphysical assumptions need not to be seen as final truths, only as hypothetical inventions whose employment makes possible the solution of acute problems.

3.4. The Crisis in the Mechanical and Deterministic Way of Thinking

The core of the conception of reality adopted at the turn of the modern era, i.e. its metaphysical assumptions or presuppositions, has remained almost unchanged over the last three hundred years. By the middle of the 1800s, mechanics was widely acknowledged as the most perfect of the physical sciences, embodying the ideal towards which all other branches of enquiry ought to aspire. The particle-mechanics depiction of the world has permeated almost the whole of modern society stamping its presumptions both on everyday life and in the methodology of science. Typically, the Newtonian model has driven the search for theories and methods of description in which the investicated phenomena can be reduced to well-defined and measurable objects and their properties. The most highly-valued knowledge was that which could be expressed by precise, context-free equations that captured general patterns applicable everywhere in reality.[369]

In recent decades, the materialistic and technological character of modern culture has however been the subject of ever-stronger criticism. Newtonian mechanics, once pre-eminent as the most-universal and perfect science, and its subsequent decline from this position, have provoked vigorous controversy concerning the adequacy of scientific method as it is traditionally conceived and practised.[370] Today, many researchers who take a critical standpoint even consider that the "scientific world-view", i.e. the governing metahypothesis of the modern era, has been decisively falsified by its damaging and counterproductive consequences in the empirical world. Established truths are once again relativised. For example Stephen Toulmin has provocatively stated that modern science has presented the presuppositions adopted at the turn of the modern era only as a collection of temporary and speculative half-truths. He concludes that it is no longer necessary to consider nature as unchanging or matter as clearly inanimate, nor does the

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[369] Tarnas 1998, 365. Toulmin 1998.

"objectivity" of scientific work necessarily mean that the observer is detached from the processes being investigated.[371]

Global problems with the environment and development have provoked many to take the view that our current ways cannot be continued. Environmental movements and NGO activist groups in many parts of the world see our mechanistic and material concept of nature as one cause for the interrelated and world-wide problems in development and the environment.[372] Unexpected consequences of many scientific innovations gnaw away at people's confidence on the automatic progress produced by science and technology – an idea inherited from Francis Bacon. Critical investigations focused on both science- and religion-based institutions have been initiated in different kinds of New Age movement. People are searching for feelings of significance and meaning in their life by defining themselves what they want to believe in. There is criticism against the emphasis on objective technological methods of approach also on such special fields as highly-developed medical science. Human well-being is seen as being born out of the interaction between many different elements, so that our own internal state as well as environmental and social factors should be taken into consideration.

In modern history, the world-view of natural science, i.e. the presumption that the world works like a mechanical machine, has been called into question many times before, for example by artists of the Romantic Age or philosophers who have highlighted spiritual values. In recent decades, however, criticism has been voiced by much larger groups of people. Human activity and its relationship to the environment we live in have risen to become central themes in environmental and eco-philosophical circles. In addition to the criticism that is traditionally voiced by humanists or post-modern philosophers, scientific methods have also come to be questioned by many physicists, mathematicians, biologists and neuroscientists. They have taken a critical attitude tovards some of the most fundamental assumptions of the modern scientific method anticipating on the disintegration of modern-era "building structures". For example, the former physicist Fritjof Capra, who has arrived at an all-embracing synthesis concerning the roots of many problems, pointed out that the Cartesian-Newtonian world-view is inappropriate to deal with problems in a globally-interconnected world, in which biological, psychological, social and environmental phenomena are all interdependent.[374] According to the mathematician Keith

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[370] Nagel 1961, 155.
[371] Tarnas 1998, 365. Toulmin 1998.
[372] For the situation in Finland, see Heima-Tirkkonen et al. 1996.

[374] Capra 1983, xviii.

Devlin, many obvious problems have questioned the boundaries imposed by the legacy of Plato, Aristotle, Descartes and all the great thinkers in our two-thousand-year intellectual tradition.[375]

This criticism is relatively new and almost all of it is controversial. The depth of the crisis and its character have not yet become quite clear. The majority of natural scientists do not, in general, share the relativism and scepticism expressed by the critics of scientific-technical culture. The widely adopted modern scientific-technical way of thinking has offered a working framework for the solution of countless problems. It has been possible to provide detailed descriptions and explanations of different real phenomena in mechanical terms - by investigating the structures and laws of material things. Natural scientists also understand and value the unprecedented precision and quantity of our knowledge concerning the world. While Aristotle was more or less only able to classify and name different phenomena, modern science has, in an awe-inspiring manner, proved capable to provide legitimate explanations of natural facts and laws by reducing the plenitude of observed phenomena to a few fundamental invariances. The mechanistic-deterministic conception of reality and the attempts to control nature have also resulted in unprecedented technical and economic development – whether it is considered a benefit or not.

On the other hand, even though natural science – and especially physical research at the macroscopic level – made good progress on the basis of the mechanistic-deterministic paradigm, attempts to understand humans or the workings of society within a similar framework have not produced such influential results. On the basis of the mechanistic-deterministic paradigm, it has also not been possible to forecast the risks involved in the manipulation of nature. The particlemechanistic conception of reality may not provide access to the complex relationships between different variables and processes and their internal dependencies. As humans do not have a clear understanding of their own place as a part of nature, they have heedlessly destroyed the preconditions for their own existence. Also, in our materialistic culture, the significance of values as the foundations of man's responsibility for nature and society has generally been poorly understood. The existential problems like lack of meaning of life and the environmental problems, can both be taken as anomalies linked to the mechanistic-deterministic conception of reality.

In spite of the problems, the target of a consistent and overall representation of reality should not be abandoned. The general reductionist thesis can be said to have driven science forward, even

[375] Devlin 1997, 276-279. Examples of other critical philosophers and scientists are Heidegger, Toulmin, Maturana,

though it, in the final analysis, would turn out to be wrong. When defending or resisting mechanism and reductionism it should be remembered that all general theses always include disputable metaphysical elements.[376] History shows us that unified representations of reality or bases for explanation cannot be born, or preserved, if their foundation is too narrow. In the pursuit of knowledge and understanding concerning reality, we cannot avoid being vulnerable with fallible hypotheses. Blind alleys can only be avoided by being prepared to evaluate also our most fundamental beliefs – the hidden metaphysics that only becomes visible when knowledge is further generated.

3.4.1. The limitations of classical mechanics in physics

Before the birth of modern physics, the theory of relativity and quantum mechanics, the analytical mechanics of point masses for two centuries dominated the minds of physicists as the candidate with the highest qualifications for the role of *a universal science of nature*. However, only in astronomy was the Laplacian ideal of rigorously-deterministic science employed with all strictness and practical success. The mechanical definition of state which is an essential feature of this theory, proved to be either unrealisable or too difficult to realise in most other domains. Physicists continued to pay lip-service to that ideal, but in actual practice they they could not avoid the adoption of different, or at least modified, definitions of physical state in most branches of their science. After decades of unsuccessful effort to develop a theory of electromagnetics within the framework of requirements for a pure mechanical theory, Maxwell (1831-1879) constructed a fully adequate theory of the subject by employing a form of state description that was different from the mechanical one.[377]

The particlemechanistic conception of reality offered physicists a working framework which supported progress in research, but as a result of the acceptance of the concept of field,

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Varela, Damasio, Prigogine…

[376] Niiniluoto 1983, 308-310.

[377] Nagel 1961 285-286. Field theories were first developed in physics in the study of continuous media, for whose analysis partial, as distinct from ordinary, differential equations were required. They came into special prominence in inquiries concerning electrical and magnetic waves that propagated with a finite velocity. They could not be effectively analysed in terms of Newtonian forces acting instantaneously ”at a distance”, and Maxwell in his electromagnetic theory abandoned the mechanical conception of state. In spite of some initial resistance, Maxwell’s theory eventually took its place alongside the particle mechanics of Newton as a well-established system of ideas. Both theories possess a deterministic structure despite the fact that the electromagnetic description of the state of a system is defined in a different way to the mechanical state. Nagel 1961, 287-288.

Democritus' assumption that all events could be reduced to properties of eternal atoms became problematical. Electrons were discovered in 1897 and photons at the beginning of the 1900s. Currently, electrons are taken to be the smallest units of matter and photons are considered to be the smallest units of radiation.[378] Modern elementary particles are not eternal and indestructible building blocks of matter, as they can be destroyed in collisions and change into each other within the confines of the laws of conservation. As will be presented in more detail in Section 4.3. of this thesis, the structure of these particles only be "precisely" described with the help of mathematical probability functions. The theory of relativity and quantum mechanics demonstrated the Newtonian way of thinking to be a limiting approximation which can only be employed when investigating relatively large objects which are moving at no more than a fraction of the speed of light.

In spite of the giant strides in the development of physics, straightforward understanding of the nature of reality has actually become more problematical. The abstract formulae of modern physics no longer provide a clear picture about the essential nature of matter. One consequence of the new features of quantum mechanics is that the question of the concrete fundamental character of observed objects is lacking any clear answer. The macroscopic world does not appear to offer a usable analogue for understanding phenomena in the microscopic world. Even though the advent of quantum mechanics has meant that the earlier clarity offered by physics has had to be surrendered, there is not a single physicist who doubts that our knowledge of reality is now much better than it then was. The problem is only how to describe and explain its character using ordinary understandable concepts.

The existence of the problems of interpretation implies that quantum mechanics is difficult to locate in the Laplacian super-deterministic and reductionist clockwork-world. This frustrating situation has resulted in many physicists emphasising the value of the knowledge gained as an instrument. Instead of aiming to ontological understanding and explaining of reality, they have to an increasing degree concentrated on the optimal mathematical description and control of phenomena they encounter. This instrumentalist and operationalist development has obscured the traditional Realist belief that physics will truly resolve the structure of the reality that

[378] Han 1999, 1. Professor Han's book presents the major developments in atomic, nuclear, particle and quark physics over the past hundred years in a style also accessible to a layperson.

[379] See Horgan 1998, 71. Horgan has interviewed many experts and ended up concluding that a superstring is neither matter nor energy, but some kind of mathematical ur-stuff that generates matter, energy, space and time but does not itself correspond to anything in our world.

surrounds us. This may be a problem for the scientific approach. If even physicists who are directly dealing with reality cannot provide a clear overall picture of their research objectives, the arguments of post-modern Relativism are difficult to block. Physicists who belittle the problem of the interpretation of quantum mechanics have not perhaps understood that the requirement for a clear interpretation is not an attempt to impose limitations on the methods used by physicists, it is more the use of theories developed by physics to achieve an improved understanding of reality. Clarification of the foundations for our conception of reality might even provide some solutions to the current cultural crisis.

3.4.2. Crisis in the scientific portrayal of the human being

Methodological monists interested in the success achieved by classical physics have usually taken the view that only a single scientific method is needed to follow the whole of reality. The attempt has been made to fit all possible phenomena from pyschology to economics into a Newtonian framework in order to combine all scientific results into a single unified world-view. Even today, for example, many social biologists and evolutionary psychologists strive to reduce human and societal phenomena to physics and chemistry. In the pursuit of a consistent basis for the explanation, it has been over and over again proposed that living beings are nothing more than assemblies of matter which obey physical and chemical laws.[380]

Science has not, however, succeeded in finding final solutions to the metaphysical questions which concern the nature of reality. The achievements of classical physics did not prove the world-view of ancient atomist to be basically true. The limitations in particlemechanistic approac gave rise to the psycho-physical problem that has troubled philosophy throughout the modern era and in spite of many efforts we still do not really understand the relationship between the human mind, will and intention, and a world assumed to consist of matter that obeys mechanistic-deterministic laws. Even though the human mind and consciousness are generally presumed to be products of evolution, the feedback produced by human influence and choices on cultural evolution and the formation of natural processes is difficult to explain on the basis of a universal materialistic and deterministic conception of reality.

At the beginning of the 1900s, psychology and phenomena of the human mind were generally approached via behaviourism. Favouring an experimental approach, the Behaviourists charted an external, objectively measurable relationship between physical stimuli and the reactions that were generated. In the Behaviourists' view, assuming the existence of internal states of mind was unnecessary. According to the logical behaviourism shaped by philosophers, all concepts referring to mental processes and phenomena could be interpreted by making reference to external behaviours or propensities, i.e. dispositional behaviour of a specific type in a specific situation. No mysterious mental beings were to be found behind behaviour, the "machine" worked without any necessity for the Cartesian "ghosts" condemned by Gilbert Ryle. In the 1950s, another alternative in the philosophy of science, popular as a way of avoiding Cartesian dualism, was reductive materialism, so called type-identity theory, which identified specific psychological levels of perception with specific neurophysiological brain states.[381]

One result of research into computers and artificial intelligence at the end of the 1950s was the formation of the concept of the human mind as an information-processing system. Cerebral and nerve cells were seen as working on the "all or nothing" principle, just like computer binary-logic circuits. Cells either fired or did not fire in response to nerve impulses, and the result was always the same and of the same size. The human mind was compared to a computer program (software), which was completely independent of the machine's physical structure (hardware) in the which the program was running. The "human mind as a computer" metaphor became a starting point for classical cognitive science, a multi-disciplinary doctrine which also received material from philosophy of mind and language research, and which rose rapidly to its prime in the two following decades.[382]

The philosopher of science Hilary Putnam rejected both Logical behaviourism and Reductive materialism by stating that psychological states are functional states of the organism, not behavioural dispositions or neuropsychological states. Functionalism became the core of cognitive science. According to the concept of functional identification, mental states should be identified via their role in causality, with a specific mental state being nothing more than a causal role which it fulfils in the system. Even though functional identification does not include any ontological obligation as regards the process which carries out the causal role in question, in practical terms being a Functionalist implies a commitment to Materialism and support for event-identity theory. According to this, every mental state is implemented in some physical material,

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[380] Niiniluoto 1983, 291.
[381] Revonsuo 2001, 54-55.
[382] Revonsuo 2001, 53-54.

and what makes states belong to the same class is not their similar physical character, for example their neurophysical characteristics, but their identical causal role.[383]

Within a mechanistic-deterministic frame of reference, it is difficult to explain how a specific causal role, a multibly-realisable functional state which cannot be reduced to a certain physical basis, can be born out of matter.[384] At the beginning of the 1980s, many philosophers critical of cognitive science blurred its identity to such an extent that now, during the first years of the 21st century, there is no consensus about the fundamental nature of cognitive science. Also, in more general terms, philosophical theories concerning the fundamental character of the human mind are currently in a state of ferment. Even though both brain research and cognitive psychology, which attempt to describe and explain, among other things, perception, thinking , the making of decisions and the production and understanding of language, have been making progress, so far no single unifying theory has been conceived which at the same time provides a solid theoretical foundation for multi-disciplinary cognitive research and also takes account of the new results obtained from empirical research. It has been particularly difficult to provide a tenable explanation of the subjective character of the phenomena of consciousness.[385] Scientific explanation of these phenomena cannot perhaps succeed within a mechanistic-deterministic framework, but as will be discussed in Chapter 5, the quantum framework may offer preferable options.

The mathematician Keith Devlin, a researcher into language and communication, has come to the conclusion that the truly difficult problems of the information age are not technological but concern ourselves – what is it to think, to reason and to engage in conversation. He has found growing evidence that the existing techniques of logic and mathematics – i.e. the whole traditional scientific method - are inadequate for the task of understanding the human mind. The main reason that we come up against the limits of the traditional framework in the human and cognitive sciences is that any statement always makes a claim about some situation. Cartesian science, the great investigative tradition which has freed the study of phenomena from all context, is not suitable for the investigation of human reasoning and communication. It is Devlin's view that in trying to develop an understanding of mind, language, and everyday reasoning, we should abandon Descartes' decontextualised approach and go back to the view

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[383] Revonsuo 2001, 56-58. In Daniel Dennett's (1978) functional decomposition theory, complicated mental states are reduced to simple ones through different levels of description and explanation. It is supposed that the level of extremely simple functions is comparable to those in digital computers.

[384] The author suggests that the new concept of state in quantum physics might offer new tools to deal with the problem. See also Section 5.2.

advocated by Aristotle – i.e. put reasoning and communication back into a context.[386]

In general terms, the approach adopted by natural science which concentrates on the universal natural laws that rule external reality can be said to be reminiscent of pre-Socratic times in antiquity. It was only during the blooming of ancient thought that Plato and Aristotle began to pay more attention to humans. Over and above the general laws and principles, the scientific approach should include what was unique and possible. Internal human experiences and the meaning attached by each person to these are obviously individual and often unique, but at the same time, they are not formed at random. Even though traditional Newtonian science had no tools to handle this kind of conformity to laws, nothing needs to stand in the way of developing scientific method so that we would better learn to understand and handle the contextual processes of reality that take place inside humans.

The concentration on nature's objective processes has resulted in less attention being paid to intrinsic and regulative functions of the human mind. The question of the character and significance of each person's psychic and spiritual talents has however become more relevant than previously when, as a result of research into artificial intelligence, more has begun to be said about learning and thinking machines. Technologically-oriented utopian researchers into the future have already announced the birth of *tekno sapiens*, a new species. "Thinking machines" will be able to take over troublesome routine mental tasks and they also can solve all the problems of humankind by joining us or by taking over man's position as the intelligent controller of this earthly kingdom. Increasingly often, this kind of biased vision of the future has also awakened consideration of the deeper problems of human existence. Are people just technologically determined robots bound to obey externally imposed laws, or are they able to make their own decisions about their future development?

Even though defenders of machine intelligence condemn their critics as paying romantic and irrational attention to some special biological or psychical features, human choice and responsibility cannot be ignored in technological development. Even if both machines and humans could be thought of as "products" of a material evolution, all development hardly takes place automatically. To a significant extent, humans seem to be able to choose the type of future they construct: i.e. the types of machine they develop and the limits of the power that these

[385] Saariluoma 2001, 26-48. Revonsuo 2001, 51-52, 60.
[386] Devlin 1997, viii-ix, 82-83, 260-270. Referring to the established mathematician Gian-Carlo Rota, Devlin argues that the day will come when currently vague concepts such as motivation and purpose will be made formal and

machines are given.[387] It is also relevant to ask the fundamental question whether human understanding, judgement or intentionality really belong in a machine. Researchers into artificial intelligence have not yet been able to build a machine which has even the smallest amount of common sense or which can discuss everyday matters using normal language. The deductive computer is a syntactic piece of equipment which manipulates symbols, but has no creativity and does not understand meanings.[388]

The lack of solutions to basic questions concerning the character and meaning of life does not necessarily have to be counted as a defect in the mechanistic-deterministic conception of reality. More problematical is the fact that neither qualitative change in the system or questions concerning emergence can be handled unambiguously and in a clear manner within this framework.[389] The Nobel prized physical chemist Ilya Prigogine who has studied the dynamics of unstable systems has for a long time argued that Newtonian determinism fails; the future is not determined by the present, and thus the symmetry between past and future is broken.[390] The biologist Humberto Maturana and his student Franscesco Varela have maintained that it is misleading to reduce a living system to its different constituent parts, we must also consider both its environment and its history.[391] The acceptance of this kind of emergent and holistic features has been problematical. The systematic emergence or self-organisation of different systems, is difficult to explain within the existing mechanistic-deterministic framework of thought, within which events are explained by strict external causes. In criticism of holism, scientific character is usually perhaps unwittingly identified with forms of definition adopted at the dawn of the modern era: i.e. the metaphysical presuppositions within whose frames it was customary to conduct research.

In recent decades, the idea of emergent features showing up in certain contexts has become more common in science. Philosophical considerations related to quantum mechanics, and for example system thinking and non-linear phenomena point to the inadequacy of Atomist and Reductionist methods of explanation. Reductionist thinking has nowadays been questioned even in research

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accepted as constituents of a revamped logic, side-by-side with axioms and theorems.

387 Kallio-Tamminen 2003.

388 Winograd 1990, 1-2. Devlin 1997, 152-156.

389 The issue whether emergence and reductionism are compatible is controversial and depends, for example, on the definition assigned to emergence (weak, strong) It is also a matter of discussion whether non-linearity implies non-reductionism.

390 See e.g. Prigogine 1997, 6.

391 Maturana and Varela 1980. Varela, Thomson and Rosch 1991.

into the influence of genes.[392] In biology, it is more fruitful to see a living organism as a developing system whose formation is influenced by the many factors and possibilities existing in its environment.[393] Even though mechanistic-deterministic thinking is sometimes understood as being almost synonymous with the scientific approach to things, the unusually distinguished and successful role of Newtonian mechanics in the history of modern science does not guarantee its validity as a general research programme.

3.4.3. The status of mechanical and deterministic view

The status and scope of the mechanistic-deterministic way of thinking as a general research programme is not indisputable. The foundations of Newtonian mechanics have been the subject of vigorous debate since Newton first formulated his axioms of motion. Moreover, although the axioms have received more than two centuries of critical attention from outstanding physicists and philosophers, there still is widespread disagreement about exactly what they assert and about their logical status. No brief and simple answer can be given to the question: What is the logical status of the Newtonian axioms of motion? It is nowadays quite certain that the axioms are not *a priori* truths to which there are no logical alternatives; and it is equally clear that none of them is an inductive generalization, in the sense of a generalization that has been obtained by extrapolating to all bodies interrelations of traits found to hold in observed cases.[394]

The basic task of scientific research is generally taken to be the seeking of information about the true nature of the world, and the results obtained are condensed in the form of laws and theories. These work as premises for explanations on the one hand, and on the other for predictions.[395] As will be presented in more detail in Chapter 4 of this thesis, in physical research, quantum mechanics has replaced Newtonian mechanics in the study of small particles. The statistical

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[392] Kaila 1998, 10-13.
[393] Haila 2000, 23-26.
[394] Nagel 1961, 174, 202. The axioms have been claimed to be *a priori* truths which can be asserted with apodictic certainty: to be necessary presuppositions of experimental science, though incapable either of demonstration by logic or refutation by observation; to be empirical generalizations, "collected by induction from phenomena"; to be general hypotheses suggested by facts of observation, but no more than probable conjectures relative to the experimental evidence confirming them; to be concealed definitions or conventions, without any empirical content; or to be guiding principles for the acquisition and organization of empirical knowledge, but not themselves genuine instances of such knowledge.
[395] Niiniluoto 1983,227-229. The universal laws stating that all As are B are considered to be the basic type of natural laws. A and B are qualitative or quantitative conditions and B does not logically follow from A. This means that natural laws cannot be logically true. The same holds for probabilistic laws whose basic form is that As are B with probability r.

predictions of the theory perhaps demand some re-evaluation concerning the nature of natural laws. The principle of determinism was shaped in the modern age, with the aid of a universal law of causality. Kant presented this law as follows: every event has a cause of which it is the inevitable consequence. His proposal was that this was a synthetic *a priori* truth. Leibnitz had proposed a weaker principle, according to which every event had a cause which made the occurrence of that event more probable than its non-occurrence. The nature of the causal relationship could not be established on an empirical basis, but the magnificent success of Newtonian mechanics convinced many thinkers, in addition to Kant, to plump for determinism.[396]

Confusion in the discussions concerning mechanism as well as determinism was also caused because both could be talked about at different levels – as systems, as laws, as theories and as worldly connections. In speaking about the inevitability of events, a property of theory, i.e. its determinism, is perhaps rashly universalised as pertaining to the whole world. It is at least potentially misleading in suggesting that it is *a system of bodies*, rather than a *theory* about certain properties of a system of bodies, which is said to be deterministic.[397] Regardless of the importance of laws, theories or theoretical research programmes, the accepted view of their nature, not to mention their relationship to the world, is neither unambiguous nor uncontroversial.

When even the question of the nature of the scientific laws and paradigms is uncertain, it is no wonder that the discussions between the defenders and critics of the scientific way of thinking have generally proved to be unfruitful. Neither modern and postmodern ways of thinking, nor the scientific and the humanist standpoints have been able provide clear insights concerning the strategies for future development. In spite of the frequent criticism aimed at the one-sidedness of natural science, developments in physics already outstripped the limitations of the mechanistic-deterministic paradigm at the beginning of the 1900s. It is possible to claim that modern physics has been in the front row of science in fundamentally questioning the ways of thinking and methodologies adopted at the beginning of the modern age. It offers comprehensive and empirically-based theories which can also be used to re-evaluate both basic concepts and methods of approaching reality. This re-evaluation is essentially a task for natural philosophy, and one in which metaphysics cannot be ignored.

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[396] Niiniluoto 1983, 246-247, 251.

3.4.4. The metaphysical foundation of theoretical constructions

By metaphysics, Aristotle meant that which lies behind physics, the general principles that physics does not reach. Nowadays, the term is generally used to refer to such presuppositions, beliefs and theories that cannot be verified through scientific research or sense perception.[398] The meaning and significance of the term ”metaphysics” does however vary from individual to individual. For example, the physicist Victor J. Stenger, a vehement defender of locality in quantum mechanics who has rejected the possibility of there being any real problem in the interpretation of quantum theory, understands metaphysics to imply that behind the imperfections of the material world there is some kind of perfect world. ”In religious terms heaven, the domain of the spirit, in western philosophy, Plato’s world.”[399] By allocating metaphysics such a restricted role, Stenger is incapable of seeing the metaphysical basis of his own arguments, even though his position is based on it.

To some extent, physicists’ ignorance of metaphysics is understandable, since its significance has been undervalued in both the scientific tradition and in philosophy. The most-recent attempt to escape from metaphysics culminated in Verificationist positivism, which denied that there was any need for it. Nowadays, according to Galen Strawson, the most common form of the delusion is to think that one can be free of both metaphysics and Positivism by admitting that one is a hard-nosed Materialist. This is, however, a metaphysical position if it is supposed that sense perceptions or reality exist. ”As soon as one admits that something exists, one has to admit that it has some nature or other – or one has to admit that one can be wrong about its nature, in which case there are various metaphysical possibilities, even if one can never know for sure which is correct.”[400]

Even though Positivism shook the foundation of metaphysics, on which it had rested during the golden age of German idealism, predictions of its demise have proven to be wishful thinking. Metaphysics has been defended by many thinkers who are also masters of the precise language of science. One of first such individuals was R.H. Lotze (1817-1881), who attempted to adapt the mechanistic explanations of nature to research into physiology and mental phenomena. In his

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397 Nagel 1961, 280.
398 Trusted 1991, ix.
399 Stenger 1995, 7.
400 Strawson 1994, 78-79.

philosophical works he also wanted, over and above his empirical laboratory work, to defend the right of metaphysics to exist. Lotze saw that in the final analysis, human intelligence would not be satisfied with an impeccable description of observed events, but that it would also strive to interpret the world to which human beings belonged. For this reason, it was essential to proceed further than what was offered by observed reality and use the metaphysical way of thinking. According to Lotze, each thinking being walked this road, even though they might claim that they did not busy themselves with such unscientific questions. For Lotze it was better to be a conscious metaphysicist than an unconscious one.[401]

In discussions with Positivist philosophers at a conference organised in Copenhagen, Niels Bohr wondered why Philip Frank had used the term ’metaphysics’ in his lecture simply as a curse or, at best, as a euphemism for unscientific thought. Frank had spoken of metalogic and metamathematics and Bohr could not see why this prefix ’meta’ which merely suggests that we are asking further questions, i.e. questions which bear on the fundamental concepts of a particular discipline, could not be connected with physics. Bohr fully endorsed the Positivist insistence on conceptual clarity, but their prohibition of any discussion of wider issues simply because of a lack of sufficiently clear-cut concepts in this particular realm, did not appear very useful to him. Such a ban would prevent our understanding of quantum theory.[402]

Metaphysics is an abstract dicipline which concerns exploration of the most general features of the world, the broad nature of reality, and the possibility of its objective representation. It can be divided into three parts: conjectures, basic presuppositions, and mystical beliefs, between which it is impossible to draw clear lines. Speculative conjecture can lead to empirical theories and even to fundamental presuppositions, and even though many mystical beliefs can be rejected as being nothing but nonsense, we can never be certain whether some of them are still left to the group of fundamental presuppositions that we cherish as being true. Speculative guesswork has played an essential part in the development of science. Even though its predictions cannot always be verified immediately in any experiment, they are neither insignificant or meaningless. Just the reverse, they can turn out to be viewpoints which are extremely informative and which drive development forward. For example, Democritus’ atomic theory or the proposition put forward by Copernicus that space was so large that the earth could perhaps be moving even though the fixed stars appeared to remain stationary, was later proved to be justified on the basis of observations. On the other hand, it has never been possible to prove by observation that Newton’s theory of

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401 Aspelin 1995, 515.

inertia, according to which the change in the velocity of a body requires the influence of an external force, is true, even though this theory of inertia is a basic presupposition in classical physics.[403]

Fundamental presuppositions are absolutely essential if we wish to create a wide-ranging frame of reference within which we can interpret our observations and provide factual descriptions that relate to the world. As the English philosopher William Whewell (1794-1866) said: ”Facts are a combination of things and our thoughts about them”.[405] In the last century, criticism of positivism has also highlighted the theory-ladenness of observations. Observing facts is not simply collecting raw data produced by the senses, it includes the organisation and largely-unconscious interpretation of data, and this requires wider theories. In creating such an expanded frame of reference, conjecture is essential and its pertinence is only recognised at a later stage as a result of extended research. All the fundamental presuppositions implicit in our conception of reality are not usually subjected to serious questioning. Periods of cricis like the interpretation of quantum mechanics demand more-accurate analysis throwing new light on such fundamental questions.

While the explanation and understanding of facts concerning reality demands wide theories containing theorethical terms which cannot be verified on the basis of sense-experiences, the question of what is the suitable scope for a theory to leaves some room for interpretation. Is it, for example, reasonable to strive to offer the narrowest-possible physical explanation, or should some attempt be made to address some greater reality that is the background for our sense-experiences? Even though the narrowest physical explanations are not entirely free from fundamental metaphysical hypotheses, the creation of wider-ranging explanations borders on the regions of mystical belief. To this class belong religious claims, including the Platonists' thinking concerning the world of Ideas, but also the thoughts that the world is a deterministic machine in which every event is predetermined, or that individuals always do have a freedom to choose what they will do. It is difficult to clearly separate mystical beliefs from other speculative theories or physical presuppositions which have, in a very fundamental way, shaped and motivated all our attempts to understand and explain the physical world and our place in it.[406]

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402 Heisenberg 1969, 283-286.
403 Trusted 1991, ix.
404 Granit 1977, 84-85.
405 Trusted 1991, 128-131.

406 Trusted 1991, x.

In recent philosophy of science, the once popular view of Logical empiricists that ”metaphysics is meaningless” is no longer tenable. An increasing number of philosophers have began to discuss the question of whether contemporary physics needs a new metaphysics. Instead of the epistemologically orientated philosophers of science who wonder whether philosophers should believe what the scientists tell them, metaphysicians concentrate on philosophically puzzling features of the natural world: How should the natural world be described if the scientists are right? What must the world be like in order for quantum phenomena to be possible?[407] The precise connection between physics and metaphysics requires clarification, but on the basis of historical evidence it is arguable that physicists cannot avoid doing metaphysics or making metaphysical assumptions. As metaphysics seeks the greatest or highest generalities or universalities that extend beyond the generalities sought within the natural sciences, it is, usually tacitly, involved in the enquiry into nature.[408]

Philosophers who believe that science has strong metaphysical implications usually presuppose 1) That science and metaphysics cannot be sharply separated from each other, and 2) That metaphysics must, in some way be based on the best available science.[409] It is naturally impossible to believe that we could create, or change, the conception of reality on the basis of arbitrary speculation. As quantum mechanics, the fundamental modern theory concerning the physical world, does not however fit the ruling conception of reality, there is good reason to take the possibility of the wholesale renewal of this conception seriously. The generally accepted mechanistic-deterministic way of thinking has offered a working frame of reference for the solution of innumerable “permitted” or ”promising” problems which lie within its compass, but it is also legitimate to ask whether the paradigm which constitutes the foundations of physics has also frozen or petrified our thinking and limited our view to that which lies within predefined limits, and perhaps even prevented the voicing of possible connections that would have seemed quite natural within an alternative paradigm.

Since natural science is not able to operate without fundamental metaphysical presuppositions, their existence should not be avoided or forgotten. On the contrary, the attempt to clarify the metaphysical elements in our thinking is vital if we would like to plan the of future development of our culture or evaluate the scope and appropriateness of the scientific method.. Making critical

[407] Papineau 1996, 290. Kitchener 1988, 5.
[408] Leclerc 1988, 25-37.
[409] Kitchener 1988, 16.

evaluations of our basic beliefs is significant even though science cannot demonstrate metaphysical claims to be right or wrong. Science and metaphysics seem however to be correlated in a way that the error-correcting practices of science do little-by-little make us aware of the binding metaphysical beliefs which underlie our thinking.[410] If the fundamental assumptions which have controlled research during the modern era were subsequently found to be in error, the question would not be one of a defeat for the scientific method, but rather a victory. The hypothetical-deductive method employed by science would be applicable to address mistakes in its fundamental presuppositions.

In the following section, I will attempt to investigate what basis there is for supposing that the conception of reality adopted at the beginning of the modern era really is incorrect. In Section 3.5, the general nature of world-views and the process of their changes are examined in greater detail. In Chapter 4, the focus is on quantum mechanics and its interpretation: the reasons behind the birth of the theory; its theoretical structure; and the new features associated with it which cannot be understood within the frame of reference provided by classical physics. In Section 4.3.4, an attempt is made to prove that the discussion concerning the interpretation of quantum mechanics can be viewed as a case study which has its basis in the process of change in conception of reality.[411]

3.5. Hypothetical-deductive Development of the Conception of Reality

This section is a closer examination of the nature of our conception of reality and its development. On the basis of material provided by history and philosophy of science, we ask whether a conception of reality or a world-view can be understood as some kind of metatheory, a paradigm which has a wide general effect on culture, and to which the activities and scientific conceptions of a particular age conform. In such a case, discussion concerning the interpretation of quantum mechanics which deals with the metaphysical foundations of the conception of reality can be considered to be an outstanding example of a fundamental paradigm change

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[410] For example, at the beginning of the 1900s Ernst Mach removed the problem of matter and mind from the domain of science in his important work *Analyse der Empfindungen*. He stated that science is ”concerned with different basic variables and different relations. Neither the facts, nor the functional relations will be changed if we treat everything as conscious experience or as partly or wholly physical. Granit 1977, 84-85.

[411] The interpretation discussion can be viewed in Kuhnian terms. Copenhagen interpretation demanded a radical renewal of both the accepted conception of reality and the position of human beings, but subsequent attempts at interpretation have attempted to find a route back to classical conceptions of reality, by postulating a variety of auxiliary hypotheses.

connected with a transitional phase.

Even though it is difficult for an individual to imagine renewal of a conception of reality that permeates a whole culture, philosophy of science does not pose any fundamental barriers which would prohibit a re-assessment of our basic conception of reality. In western culture, conceptions of reality have changed in a radical manner in ancient times as well as at the turn of the modern era. The English philosopher R.C. Collingwood identified three fundamental constructivist phases in cosmological re-assesment. In the first, the idea of nature was a central part of thinking in ancient Greece. The second time world-view was intensively reflected in the beginning of the modern era in the 1500s and 1600s, when developments in natural science challenged the existing organic conception of nature. Currently, according to Collingwood, the third phase is under way, in which change, process and evolution have become the central subjects of thought.[412]

As in the case of Collingwood, many others have seen that the modern world is undergoing a period of re-assessment comparable to those taken place earlier when the failure of generally-accepted ways of thinking has led to cultural crises.

If a world-view is interpreted as a ontological model, hypothesis concerning reality that is generated by humans, it is understandable that it will change when its basic presuppositions are no more considered credible. The development and changes of such a world-view can perhaps be understood by using the methods developed by Thomas Kuhn and Imre Lakatos for scientific theories. They consider the theories of empirical sciences as hypothetical-deductive systems within which research is conducted. The accepted paradigm provides the criteria and the tools on the basis of which correct and solvable ”scientific” problems can be identified and solved. Paradigms continuously undergo gradual changes, but occasionally the position of a ruling paradigm becomes uncertain when it appears that research is no longer making progress on the old foundations, but requires ever-more-complex auxiliary hypotheses to bring anomalies within the scope of previous assumptions. In these cases rapid and almost discontinuous paradigm changes may happen. Further experience and knowledge can falsify theories – perhaps it is able to falsify world-view, too.[413]

[412] Collingwood 1960, 1-12. The occurrence of in-depth changes is difficult to deny, but their total number can be seen slightly differently from various perspectives. In Europe, for example, Christianity profoundly reorganised the conception of reality and world-view.

[413] In this case the precise methods of natural science and its comprehensive theoretical frameworks can be seen as a

3.5.1. The conception of reality as a cultural paradigm

As became clear in the review of the formation of conceptions of reality carried out in Chapter 2, the world around us is, in all cultures, accompanied by beliefs, myths and models that are accepted as being rational in their own context. In antiquity, the real world could only be reached through the intellect, in the Middle Ages, through belief. In the modern era, it is assumed to be objectively measurable. We cannot know what deficiencies or errors are present in today’s way of thinking. Even so, it is hard to doubt that the portrayal of the structure of the material world given by modern science is not overwhelmingly superior to those of earlier times.

The ruling conception of reality in a culture tells individuals what kind of world they are living in and what kind of things it is possible for them to do. Conceptions of reality incorporate the basic ontological and epistemological beliefs influence culture and its athmosphere what is believed to be possible to happen. The basic patterns of world-view reality provide a framework for the existence of individual human beings and through this, he or she analyses the phenomena he or she encounters. The basic presuppositions concerning the nature of reality are adopted at an early age and they create a foundation for common sense which is later difficult to question. Hardly ever is the ruling conception of reality experienced as limiting. If a particular phenomenon cannot be understood within the framework of the familiar world-view, the urge is to forget or to deny its whole existence.

Conceptions of reality permeate whole cultures and leave their mark in different areas. In anthropology, culture is traditionally handled in a holistic manner. The pioneering anthropologist Ruth Benedict viewed culture as an organic whole which is more than the sum of its parts. She considered the characteristic features of a culture as step-by-step striving to establish a coherent whole which is a unique collection of systems and relationships. This cultural form is something bigger and higher than its individual units have desired and created. Its existence limits the possibilities of changes and is usually much longer-lasting than any particular changes in its content.[414]

Benedict based her thoughts concerning the character of culture on both gestalt psychology and

tool in a wider hypothetical-deductive process of understanding reality.

historical developments, but when she presented her thinking in the 1930s these were the target of severe criticism. In her day, sociologists and social psychologists attempted to reject her thoughts concerning ”group delusion” and reduce society to nothing more than a collection of parts whose behaviour should be addressed through individual psychology.[415] Quite clearly, Benedict’s method of explanation which emphasised a totality was not in tune with the dominant mechanistic-deterministic paradigm, or the accepted form of culture, so the attempt was made to sideline it. This was actually something to be expected on the basis of Benedict’s thinking: culture is frequently dominated by a subconscious tendency to select such features which are shaped by the general maxims and which can be used and modify others in a suitable way, or reject them in their entirety.

The conception of reality adopted at the turn of the modern era can be understood not only as a form which constitutes modern cultural development, but also as a comprehensive metatheory or research programme. When a concept of reality is understood as some type of metatheory, a paradigm that has a general influence on culture and with which both activities and scientific concepts of certain period of time are in agreement, the philosophy of science may illuminate its development. Changes in ways of thinking can be considered to be in line with the concepts of dynamic development in scientific theory proposed by Thomas Kuhn and Imre Lakatos. When there is a dominant specific ”normal world-view”, attempts to understand new phenomena are generally based on the core presumptions of the dominant paradigm and explanations employ the concepts that are already in use. People who have internalised the concept of reality prevailing in a specific period live in the same generally-accepted ”common sense” reality, in which they seek that which is considered reasonable. The generally-accepted assumptions which underlie the paradigm are not questioned, since all the phenomena encountered are automatically analysed on that basis. When a concept of reality has a much wider and longer frame and period than any individual scientific paradigm, its whole existence and influence may remain almost unnoticed by people who live under its guidance and never question it.

Application of the viewpoints developed within the philosophy of science to a complete world-view also offers the possibility of an improved understanding and perception of the dynamics of the longest-term models of reality. Kuhn and Lakatos verified the observation made by

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[414] Benedict 1951, 46-62.
[415] Benedict 1951, 231-234.

W. Whewell in the 1800s that theories or ways of thinking which are considered to be fruitful are held on to in a persistent way. An example of this is the hard-core conceptions of reality handled by Imre Lakatos' scientific research programme, whose core presumptions concerning the nature of reality have remained unchanged in the modern era. In Kuhnian terms, the situation can be stated as being that an attempt has been made to harmonise both theories and activities with the fundamental presumptions of the almost-300-year-old ruling "normal world-view". Even though individual theories have developed and changed with the passage of time, the fundamental metaphysical presuppositions which are based on classical physics have not been questioned.

When researching the development of theories, philosophers of science observed that old viewpoints sometimes only disappeared together with older generations. Individual anomalies do not bring down theories as it is always possible to make additions or corrections which save them, at least for a while. Even though the new theories of modern physics have revealed that the classical-physics particle-mechanics view of reality has limitations, many physicists oriented towards Realism do not wish to abandon the classical paradigm, even though the Copenhagen interpretation and Neils Bohr's thinking required the rejection of classical metaphysics.[417] Ways of thinking that suit the classical framework have become an almost self-evident starting point for the reasonable defining of things and giving this up is certainly not the easiest thing to do for physicists who have wholeheartedly accepted it and profited most from its methods. The more profound consequences of quantum mechanics for our world-view concerning ontological and epistemological issues like the nature of the observer and objects and their properties, and their relationship to observer, will perhaps have to be waited for.

The development of theories concerning the conception of reality requires both scientific research and the formation of fundamental concepts and theories. From historical perspective, different philosophical systems always provide, more or less consciously, the initial assumptions for more detailed research. On the other hand, also philosophical systems get influences and often are the result of particular types of generalisations of scientific results. From the viewpoint of philosophy of science the theories of empirical science are hypothetical-deductive systems whose basic statements can be indirectly supported when investigating their testable consequences in reality. When, as a result of research, an ever-increasing number of anomalies (i.e. material that is incompatible with the paradigm and phenomena that it cannot explain) starts to accumulate, critical examination of the foundations of the paradigm begins. As with other

[417] For more details see sections 4.3.1. to 4.3.4.

theories, the fundamental presuppositions of the mechanistic world-view adopted at the turn of the modern era, could then be discovered to be falsified in principle, even though no amount of testing can prove that its fundamental assumptions are right any more than any other scientific theory can, in the final analysis, be proved to be true.

If the conception of reality adopted at the turn of the modern era is thought of as a ”rationally”-constructed research programme, its fundamental ontological and epistemological presumptions can evidently be set aside if they do not, in the end, yield the hoped-for fruit. The abandonment of a theoretical research programme, i.e. a ”scientific revolution”, finally takes place when some competing way of thinking proves itself to be superior. In the final analysis, the ”irrefutable” core assumptions of a research programme or paradigm are not, therefore, outside the domain of what can be controlled by experience. The credibility of metaphysical presuppositions independent of direct experimental verification can therefore be estimated on an *a posterior* basis by examining which kind of consequences they generate in the long run.[418]

3.5.2. Transformation of the conception of reality

The Greeks believed they were living in a rational and organised reality, in a macro-cosmos in which the mind was a controlling and directing element contained in all material. The viewpoint adopted at the turn of the modern era turned this approach upside down. Nature was no longer seen as spiritual or divine, but as just a mechanical machine without intelligence or life. It not longer controlled its movements, all movement was decided externally and controlled by natural laws. This change in thinking could perhaps not have been tolerated without the transitional idea of a Christian creative and omnipotent God. As the external creator of the world, he could be believed to have created the order that ruled it. Quite probably, a significant factor in moulding the new conception of reality was also the new metaphors provided by new technology, such as the idea of a clock, which once manufactured and adjusted, could be left to do its job.[419]

Both the Greek’s organic thinking and the machine-like thinking of the Renaissance can be seen as analogous by their nature. Since, in antiquity, nature was generally understood to be a living and harmonious totality, the human micro-cosmos offered a model for the whole macro-cosmos.

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[418] Niiniluoto 1983, 195-199, 211.
[419] Collingwood 1960, 3-8, 102-103.

When humans learnt how to construct a clock, the world began to resemble a machine and the thought of God as creator of the world was simplified to the role of a clockmaker. These examples already illustrate the fact that portrayals of the nature of reality have been metaphorical and bound to the experience available at that time they were made. The metaphors employed both shaped the dominant way of thinking and were in line with it. Evidently, a similar phenomenon can be observed when as a result of the advent of computers, human cognitive abilities are nowadays described using methods of operation made possible by these electronic devices. Metaphors can help to improve the understanding and explanation of some phenomena or connections, but can also suffer from limitations when they are moved to a new domain.

The move from Aristotlean physics to that of Newton was accompanied by a significant transition of key maxims from the idea of harmony to their being causal mechanisms. The same transition was reflected in the change from alchemy to chemistry and from witchcraft to psychology.[420] Clearly, whenever the nature of reality is understood in a new way, the nature of individual subjects of natural research changes and acquires new features. Mechanistic thinking targets and explains many phenomena in a way which is unusually fruitful and beneficial, and its undoubted attractiveness in current times can be thought as a consequence of its abstract elegance and theoretical simplicity. However, in their search for theoretical universality, followers of Newton and Descartes were perhaps blind to the inescapable complexity and contextual character of many of the events and phenomena humans experience.[421]

Collingwood (R.C.) observed a weakening in the mechanistic way of thinking from the end of the 1700s. According to Hegel and Darwin, nature could no longer be understood as completely mechanical. Research into evolution and change gave rise to the thought that both function and process could play a more significant role than the structure and substance of nature. Static existence was no longer judged to be of particular importance compared with the way in which a system operated. According to Collingwood, modern cosmology was influenced by historical research. The process of natural evolution could be viewed as an analogue of human history. When nature is thought of as a continuing process, it is also easier to place teleology within it than to view the world as a machine.[422]

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[420] Hooker 1972, 186-192.
[421] Toulmin 1998, 375.
[422] Collingwood 1960, 9-17.

Collingwood’s opinion of the revolution currently taking place in our conception of reality is justified. If we examine only the developments taking place in philosophical or biological circles, the revolution can, in tune with him, be identified as having started two hundred years ago. Since that time, an ever-increasing number of holistic and organic ideas of reality have been presented alongside the mechanistic concept of nature. In my opinion, these alternative conceptions have anyway been peripheral to the mainstream of scientific-technical culture and, for example, physical research. The mechanistic-deterministic research program created at the turn of the modern era was in practice quite sufficient for research up to the 1900s and its generally-accepted presuppositions still continue to exert a powerful influence on the world-view adopted by our culture. If the most fundamental concepts of the mechanistic-deterministic paradigm such as the particlemechanistic idea of the world as fundamentally consisting of “dead matter” or the idea of external objective observers turn out to be incorrect, ahead of us lies even-more radical change than that which Collingwood expected.

The particle-mechanistic model of reality resulted from a combination of ancient Atomism and the mathematical portrayal, but as will be addressed in greater detail in the following chapter of this thesis, this model of reality can, in the light cast by quantum mechanics, be considered less than perfect. If a conception of reality is understood as a wide-ranging research programme, some kind of ontological-epistemological metaparadigm with which the activities of a specific period and scientific concepts are in tune, the precise research carried out by physics can step-by-step to either strengthen or prove incorrect those wider philosophical hypotheses which concern the nature of reality. In the final analysis, fundamental metaphysical presumptions concerning the understanding of reality can be expected to move forward. Even if the ontological and epistemological assumptions of classical physics views continue to mould the generally-accepted basis for the use of ”healthy common sense”, difficulties in the interpretation of quantum mechanics have highlighted problems associated with the particlemechanistic way of thinking. The fundamental metaphysical assumptions concerning the nature of reality have become subjects for discussion. As a result of this discussion, speculations by ancien thinkers concerning the basic substance of reality and its subdivision are once again of current interest. This makes it appropriate to examine again the criticism directed at the ancient Atomism by Plato and Aristotle.

Development based on the mechanistic-deterministic paradigm has not confirmed the correctness of its fundamental presuppositions concerning the nature of reality, since the functionality of a

paradigm or research programme cannot guarantee its truth. It is in the nature of paradigms that they always lead to a search for problems and methods of description in which they work.
In spite of its scientific character, there is no requirement for even the ”broad lines” of the conception of reality formed at the turn of the modern era to be close to the truth. Regardless of the success achieved by classical physics and scientific-technical ways of thinking, science could well be acquainted with just the coarse surface layer of reality. If the problems of interpreting quantum mechanics were to be viewed as a controversy associated with a major paradigm change, the consequence of such a paradigm change would probably be to see the world in a new light. Kuhn clarified the change of a scientific paradigm in terms of a gestalt switch: the same drawing which first appears to be a duck is suddenly seen as rabbit.[423]

When a world-view is interpreted as a theory formed by humans, it can be evaluated using the same scientific-philosophical criteria as those used to examine other theories. The world-view dominating the modern era can be taken as being more scientific than many previous speculations or explanations of the world based on revelations. According to Popper's criterion of demarcation, mythical or religious explanations of the world can be classified as being almost wholly metaphysical theories: it is hard to invalidate them on the basis of observations or experiment.[424] On the other hand, the mechanistic conception of reality is based to a great extent on Newtonian mechanics, i.e. empirically-tested and confirmed scientific theories. Its metaphysical elements are only part of the theory's initial presumptions. If new experience does not confirm predictions made by the theory, its hypotheses can, little by little, be proved to be either false or non-believable.

By changing paradigm, scientific research can provide a more reliable and truthful description of the world regardless of the fact that our fundamental concepts concerning reality are by their very nature metaphysical. The hypothetical-deductive method made familiar through the formation of scientific theories thus appears suitable for the construction of a conception of reality, even though the fundamental presuppositions about the nature of reality lie outside any dimension that we can directly experience. Since the basic metaphysical statements of the theory can be indirectly tested by investigating their consequences, hypothetical-deductive development

[423] E.g. the astronomers in Europe started to notice changes in the sky only after Copernicus, while the Chinese, who did not presuppose the sky above us to be unchanging, had observed new stars and spots on the Sun centuries earlier.
[424] Popper's demarcation criterion states that scientific theories cannot be proved to be correct but they are in principle falsifiable by experimental observations.

of the conception of reality is also possible. Via the creation and subsequent refutation of new paradigms, metaphysics is not beyond the reach of rational criticism.

3.5.3. Form and content in the thoughts of Niels Bohr

Bohr skirted the role of metaphysics, paradigms and discussion concerning the theoretical content of observations by talking about form and content. He stressed that content could not be available and no experience could be described in the absence of form, a logical framework in which these can be placed. On the other hand, when the world we are operating in yields new observations and we examine these on the basis of a theoretical symbol-world based on what existed previously, every one of these earlier created forms can turn out to be too constricted to face the new experience. A unity of knowledge and harmonious comprehension of ever wider aspects of our situation can only be gained by an appropriate widening of the conceptual framework..[425] In this way, scientific research and the whole of our attempt to perceive our environment and our experiences can be seen as a continual struggle between form and content. When a new experience, i.e. new content, cannot be accommodated within the old structure, a new and wider framework must be created: a new system of symbols and way of shaping through which we can also understand our new experiences. The pursuit of knowledge is an endless striving for harmony in structure and content. Knowledge is increased by a process of trial and error operating within a framework formed out of basic assumptions.[426]

A consequence of the increased number of experiences and new content is gradual change in the symbol-world in which our collective knowledge is stored, and the consequence of this is that our conception of the world develops. When earlier basic presuppositions become subject to sufficiently deep questioning, the result could be that the whole of the structure used up to that point would be revealed as too limited, and a change of paradigm is needed. Bohr saw that both classical physics and its associated conception of reality were the creation of men. Quantum mechanics, a more-comprehensive physical theory, made the preceding concept of reality appear limited. This showed Bohr that a framework of any type, however useful it had proved up to any particular point in time, could be considered to be too narrow when attempting to understand new experience. If new experience arising out of quantum mechanics is not forced in advance to

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[425] Bohr 1958, 82.
[426] Bohr 1958, 65, 67.

fit the given mechanistic-deterministic framework, but we strive, as Bohr did, to engage in the most open possible dialogue with the new facts and situation, the results of our activities can, step by step, enable us to perceive the outline of a new structure, a new type of description and a new way of understanding the world and our position in it.

Bohr’s view of the development of knowledge can be compared with the thinking of Kuhn and Lakatos. Bohr’s ’frame’ or ’form’ are reminiscent of the concept of paradigm: he saw in each entirety of assimilated knowledge certain specific and unchanging core assumptions. All knowledge that we can offer to each other is always presented within a specific conceptual frame, a specific paradigm which accommodates our previous experience. Any frame can however appear too narrow when attempting to understand new experience. New knowledge therefore makes it necessary to strive to form a new synthesis, a new and wider frame. For Bohr, it is not necessary for the new frame to be completely irreconcilable with earlier viewpoints in the way that Kuhn’s paradigms are usually interpreted. In the same way that the theory of relativity and quantum mechanics can be reduced to classical physics, if we are satisfied with the examination of bigger, relatively slowly moving macroscopic bodies, the new frame is built upon the foundation of those which preceded it. Since the new frame allows things to be perceived in a wider and more fundamental fashion, it can also be used as a basis for explaining why the preceding way of thinking proved to be too narrow.

Bohr was satisfied that the increasing of our knowledge, even though at some moments this appears to lead to the abandonment of an understanding of the whole, always leads in the end to unity, a harmonious synthesis, because it teaches us to find a connection between groups of phenomena previously thought to be unconnected. He emphasised that in spite of our increasing specialisation, we should be aware of the central dependency of all human activity, just as we should realise that arbitrary restrictions can lead to bias or prejudice – even in science. The only way to conquer the extremes of materialism or mysticism is a continuous striving to achieve a balance between analysis and synthesis.[427] Too-extensive analysis, in which complex phenomena are analysed in a too-simplistic manner, can lead to Reductionist mechanism, and too-extensive synthesis can lead to metaphysics which lacks an experimental foundation.[428]

Even thought quantum mechanics appeared to invalidate previous objective descriptions of nature, Bohr did not doubt that natural science could also offer tools that would allow an

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[427] Bohr in the "International Encyclopedia of United Science". Quoted by Holton 1978, 140.

improved understanding of the nature of reality.[429] Quantum mechanics did not require that realism be abandoned, just that the conception of reality be renewed. The failure of the mechanistic-deterministic paradigm signalled that the road opened up by the Newtonian framework had come to an end, but the reality of the world was not in any way lost. Bohr believed that quantum mechanics, just like any great and profound problem, carries its own solution along with it. Finding it only demands from us that we change our thinking. Bohr was prepared to countenance a radical revision of the old ways of thinking as a result of the new experience yielded by quantum mechanics. He understood that in just the same way as with the earlier mechanical model, a new and more comprehensive framework can result in profound changes in both ontological and epistemological presuppositions, in methods of explanation, and in theoretical terminology. In a more extensive framework, the position of humans and the nature of knowledge are illuminated in a new light.

Bohr's fundamental view of our position in nature was different to that of classical physics. As will be shown in more detail in Section 4.4 of this thesis, he saw that a correct understanding of quantum mechanics requires reassessment of the position of humans. People are not just bystanders, they are also actors on the stage of life. They cannot, as presupposed by Laplace's demon, understand the basic nature or essence of reality. They can, little-by-little, collect and organise their experiences of the world and learn to talk about them in an unambiguous manner. As many later interpreters of quantum mechanics have avoided adopting radically new metaphysical attitudes, they can be viewed as being as satisfied with the metaphysical structure adopted by classical physics. Attempts to solve problems in interpreting quantum mechanics have been made within the already-adopted ”normal world-view” with the aim of avoiding the need for a paradigm change which would result in the truly profound revision of the presumptions that underpin descriptions of reality. For his part, Bohr highlighted the new content produced by the theory which could no longer be accommodated within the old conceptual framework.

Nowadays, even though almost all physicists agree that modern physics has demonstrated that the old mechanical conception is inadequate, no solution to the problem of interpreting quantum mechanics has been found. Bohr understood that physics does not produce metaphysical

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[428] Honner 1987, 161.

[429] Bohr should not therefore be interpreted as an instrumentalist or a positivist. For more about Bohr's views, see sections 4.3.1 and 4.3.2.

knowledge concerning reality in an automatic and linear fashion, just by revealing facts which directly reflect reality. The increase in knowledge concerning reality comes through human reflection. By interacting with reality, we create models, theories and paradigms, different systems of symbols which help us to understand particular phenomena. Only the adoption of paradigms yields possibilities for new research and eventually result in changes in those paradigms when furher research makes us conscious about the limitations inherent in previous models.[430] Kuhn considered commitment to specific paradigms to be the price of scientific progress: anomalies could only emerge against a background formed in this way. We need models and theories to perceive things, but our knowledge also advances if we are able to notice that our earlier models are incorrect. If a once fruitful way of thinking cannot be abandoned when such action is necessary, it can become a false guide for further development.

By developing his interpretation of quantum mechanics, Bohr did not wish to actively postulate new speculative metaphysics, he was more interested in freeing us from the previous presuppositions of classical physics, which were often taken as almost-self-evident, by studying the correctness and feasibility of common background assumptions such as locality, determinism and the idea of the detached observer.[431] When that which in the light of new information has been shown to be incorrect can be abandoned, the picture of what new observations make possible becomes sharper, even though such possibilities may not be certain. On this basis, we can gradually recognise what is the most believable and then work and strive with the most-fruitful assumptions, things which are also worth holding onto in a changing environment.

If the fundamental presumptions of the mechanistic-deterministic world-view are now truly found to be inadequate or in error, the conception of reality adopted at the turn of the modern era will have to be thought of as nothing more than a hypothetical model constructed by humans on the basis of earlier but insufficient information. Poorly-operating paradigms will not, however, be abandoned before alternatives are on offer.[432] New syntheses or a new and credible concepts of reality are not born by chance. A new way of thinking must be discovered and justified before it can begin developing its own coordinates. Only a new and clearly presented interpretation, a new paradigm, can help us to see that something was actually missing in the earlier formation.

[430] See Kuhn 1994, 64,76,112. Kuhn does not however believe that paradigm changes imply approaching the truth.

[431] Bohr pays serious attention to the inadequacy of our descriptive concepts. His synthesis solves the paradoxes of quantum mechanics by reconsidering the metaphysical presuppositions concerning the position of human being and the nature of our knowledge.

In the new quantum framework, modern physics can offer a more extensive and durable foundation for perceiving reality. Changing the conception of reality does not however signify absolute relativism or total rejection of the best features of earlier viewpoints. Even though the scientific method cannot provide absolute certainty or truth about the nature of reality, information concerning reality can be seen as developing related to specific problems and their solution. In the final analysis, Bohr's view that quantum mechanics requires a re-evaluation of the mechanistic-deterministic concept of reality implies a confidence that in contrast to Kant's supposition, scientific research can lead to rational criticism of the metaphysical foundations for conceptions of reality and an increase in knowledge of "things as they are". Development takes place via the construction of theoretical models which depict reality and the development of content.

3.5.4. The classical and quantum frames of reference

Conception of reality based on scientific research can obviously gain new features via empirical research as well as via new thinking. Knowledge of real events can grow in a cumulative manner within a specific paradigm, but in a period of crisis, changes in ways of thinking can be so profound that it is justifiable to speak of a new conception of reality, or even of a revolution. In this type of fundamental change earlier unquestioned or even unrecognised fundamental metaphysical presuppositions concerning the nature of reality become subjects for discussion and may change. This kind of fundamental change concerning knowledge does not remain within small groups of specialists, but it filters little by little into surrounding society and the generally-accepted ”common-sense” view of reality changes. For example, Einstein's theory of relativity or quantum mechanics not only changed scientific ways of thinking, they also influenced the common-sense view of the nature of the world as they contain radical revisions to previously-unchallenged metaphysical assumptions.[433]

Newton crystallised the basic principles of his model into three laws which were presumed to be completely and universally applicable and suited to all situations. Even if it is now commonplace that the range of the explanatory powers of the Newtonian theory of mechanics is less extensive than was once supposed, it has had a long and successful career, certainly a much longer one

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[432] Kuhn 1994, 89,155.
[433] Trusted 1991, 163.

than other modern theories of comparable scope.[434] Newton's *Principia* led to a greater expansion in areas of research and improvement in precision than any other work in the history of science. The specifying of mathematical and dynamic ideas, their systemisation and application to different problems, offered a framework, a working paradigm, for classical physics.[435]

The process of verifying the basic ideas of classical mechanics lasted almost two centuries. Research advanced independently within the mechanistic-deterministic frame of reference as a wide spectrum of natural phenomena were successfully handled by employing the basic principles expressed by Newtonian mechanics. A long line of subsequent workers such as D'Alembert, Lagrange, Laplace, Gauss and Hamilton recasted and elaborated the fundamental principles of mechanical science, and applied it to a surprisingly large number of diverse domains.[436] When, in the 1800s, it was possible to address even the phenomena concerning propagation of sound and heat within a mechanical context, the last sceptics began to be ready to believe that the most fundamental structure of nature had been revealed. This belief was strengthened by the many mechanically based technical inventions which had become an essential part of society.

In the middle of the nineteenth century, Faraday's and Maxwell's research into electromagnetic phenomena introduced fields as precise explanatory concepts within classical physics. Fields induced forces, and caused electrically charged particles to move. These happenings appeared to have no direct link to Newtonian mechanics but in the beginning, an attempt was made to handle fields in a mechanical manner with the help of the ether hypothesis. Gradually this hypothesis became discredited. causing problems to understand the nature of immaterial energy fields.[438] Einstein soon further rocked the foundations of classical physics by defining new space-time. As will be discussed in greater detail in Section 4.1 of this thesis, research into the interactions between matter and radiation was to be confronted by even bigger problems which could not be solved within the Newtonian framework.

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[434] Nagel 1961,174.

[435] Kuhn 1994, 43. Lehti, 1988, 67, 70.

[436] Nagel 1961, 154. One branch of mechanics, namely statics, had reached an advanced stage of development by the time of Archimedes in the third century B.C.. However, attempts to extend such analyses to cover the motions of bodies not in equilibrium were not entirely successful until the signal achievements of Galileo and Newton.

[438] The existence of ether was a matter of general belief at the end of the 1800s even if its actual nature was ambiguous. Some serious scientists suggested that it was a link between matter and spirit, others thought it was matter which had unconventional qualities. Trusted 1991, 154-162.

In the light of quantum mechanics, Newtonian mechanics proved to be an approximation, adequate only when describing macroscopic phenomena. Quantum mechanics has become the basic tool of modern physics, and has been applied just as successfully to the challenges of modern-day research as Newton's formalism was in earlier times. Quantum mechanics gave rise to a huge body of unanswered questions and physicists have been rushing to apply the theory to new phenomena. Just as Newtonian mechanics did in its time quantum mechanics now signifies a new framework for physics. It has affected the core of physical research, for example by requiring the adoption of a new idea of state and statistical predictions. New theories of physics conforms to the principles of the quantum framework such as superposition or non-locality [439]

A theoretical framework differs markedly from a normal theory in that it includes fundamental principles which are constituent parts of all the theories than belong to that frame of reference. Newtonian mechanics can be taken as a classical example of a theoretical framework. It contains universal principles which were assumed to be adequate for explaining all phenomena encountered. These general principles are both the strengths and the vulnerability of theoretical frameworks as they lead to consequences, i.e. laws, according to which the principles can be tested.[440] While quantum mechanics revealed the principles of the Newtonian framework to be inadequate, all the subsequent theories such as the quantum field or strings theories belong to the quantum framework in just the same way as the theories concerning sound and temperature were part of the classical framework. The fundamental ontological and epistemological problems connected with these latest theories are the same as the ones already raised by quantum mechanics. Problems of interpretation are not just associated with individual theories, they relate to the quantum framework.[441]

A conception of reality is a wider frame of reference than a physical theory or framework, and its creation also requires the interpretation of physical theories. While classical physics is connected to a mechanistic and objective notion of reality, quantum theory awakens the need for in-depth discussion of both physical knowledge and the nature of reality. In discussions concerning interpretation, it has been necessary to remember that the basic presuppositions of classical physics such as determinism, reductionism, dualism or even metaphysical realism cannot be

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[439] Marsch 1957, 46-47.
[440] Omnes 1999, 248-250. Omnes differentiates between empirical rules, principles and laws. Empirical rules systematise observations but do not provide explanations. Principles are supposed to be universal.
[441] D´Espagnat 1989, 192-193.

proved correct by any quantity of experiments. They appeared to be valid as long as research continued on the old basis. The new experience gained as a result of quantum mechanics forced a questioning of the correctness of what were earlier fundamental hypotheses. According to Kuhn, a resort to philosophy is usually connected to a transitory period.[442] The changing of a paradigm requires both the abandoning of what was previously a fundamental presupposition and the postulating of new metaphysical propositions. Because of these factors external to physics, it is not possible to conduct paradigm change or the formation of a new perception of reality inside physics, any more than normal science can alter its paradigms using its own points of departure.

When the universal principles intended for a frame of reference are thought to be generally adequate and applicable to all events, a fundamental attempt to also understand the nature of reality can be made via comprehensive physical frameworks or paradigms. As can be concluded from the prolonged debate over the interpretation of quantum mechanics, physical theories or frameworks do not offer direct answers to such wider metaphysical questions. Abstract mathematical theories do not even reveal the nature of the entities to which the concepts of the theory can be applied. These problems were already encountered during the birth of classical physics. Even if in *Principia*, Newton clearly separated the mathematical and physical sides of his theory, the relationship between formal theory and its physical interpretation was considered problematicalduring during the formation stage of the paradigm. For example, the question was asked whether the theory completely corresponded to empirical reality or if its truth was simply the result of the truth of its axioms.[443]

When physics became differentiated from philosophy at the beginning of the modern era, it was supported by a strong metaphysical foundation in addition to its mathematical formalism. Physics began to unravel the structure and conformity to laws of what was assumed be a three-dimensional material world. In questioning the particular nature of this world, Newtonianism however had, in spite of its mathematical foundations, rather few fixed elements. Its background assumptions varied. Newton himself supported the neo-Platonic concept of space as the immanence of God but developments in mechanical and deterministic direction culminated at the end of the century in Laplace's concept of an all-knowing demon, an entity able to calculate everything in the universe by using mechanistic laws. The metaphysical changeability inherent in the background to Newtonian mechanics is indicative of the fact that projection of the theory's

[442] Kuhn 1994, s.103.
[443] Lehti 1988, 67.

presumed features as features of the world was not legitimate.[444] In contrast to Descartes, Newton did not himself claim that his narrative was the truth. In an addition to a new printing of *Opticks*, he wrote: When account of all these factors is taken, it appears quite clear to me that in the beginning, God made matter out of solid, massive, hard, impenetrable moving particles, whose size and form and other properties and situations were such that they were best suited for the purpose for which he made them.[445]

Kuhn considered that the creation of paradigm required external criteria, according to which different propositions could be scrutinised.[446] When physics attempts to explain the structure of reality, its precise theories are always contained within some wider way of viewing reality and because they are examined within this framework, can lead to anomalies and drive development forwards. In spite of the obvious precision of physics, it should always be remembered that this wider frame is a hypothesis. It can change as a result of new knowledge, and such change can destroy the uncertain basis on which a whole world-view is constructed. Even though a physical theory cannot, as it is, force the acceptance of new metaphysical assumptions, the basic presuppositions of an old paradigm can, in the light of new knowledge and theory, appear to be non credible. The need for dramatic change may be connected to the fact that we cannot perceive our environment in any other way than via the limited analogies and metaphors that we absorb from our experience. These descriptions may be incommensurable, even though they target the same reality.

Whether a conception of reality or a theoretical world-view is considered to be either a realistic reflection of the structure of the external world or just an appropriate systematic view of the current state of our total knowledge, the construction of it requires, in addition to empirical knowledge, creative imagination and speculative common sense. The Positivists have not even succeeded in dismissing from scientific theories the metaphysical material that cannot be reduced to observations. An even-more-impossible task is the striving to remove metaphysical presumptions from the world-view which forms the background to these theories. The Positivists' honourable attempt did however have consequences – new scientific-philosophical tools which are well-suited to the construction of a believable world-view. Thoughts concerning metaphysical matters do not need to be either meaningless or beyond rational criticism.

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[444] Niiniluoto 1988, 299.
[445] Toulmin 1998, 230.
[446] Kuhn 1970, 106, 121

Even though the philosophical premises which form the basis for quantum theory have been a subject of discussion for almost a hundred years, the discussion itself has not touched the mainstream of physical research. Quantum mechanics does not directly produce a new concept of reality, but, as will be described in more detail in Section 4.3. of this thesis, can be said to disprove the basic principles of classical physics and the mechanistic-deterministic concepts of nature associated with these. At the same time, quantum theory offers reasonable material for the formation of a new and more-credible concept concerning reality. The structure of the quantum frame of reference and its new presuppositions clearly shuts out not only the mechanistic-deterministic conception of reality but also many other possible world-views. Just as quantum mechanics is a more all-embracing and precise theory than classical mechanics, with the result that it can be used to address a larger body of real phenomena, so its corresponding concept of reality can be thought of as being wider and more fundamental. Newtonian mechanics and the quantum frame of reference are not completely incommensurable. Since the applicability of the new frame of reference is wider, areas and ways in which the previous viewpoint was too limited become clear and cumulative growth in the knowledge concerning reality can take place.[447]

Classical physics gave birth to differential equations, but quantum mechanics brought with it complex numbers, multi-dimensional spaces and probabilities. While the equations of Newtonian mechanics were a natural way interpreted as describing the movement of point masses in space, many of the new features of quantum mechanics such as new commutation rules for conjugate variables or non-local connections remain incomprehensible in the current frame of reference. The holistic features revealed by quantum theory cannot be understood by attempting to reduce them to movements of particles in space-time.

For almost a century, the particlemechanistic view of reality has no more supported the advance of physical research, but quantum mechanics still lacks a generally-accepted ontological interpretation. Chapter 4 of this thesis examines the painstaking process of scrutinizing the plausibility of the fundamental premises of the prevailing conception of reality in the light cast by the interpretion process of quantum mechanics. The purpose of the study is to find out whether quantum mechanics requires a reassessment of the mechanistic-deterministic conception

[447] Kuhn also points out that transformation from the later paradigm to the previous one can be executed afterwards even though he has elsewhere defended the incommensurability of different paradigms. See Kuhn 1970, 114.

of reality that was formed at the turn of the modern era.[448]

4. Quantum Mechanics and Renewal of the Conception of Reality

4.1. The birth of quantum theory and its structure

4.1.1. Early quantum phenomena

In the field of classical physics, the world was presumed to consist of material particles and radiation, which consist of waves connected with electromagnetic fields. At the end of the 1800s, it was generally believed that future development would only result in the better definition of some of the details of this way of thinking. At the beginning of the 1900s, however, the clear and perceptible ideas of classical physics were proved inadequate when the interactions between matter and radiation were subjected to closer examination.

The first signs of the ”particle nature” of radiation were discovered by Max Planck, who was pondering the experimental results concerning the radiation emitted by heated glowing metals, so-called black-body radiation. As metal was heated, the heat energy given off became light. Gradually, the heated body turned red, and then glowed white or blue-white. At the beginning of the 1900s, the intensity distributions of the light emitted by different materials were known at different temperatures. Planck attempted to find a mathematical formula which corresponded to the curves obtained in experiments. He noted that correct results could not be obtained on the basis of classical laws. To obtain the desired curves, Planck had to assume that heat could change to light only in ”packets” of a specific size, energy quanta, not in random amounts. The size of these quanta depended on ν, the frequency of the light that generated them, and on the energy connected with a specific frequency

$E = h\nu$ where h is Planck’s constant ($6{,}6 \times 10^{-34}$ Joules/second), $\nu = c/\lambda$

Planck considered radiation to consist of tiny vibrations which could only possess a specific

[448] If the particle-mechanistic method of explanation adopted at the turn of the modern era appears inadequate and the description of real events cannot be reduced to clearly-separate ”mechanical” parts, this does not mean that a physics-based description of reality cannot address all events taking place in nature.

amount of energy. He was not able to explain why this should be. The mathematics simply did not allow all possible energy values, even though this idea of ”quantisation” was completely foreign to classical physics, which could not provide a foundation for transfers involving jumps. Change always had to take place in a continuing manner through all intermediate phases. At first, it was generally believed that Planck’s quanta were only a temporary mathematical hypotheses and Planck himself did not acknowledge the reality of non-continuity until the year 1909.[449] Soon, however, Einstein was using quanta to explain photoelectricity, and Bohr incorporated them into his model of the atom.

The photoelectric phenomenon

At the end of the 1800s, it was observed that directing light at metal could result in the production of electricity. In itself, this was nothing particularly remarkable. Electromagnetic fields were known to affect charged particles, and could release electrons from metals. More-detailed investigations revealed however that while increasing the amount of light resulted in more electrons being released, their speed did not increase. Their speed was found to depend on the wavelength of the light employed. Short-wavelength blue light imparted more kinetic energy than longer-wavelength red light. This phenomenon could not be understood within the framework of classical physics theory.

Einstein explained the photoelectric phenomenon in 1905, the year in which he also published an article on Brownian motion and his special theory of relativity. Planck had been led to assume that radiation was generated in ”packets”. Einstein concluded that it must also be absorbed in quanta of size $h\nu$. Radiation had a ”grainy” structure. Light quanta either displaced an electron, using all the energy they contained in the process, or gave the electron no energy at all. No intermediate forms existed, quanta could never surrender only part of their energy. Since a single free electron always absorbed a single ”grain of radiation”, a quantum, the energy it gained depended only on that quantum’s energy, i.e. its frequency, not the intensity of the light. By using the well-known formula $E = mc^2$ from his general theory of relativity, Einstein was able to derive an equation which could be used to calculate the masses of ”radiation grains”.[450]

[449] Enqvist 2000, 1. The article gives a comprehensive account of the development of Planck’s ideas. For the development of quantum physics in Finnish, see Enqvist 1996.

$$m = \frac{h\nu}{c^2} = \frac{h}{\lambda c}$$

Strictly speaking, this formula is invalid because photons do not have any rest mass. The concept of mass here refers to the mass of motion, which is nothing but kinetic energy.

The phenomenon of photoelectricity demonstrated that particles and field vibrations were somehow connected: in a specific way, a vibrating field can always be thought of as being a connected mass of a certain size. Radiation previously taken as moving waves could be considered to consist of tiny particles, photons. On the other hand, several experiments on interference and polarisation provide information that light propagates in the form of waves. Confirmatory experiments connected with the diffraction of light resulted in the wave theory of light displacing Newton's particle theory at the beginning of the 19th century. The proposition that light did in fact have the character of particles was not an easy one to re-accept. As late as 1913, when Einstein was proposed for the Preussian Academy of Science, his supporters apologised for his incorrect assessment of the nature of light.[451] In 1921, Einstein received the Nobel prize for his explanation of the phenomenon of photoelectricity. The theory of relativity was still too controversial to qualify for such recognition.

Bohr's model of the atom

At the beginning of the 1900s, the Englishmen J. J. Thomson and Ernest Rutherford were investigating the structure of the atom. Rutherford was able to prove that the atom's positively-charged mass was concentrated in the nucleus. The atom also had negatively-charged particles, electrons. The problem was to explain why the atom did not completely collapse, since the oppositely-charged particles attracted one another. Rutherford suggested that electrons orbited the nucleus just like the planets orbit the sun. This did not however solve the problem, since according to classical theory, orbiting electrons would radiate light and lose a corresponding amount of energy. Before long, they should fall and become imprisoned in the nucleus.

The young Danish physicist Niels Bohr won a scholarship to England in 1911. He became

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[450] Laurikainen 1973, 132-134. Since the velocity of radiation quanta is c, their rest mass must be zero. 'Material' particles can never achieve the velocity of light.
[451] Herbert 1985,

acquainted with Rutherford and Thompson's laboratories and decided to adapt the quantum hypothesis to atomic research. Bohr quite simply proposed that for some as yet unknown reason, electrons did not lose their energy when they orbited the nucleus along certain permissible paths. The permissible orbits were related to quantum conditions and connected to the form and dimensions of the atom, which guaranteed the atom's stability or unchangeability. Stability was already a basic property of atoms in Democritus' atomistics, but in contrast to Democritus, Bohr's atom was neither indivisible or completely full. Closer examination of the internal structure of the atom made possible an improved understanding of atomic properties.[452] When an atom received energy from an external source, for example as a result of being heated, electrons could move to higher excitation states. An electron which returned to its basic state would release a quantum of energy whose size corresponded exactly to the difference in energy levels between the two states. In this way, atoms could both receive and radiate energy only in ”packets”. Their energy was quantised. No forms of intermediate state were permissible. The transfer of an electron from one shell to another could not be portrayed in the classical manner, i.e. as movement through the space between them.

Classical physics is not able to explain the existence of quantised states to any greater degree than the sudden changes in the state of the atom. When this so-called ”old” quantum theory was developed, it often led to conflict with classical thinking about causality. For example, in discussion with Bohr, Rutherford wondered how an electron could decide in advance in which ”stationary state” it should stop and thereby select a suitable wavelength.[453] In spite of the criticism, Bohr considered the concept of a ”stationary state” to be the core of atomic theory. He understood the situation of ”electronic orbits” to be an illustrative model, and warned against giving this model too realistic an interpretation. The new atomic theory contained both classical features and new assumptions which had no classical explanations. Even though the existence of a stationary state was a postulate without foundation, Bohr believed that Planck's quantum hypothesis revealed a fundamental feature of the atomic world. He also believed his atomic model to be a small step towards an better understanding of atomic reality.[454]

Even though Planck's proposition concerning the quantising of radiation and its corresponding

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[452] Laurikainen 1973, 126.
[453] Pais 1985, 7.
[454] Folse 1985, 63-65. Bohr's caution turned out to be wise. The particle-mechanistic model is properly applicable only to the hydrogen atom, the simplest one.

particulate nature proved to be justified and led to fruitful developments by Einstein and Bohr, the idea that the emission and absorption of radiation takes place only in quanta of specific size was seen as very problematical and difficult to accept. It did not correspond to the generally-accepted concept of reality in which radiation was ”already known” to consist of waves. Fundamental features of radiation observed in experiments, such as interference and polarisation phenomena, could simply not be explained without the assumption that radiation consisted of waves. The problems of depicting particles and waves became even more concrete as a result of Louis de Broglie’s astonishing doctoral thesis, which was later awarded the Nobel prize. In 1924, de Broglie, a Frenchman, proposed that in the same way that waves appeared to have particle-like properties, particles could also possess wave-like properties. He derived a formula which allowed the wavelength of particles to be calculated. It was obtained by simply solving for wavelength λ in the preceding formula and replacing c, the speed of light, by v, velocity.

$$\lambda = \frac{h}{mc} = \frac{h}{p}$$

Wavelengths providing solutions to the formula resulted in the macroscopically-observable particles being so small that they could not be analysed using any available measurement technique. At the atomic level, matters were quite different, since the wave connected with the electron was approximately the size of the atom’s diameter.

The waves related to all particles offered an explanation for the permissible orbits that Bohr had postulated in his atomic model. De Broglie proposed that permissible atomic states are standing waves that are dependent on electron wavelengths. In the same way that a spring of specific length can only oscillate at a certain frequency, the only electron orbits which are possible are those in which the length of the orbital path is a multiple of some wavelength connected with an electron.[455] De Broglie’s hypothesis concerning the connection between particles and waves received experimental confirmation in 1927 when Davisson and Germer, who were investigating the reflection of electrons by crystals of nickel, observed interference between electrons reflected by different crystal layers.

Interference effects that corresponded with predictions were also observed when different beams of particles such as electrons, protons and atoms were fired through a thin film of crystalline

[455] March 1978, 198-204.

material. These experiments agreed with Young's well-known double-slit experiments[456], which had revealed the wave-like nature of light. The interference phenomena observed corresponded to De Broglie's calculations predicting the wavelength values. The power of the testimony provided by these experiments could not be denied, even though they could not be explained in any way acceptable to classical mechanics. Physicists had to accept the situation and when necessary, associate radiation with particle properties and particles with wave-like properties. The need to develop a new mechanics able to respond to the problems that had been thrown up and explain wave-particle dualism was clear. Fortunately, an extensive quantity of spectroscopic material which revealed the wavelengths at which different atoms radiated was available.

4.1.2. The development of quantum theory

At this point it was verified by experiments that in certain situations waves had particle-like features, whereas in others the objects that had traditionally been seen as particles had to be seen through their wave-like features. Nonetheless, it remained unsolved how these different phenomena could be understood and brought together: the waves spread out through the space, whereas a particle can always be localized in a single point. Even though a clear visualisable understanding of these phenomena has proved difficult, scientists had already come up with several mathematical solutions in the 1920s.

In the summer of 1925, Werner Heisenberg introduced the first actual quantum theory, namely matrix mechanics. He had discussed quantum problems with Bohr throughout the spring and had come to the conclusion that in the study of these new phenomena, all concepts and presuppositions that might lead the mind astray should be stripped away. Inspired by Positivist ideals, Heisenberg eliminated from his theory all variables and mental images that were not empirically verifiable. He did not therefore even attempt to describe how the atom was structured or what happened inside it. By moving beyond the discussion concerning the orbits and quantum jumps of electrons, Heisenberg was able to avoid the problems that classical physics confronted with its use of mechanical images and space-time descriptions.[457]

Heisenberg, who relied on mathematics, noticed that even if the traditional description of the position of the electron as a function of time in space appeared impossible, it was instead

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[456] Young's double-slit experiment will be further discussed in Section 4.2.2.

possible to study the electron through the radiation that was emitted from the atom. The kinematics of the electron had already been seen in the spectrum of radiation in classical theory, and it had been possible to measure its frequency, amplitude, polarization, and phase. Through a study of the frequency and amplitude of radiation by an atom, Heisenberg was able to construct a Fourier transformation for the electron's orbit. Traditional Fourier analysis used only simple numbers as weighing coefficients for sine and cosine functions, whereas in matrix mechanics the frequency of the radiation depended on both the initial and the final state of the electron. Heisenberg was therefore best able to describe weighting coefficients as a group of elements, as a matrix. In his matrix mechanics, Heisenberg described all observable quantities with a group of time-dependent complex numbers. Using these matrices, Heisenberg was able to treat test results without visualising occurrences and atomic objects in time and space.[459] The matrix contains all observable characteristics of the quantum system in a table form, such as the energy values of photons emitted by the atom. The diagonal elements of the matrix corresponded to the weight of a given energy level and reveal the probability of observing a given value in the system.

Within matrix mechanics, it was not possible to give a geometrical interpretation to the new quantum symbols. Nevertheless, Heisenberg adapted equations from classical mechanics to his matrices by using Bohr's correspondence principle. According to this, the new theory had to reduce to classical mechanics when describing phenomena in which the quantum impact was insignificant. Heisenberg adapted, for example, the law of conservation of energy by simply replacing the equations of classical mechanics with those of matrix mechanics. Moreover, time development in matrices was derived from the equation of motion that bore a resemblance to Newton's law. Occasional deviations from classical explanations were principally limited to the fact that matrices did not commute in the same way as simple numbers. Therefore, when the matrix of x was multiplied by the matrix of p, which respectively specified the position and momentum of the electron, the calculation did not yield the same result that followed from the multiplication of p by x.

The theory of Heisenberg contained all empirically available information, and was able to predict correct results for simple atoms. Heisenberg had striven to make the new quantum algorithm as analogous to classical mechanics as possible. In fact, scientists were soon able to show that the matrix mechanics of Heisenberg was a mathematical generalisation of the classical mechanics of

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[457] Bohr 1957, 43, 60.

[459] Faye 1991, 119.

Hamilton[460].

Erwin Schrödinger, an Austrian scientist, took as the starting point for his quantum theory the hypothesis that waves were the fundamental entities in the world. He adapted the hypothesis of De Broglie for stationary waves and attempted to describe atomic systems as superpositions of waves. Guided by the analogous features in the laws of the mechanics and those of the optics, Scrödinger formulated an equation in 1926 that could be used to calculate the stationary states of the atom. Schrödinger’s equation[461] was to replace Newton's equation of motion as the basic formula in modern physics.

$$i\hbar\frac{\partial\Psi(x,t)}{\partial t}=-\frac{\hbar^2}{2m}\frac{\partial^2\Psi(x,t)}{\partial x^2}+V(x)\Psi(x,t)$$

Schrödinger's equation is a partial differential equation that gives as a solution the wave functions ψ(x,t) that correspond to stationary waves in different situations. With his equation, Schrödinger was able to solve all the wave functions for the stationary states of the hydrogen atom, and at a later point his equation gave the correct solutions for all the heavier atoms with many electrons (multi-electronic atoms). In addition to the wave functions that describe stationary states, the equation also provides the energy values that correspond to permitted stationary states, i.e. the spectrum of the atom. With this equation, it is possible in principle to calculate the wave functions for all kinds of quantum systems. In practice, finding the solution demands some boundary conditions that are context-dependent. These boundary conditions can usually be solved for a given energy value. This leads to a eigenvalue problem that belongs to the theory of differential equations.[462]

Whereas the Bohr's particle-mechanical model worked only with hydrogen, on the basis of Schrödinger's model it was possible to think that in the multi-electronic atom waves interfered

[460] Petersen 1968, 84-88. Hamilton’s mechanics is another representation of Newtonian mechanics.

[461] The Schrödinger equation became a founding axiom of quantum mechanics even if it was a kind of lucky guess. Classical physics did not provide any grounds for substituting omega (ω) with E/h or k with p/h. The equation can be deduced by assuming that matter is a classical wave which obeys a classical dispersion relationship. In contemporary physics, the fundamental character of the Schrödinger equation has ben reduced as it does not include relativistic effects.

[462] Laurikainen 1973, 142-147. The Schrödinger equation contains two particle-mechanistic quantities: mass and kinetic energy. The system must be defined by stating these quantities before quantum mechanics can be used to establish the stationary states of the system.

with each other, and in consequence produced a new overall situation that could not be explained by using particle-mechanical models. The wave function gives an amplitude for the wave that describes the system in all possible spatial points at any given time. This wave consists of several oscillatory modes, eigenstates, while the multiplier shows the amount by which each mode influences the result. All possible oscillatory forms can be explained as superpositions of eigenstates in the same way that all the possible forms of oscillation of a string can be represented as a combination of its stationary waves, basic tones, and harmonic overtones.[463]

Many of the strange features of quantum mechanics are made easier to understand by a brief consideration of the character of waves. Typically, a wave is born when something vibrates somewhere. Light is accepted as being a vibration of electric and magnetic fields. Quantum waves are viewed as oscillations of possibility. In other respects they follow the same laws as all other waves.[464] The basic measure of a wave is its amplitude, which measures the deviation of its physical variable from the resting state. Another important variable is a wave's intensity, which is proportional to the square of its amplitude. For all waves except quantum waves, the intensity is a measure of the amount of energy a wave carries at each point within it. As quantum waves carry no energy at all, they are sometimes called "empty waves". The intensity of a quantum wave (i.e. its amplitude squared) is interpreted as a measure of probability.

Waves can take many forms. Oscillatory waves pass through specific cycles in space and time. Frequency is the number of cycles completed in a certain time period and wavelength is a measure of the space that an oscillatory wave spans as it passes through a single cycle. Each point on a wave possesses a definite phase which is a measure of how far that point has progressed through the wave's basic cycle. The phase of a wave governs what happens when two waves meet. Whenever waves come together, the amplitude at each point of the resulting wave is simply the sum of the amplitudes of the constituent waves. This is called the superposition principle or interference. Ordinary waves obey the superposition principle at small amplitudes, but not when amplitudes become large. Failure of the superposition principle is called non-linearity, and shows up as distortion in hi-fi systems and as turbulence in water waves. Quantum waves are simpler. Their amplitudes appear to sum in all circumstances.

As with all continuous periodic functions, waveforms resulting from the Schrödinger equation can also be written as a unique sum of sine waves with differing spatial frequencies, amplitudes

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463 Pais 1991, 282-283.
464 Herbert 1985, 72.

and phases. As every waveform corresponds to a unique Fourier spectrum, sine waves can be thought of as a universal alphabet which can be used to express any wave. Subsequently, it has been shown that there is nothing particularly special about Fourier sine waves, since any other waveform family such as impulse waves or spherical harmonics will do just as well, so a specific wave can be decomposed in many different ways. This means that there is no "natural" way to take a wave apart, and that unlike a clock, a wave has no specific intrinsic parts.[465] When considering their adaptation to quantum systems, this means that the same shape of wave can be represented in many different ways. The way of expression that is chosen will depend on the measurement being attempted.

To some degree, Schrödinger's equation resembles the classical equations of motion of Hamilton and Maxwell. In fact, the relationship between Schrödinger's wave mechanics and classical mechanics has been compared to the relationship between wave optics and geometrical optics: classical mechanics represents a special case within the more general wave mechanics.[468] For example, while it is possible in certain situations to solve for the position of a particle with the probability "one" using the classical equation, i.e. with absolute certainty, the square value of the amplitude of the wave function at a given point is interpreted as the probability n/N, statistical likelihood with which a particle can be observed at that point if many measurements are made. The wave function was generally thought to be some kind of probability function and Max Born stated his probability interpretation in 1926. This idea, which replaced causally-problematic words concerning quantum jumps, was adopted into the developing Copenhagen interpretation.[469]

Schrödinger hoped his theory would show that the world fundamentally consisted of waves. However, he soon encountered problems when he tried to explain the world realistically by only using the wave explanation. In his equation, waves could not be interpreted as the waves of three-dimensional physical space, because in order to describe several particles one needs to operate with multi-dimensional spaces. Moreover, the waves are complex, and their form is

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465 Herbert 1985, 84-88.
466 Herbert 1985, 72.
467 Herbert 1985, 84-88.
468 Petersen 1968, 90.
469 Pais 1991, 286. March 1957, 105. While the Psi-function is in general complex in the technical mathematical sense, the square of its absolute value is real. The Psi-function is related to matters of observation by a circuitous route. Probabilities associated with Psi enter in the calculation of various other probabilities and some of these latter probabilities are finally coordinated by rules of correspondence with certain experimental concepts. Nagel 1961, 307-308.

dependent on the chosen group of observables. The concept of a wave was essential, but on its own it was not enough. Already de Broglie had shown that a moving body could be described with wave packets constituted from different component waves: the group velocity for matter waves was the same as the velocity of the body. In collisions, however, wave packets behaved differently to material particles. They passed through each other, interfering only temporarily, while particles typically bounce away from one another. Furthermore, wave packets connected to atomic particles soon dissipate because of the different velocities of the component waves.[470]

As the concept of the wave was not able to provide an exhaustive description for all the relevant features, the wave function was generally seen as no more than a mathematical instrument suitable for calculating probabilities. It provided a comprehensible image of the mathematical function, but probability waves were not waves in physical reality. When the usefulness of the probability waves was limited to the calculation of probabilities, they were not seen as actual waves in reality, but only as a means to produce an illustrative image of a mathematical function. Nonetheless, Max Born himself was prone to see these waves as something more real. He thought that even if particles followed indeterministic laws of probabilities, these probabilities were still something real that followed laws of causality in the configuration space.[471] Albert Einstein also preferred fields and waves. He never accepted the probability interpretation, but tried to reduce all particles to field equations. Because of discontinuity his goal was not generally adopted. Accustomed discourse concerning particles went on, even if they were no longer considered the bodies of classical mechanics which could be idealised as point masses.[472]

Schrödinger's equation, not unlike those of Newton and Maxwell, produces an absolutely deterministic time development. After a wave function has been determined, its time development at the atomic level is, in principle, fully predictable.[473] On the other hand, this only applies at the atomic level where there is interference, superposition, and probabilities. When one wants to know something about the real world, the system must be measured. While this

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470 Laurikainen 1973, 138-139.
471 Born 1963, 234.
472 Laurikainen 1973, 155, 185.
473 With respect to the quantum-mechanical state-description defined by the Psi-function, quantum mechanics is a fully deterministic theory. Nagel 1961, 306. In quantum mechanics, however, the state Ψ is totally different to the state in classical mechanics which gives the exact position and velocity of particles, since it only provides the possibility of calculating the statistical distribution of expected values. Laurikainen 1973, 165.

measuring yields exact values, it also results in indeterminacy. Measurements will shortly be further discussed in the connection of Hilbert formalism. The so-called measurement problem of quantum mechanics is discussed in chapters 4.2.5. and 4.3.6. of this thesis.

Schrödinger's wave formalism did not actually reveal any more information concerning physical processes in the microscopic world than the matrix mechanics of Heisenberg had done. Schrödinger's theory did not, for example, explain what happened when the atom moved from one stationary state to another. In fact, Bohr regarded Heisenberg's matrix mechanics and Schrödinger's wave mechanics as complementary symbolic descriptions within quantum theory. They were adapted to the nature of quantum theory because both of them had been able to leave behind the classical description of motion. According to Bohr, the classical space-time description could not succeed because the handling of phenomena in the microscopic world demanded use of superposition principle. The interaction between individual particles was different compared to the presuppositions of calssical physics.[474]

It was soon realized that the theories of Heisenberg and Schrödinger were in fact two different presentations of the same formalism. Paul Dirac generalised the approaches of Heisenberg and Schrödinger in his transformation theory, which included the special theory of relativity and was of great generality and practicality. In 1932, John von Neumann put the theory on a more rigorous mathematical foundation and clinched the Hilbert space formulation of non-relativistic quantum mechanics. Instead of wave functions, this theory deals with state vectors. The collection of all states permissible for a quantum system is theoretically represented by its state space, a complete Hilbert space. The vectors of this state space represent all the possible states of the system. Every state vector | I >, which equals a given quantum state of the system, can be presented as the sum of orthonormal base vectors:

$$|I\rangle = z_1|0\rangle + z_2|1\rangle + z_3|2\rangle + \ldots$$

A quantum state is a complete summary of the characteristics of the system at a moment of time. It consists of constant characteristics such as the mass and the charge of the system and the variable characteristics that change in time.[475]

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474 Bohr 1957, 63.
475 Folse 1985, 88. Auyang 1995, 16-17.

Geometrically, the components z_1, z_2, z_3 .. measure the lengths of the orthogonal projections of the state vector at various axes I0>, I1>, I2>. These axes or base vectors correspond to measurable properties, i.e. observables, and the lengths of the projections reveal the possible values or test results.[476] The base vectors can be chosen in numerous different ways, which means that a state vector can be shown in various systems of coordinates. In general a state can be an eigenstate for many different observables, but if certain operators do not commute, then a type of uncertainty relation connects the precision with which the two observables can be determined.[477] Accordingly, it is not possible, for example, to measure simultaneously position and momentum with arbitrary accuracy, because there are no available observables that could simultaneously correspond to both properties. Moreover, when the operators that correspond to position and momentum do not commute with each other, the sequence of measurement influences the result. The state vector also rotates in the Hilbert space, and thus the values of the projections are constantly changing, depending on the forces that influence the particles in a given situation. This rotation equals the motion of the system.

If the system is left to develop without external interaction, time development occurs according to the deterministic dynamics of Schrödinger. It is however impossible to observe this kind of idealised system, since the observation in itself already means an interaction. This observation interaction can be described by using the dynamics of von Neumann, which states that a system "collapses" to one of the possible observed states with a probability that can be calculated from quantum theory. This can be illustrated in the vector space with a projection of the system state to the eigenstate of a given observable. Observables are represented by operators in Hilbert space.[478] Even though many operators are employed in quantum theories only a certain class, the self-adjoint operators, represent observables. Self-adjoint operators have spectra that consist only of real numbers. For an observable A, the spectrum $\Lambda(A)$ of its representing operator comprises the set of all possible values obtainable in measurements of A. A spectrum can be discrete, continuous, or a combination of both. If the observable A has a pure point spectrum so that $\Lambda(A)=(a_i)$ the real numbers a_i are called the eigenvalues of A. The eigenvalues can be the direct

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[476] Auyang 1995, 16-17, 86. The dynamical variables in quantum mechanics are called observables. In addition to describing state - as in classical mechanics - they also provide the possible outcomes of measurements. Quantum representations are conventions. The choice of a particular representation is arbitary and depends on what is most convenient for the solution of a particular problem.

[477] Gasiorowicz 1974, 119. For example, the transition from coordinate space to momentum space corresponds to the complex rotation of Hilbert's space.

[478] Operators are transformations or mapping-like functions, but unlike functions, the range of operators is the state space itself. From a theoretical point of view, measuring simply means that one calculates the expected value of a given operator.

result of an experiment.[479]

The characteristics of a state, represented by a unit vector, are more concretely revealed in its relation to other states. As a vector can be represented as the linear combination of other vectors, a state can similarly be expanded into a linear superposition of other states. This is the superposition principle.[480] Many of the differences between quantum mechanics and classical mechanics are caused by the existence of these superpositions. The superposition states belong to the so-called "pure states". In addition to them, it is also possible to form so-called "mixed states". If the system under studied consists of several particles, it is possible to calculate its possible quantum states by bringing together the systems that describe individual particles. In observation situations, however, individual particles are not necessarily independent of each other due to the superpositions of these combined states. An observation concerning one particle can therefore influence the state of another. Moreover, further complications are created if the system consists of several identical particles: it is simply impossible to identify any specific identical particle, even on a theoretical basis. The states in which identical particles have exchanged places must be counted as one.

By the mid-1920s, after twenty-five years of confusion, scientists had actually produced three operating versions of quantum mechanics. In fact, all these theories carried virtually the same content: it could be said that they expressed the same message in different languages. A physicist who was applying them could therefore choose which formalism worked best for his particular task. In the late 1940s, Richard Feynman introduced yet another interesting way of approaching quantum theory. In Feynman's path integrals, the quantum system is represented as a sum of all possible states. It is as if the quantum system goes through all its available options. Each particle appears to travel down all the paths available to it and everything that might happen to the system influences the future of this particle. The wave function that remains can be concluded from diagrams by summing over the histories. In such a case, most of the possibilities cancel one another out.[481]

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[479] Auyang 1995, 68.
[480] Auyang 1995, 18.
[481] Feynman 1991. For example, Forrest 1988, Herbert 1985 and Hodgson 1991 include a concise presentation of quantum formalism. For a comprehensive historical account, see Schweber (1994) *QED and the men who made it*.

4.1.3. Consequences related to quantum theory

In spite of its abstract nature and the problems of interpretation, quantum theory has proved to be an extremely accurate and efficient formalism. It has become the basic tool of modern physics, and has been successfully applied to an enormously diverse range of fields and applications. The whole of today's electronics industry with its silicon-chip technology is based on discoveries made by the pioneers of quantum mechanics. Even though the birth of quantum mechanics was a result of considering the interaction between atoms and light, the theory has not broken down as research has, over the decades, advanced from atomic physics to nuclear and particle physics. It has led to an understanding of radioactivity and nuclear reactions. All the modern physical theories which deal with particle phenomena have their foundation in quantum mechanics and using this as a basis, a physicist can, for example, control particles with unbelievable accuracy in huge particle accelerators, separating different beams of particles and arranging the desired reactions between them. When we recall that the size of an atom is ten thousand times larger than its nucleus and that the collision energies employed in experiments are billions of times greater, the astonishing universality of the theory becomes clear.

Quantum theory not only explains the structure of atoms, it can also be used to determine how atoms combine to form molecules. It has become the central theory for both physics and chemistry. The properties of all materials depend upon how their atoms and molecules interact with one another.[482] Nowadays, in addition to research into microscopic phenomena, quantum theory has begun to be used in investigations at the macroscopic level. Macroscopic quantum phenomena can be revealed in the Bose-Einstein condensate and in low-temperature physics. When a material is in superconducting mode, its behaviour is completely defined by the laws of quantum mechanics. Also, an ever-increasing number of areas of application which utilise "odd" features of the theory such as superposition states or tunnelling phenomena are being seriously planned. For example, quantum computers and quantum communication are expected to open up dazzling future visions.[483]

In spite of the development of physical theory, a satisfactory way of successfully combining quantum mechanics with the general theory of relativity has not yet been found. Both the theory of relativity and quantum mechanics required major changes in the structure of physics. The theory of relativity is used in the examination of fast-moving particles and cosmic phenomena,

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[482] Morris 1997, 95.

while quantum mechanics has been a fundamental theory concerning atomic phenomena. The theory of quantum gravity has not yet achieved its final form, since the incorporation of Newton's gravitation constant G into the united theory has proved to be surprisingly difficult. Since the gravitational interaction which defines the metrics of space is very weak compared to other forces between particles, it is generally considered that the general theory of relativity is of little significance at the atomic level. Successful handling of phenomena involving particles demands the unification of the special theory of relativity and quantum theory. The first encounter between these two theories occurred already in the Sommerfeld atomic model in the 1920s.

In 1927, Dirac combined quantum mechanics and the special theory of relativity in a new type of quantum field theory. Initially, the infinities produced by the theory resulted in scepticism, but the renormalisation technique developed by Feynman, Schwinger and Tomonaga resulted in these being forgotten.[485] With the help of the quantum field concept, both the electrical and the strong and weak nuclear forces were connected to the same theory. Quantum electrodynamics (QED) was developed in the 1940s and the electroweak theory was completed by the end of the 1960s. To date, quantum chromodynamics (QCD) is the most comprehensive form of the theory, but physicists generally believe that a so-called "theory of everything" (TOE) will soon combine particle interactions and gravitation within the same framework. Different attempts at producing a quantum gravity theory are represented by loop and string theories.

The different versions of superstring theories are formulated in ten dimensions or even more. There is no general agreement as to whether the search for a usable superstring theory is likely to succeed. Feynman, for example, bluntly called superstring theory ”nonsense” and Stephen Hawking has added his voice to those of the sceptics.[486] Even if the standard model has passed all experimental tests, there are a variety of reasons for thinking that current theory is not complete but must some day be embedded in a wider-reaching framework. For one thing, current theory contains an uncomfortable number of input parameters, some two dozen of them.[487] The fact that gravity is not included in the standard model is also a serious drawback.

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[483] For more technological details, see e.g. Milburn 1996.
[484] The three were rewarded with the Nobel Prize. Freeman Dyson showed that Feynman's and Schwinger's formalisms are equivalent.
[485] Schweber 1994, 434-436. The three were rewarded with the Nobel Prize. Freeman Dyson showed that Feynman's and Schwinger's formalisms are equivalent.
[486] Morris 1997, 116.

In spite of the mathematical accuracy and precision of physics' new theories, it is difficult to formulate a clear and explicit view of the nature of reality on the abstract theoretical foundation that they offer. When some of quite basic and fundamental problems in particle physics has remained unsolved for more than a quarter of century in spite of massive and continuous attempts to achieve this, it has been suggested, every now and then, that the solution of these internal questions of physics would require an adequate clarification of the foundation for quantum mechanics, i.e. an clear interpretation of the theory.[488] The problems of interpreting quantum theory and its wider implications associated with the conception of reality have received much less attention than the development of the standard model of physics. For one reason or another, the comprehensive but abstract theory has not purposefully been used as a "window on reality", even though a successful physical theory can, with good reason, be expected to achieve a hold on reality or reflect its structure in some way or another.

Regardless of the problem of interpretation, quantum thoery is succesfully used in the handling of many concrete phenomena. For a long time, physicists have been applying the new features of quantum theory in an unambiguous manner to actual situations in both technical articles and research proposals. Handling the new features of the theory in a mathematical way is unequivocal, even though the clear understanding of observations and their presentation in natural language has proved to be difficult. Almost unnoticed, quantum mechanics and the concept of quantum field have changed physicists' conception of reality completely from the common everyday idea of a world haunted by Newtonian billiard balls.[489] For philosophers seeking realism, modern physical theories and new experimentally observed phenomena are brimming with new material for the formation of ontological and metaphysical hypotheses concerning the nature of reality.

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[487] Treiman 1999, 230. The exact number of parameters varies and depends on the way in which they are counted. Among the parameters are six quark masses and six lepton masses, the charge of an electron, angles, coupling constants etc.

[488] For example Selleri 1990, 4.

[489] Auyang 1995, 4. In response to my presentation, a physicist once challenged the need for any interpretation because a particle and a field are the same thing.

[490] In recent years more accurate books has been published that makes the basic ideas of quantum physics availeble to a larger public, see for example Treiman 1999. General surveys of quantum formalism in concise form are also available in Forrest 1988, Herbert 1985 and Hodgson 1991.

4.2. New features connected with quantum mechanics

Quantum theory by itself has not been able to solve the problems connected with its ontological and epistemological interpretation, something which can scarcely be expected from physical theories. For example, the problem of dualism related to the description of waves and particles is simply hidden behind a mathematical structure.[491] Closer in-depth analysis of the theory and experimental results – as well as the already mentioned development of quantum field theory – has revealed many other features which cannot be explained within the classical physics mechanistic-deterministic framework. Clear understanding of these new features requires a deeper interpretation of the theory, which for its part, in the last resort, may demand unequivocal answers to questions connected with the nature of mathematical description and reality.

As will be presented in greater detail in Section 4.4., the Copenhagen interpretation considered that quantum theory demanded a radical renewal of the classical conception of reality. A profound metaphysical reassessment is also not a source of alarm to Sunny Y. Auyang, who in his *How is Quantum Theory Possible?* from a realist foundation strives to examine the conception of reality that physicists associate with quantum field theory. He describes the general way of thinking about quantum field theory as follows:

> "Going from classical mechanics to quantum field theory, the focus of physics changes from locomotion to dynamical interaction. The primary form of matter changes from discrete mass points in empty space to continuous fields comprising discrete events. The primary dynamical concepts change from action-at-a-distance to coupling-on-the-spot, from external forces to interactions generated by the interactants themselves."
>
> "A field is a whole, but contrary to its popular image it is not amorphous. A field is a genuine whole comprising genuine individuals, a continuous world with discrete and concrete entities, technically called events. The discreteness of the events and their mutual interaction are both clearly articulated."[492]

Auyang believes that the quantum field concept brings new insight to the difficult philosophical problem of the relationship between part and whole. It is his view that most philosophical theories have tension between individuals and the community to which they belong: they have difficulties accounting for the interdependence of the entity and the whole which results in the dominance of one and the sacrifice of the other. It can be argued with some justification that

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[491] Heisenberg 1958, 40.

quantum field theory reawakens the central pre-Socratean problem of the relationship between one and many, even though, as the following quotations show, a clearer understanding of the relationship between particles and fields and its verbal explanation on the basis of mathematical theory is not without its problems:

> "A field quantum is a discrete increment in a mode of field excitation and it is more often called a particle. In ordinary usage, a particle is paradigmatic of an entity to which we refer as the subject of proposition. It is a spatial unit and it is relatively noninteracting with other entities. These two features give it a distinctive individuality that enables us to pick it out even when it enters into mild relations. Field quanta, alias particles, are relatively noninteracting but they are not spatially located. They also lack numerical identities. ... If an entity is this something, then field quanta are not entities." [493]

The fact that particles emerge automatically from the application of quantum principles to fields can be seen as one of the great triumphs of quantum field theory. At the classical level, as well as at the level of quantum particle mechanics, identity among the basic building blocks had to be postulated and particles and fields considered to coexist in equal terms. At the quantum level, since particles emerge on their own as the quanta of fields in identical copies, it can even be argued that the fields are primary.[494] Quantum field theory has also been viewed as signifying a return to ancient way of thinking because the Newtonian concept of an empty state has been proved to be an error. Auyang describes a vacuum as a state in which no field quantum can be found. It is not nothingness but a definite state of the field, the state in which it has lowest energy. He believes that:

> ”Field theories present a full world. The idea is not new; fullness was intuitive to the ancients and emptiness was not. The ontology of ponderous bodies moving in empty space gained currency only with the triumph of Newtonian mechanics. It was rejected by many of Newton’s contemporaries, including Descartes and Leibniz.”[495]

The problem of emptiness and fullness handled already by antique thinkers has been highlighted by the Finnish physicist K.V.Laurikainen, who considered the question to be as yet unresolved. According to Laurikainen, in modern quantum field theory, which has been constructed on the basis of the special, not the general, theory of relativity, there is no empty space, just special fields which are said potentially to be also in a void. The theoretician conjures different kind of

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[492] Auyang 119 and 121-2.
[493] Ayang 1995, 158.
[494] Treiman 1999, 231-235, 252.
[495] Auyang 1995, 120, 159.

particles out of these fields using special particle-creation operators and destroys them using destructive operators. A void is a state in which there is nothing left to destroy. It is important to note that the field concept in this theory requires a concept of time and space. Field properties are functions of time and position, and fields can change in relation to these. The theory does not however answer the explicit question of whether time and space exist without fields.[496]

There are no simple answers for this kind of fundamental ontological questions. Even though discussion of the problem of interpreting quantum mechanics has now continued for almost a hundred years, a generally-acceptable interpretation of ”wave function (or state vector)”, which is the basic term of the theory, has not yet been agreed. This mathematical construction makes it possible to predict the probability of all the particular results which can be manifested, but a corresponding physical entity to wave function itself can never be directly observed. The wave function has been presented as depicting multi-dimensional transcendental reality or the distribution of possibilities in that kind of reality. Several physicists have said they believe that state vectors operating in a complex state-space have a completely objective meaning[497], but on the other hand, many have ignored any need for interpretation by stating that the wave function is just a mathematical instrument. Interpretations which make clear reference outside the observable space-time are considered to be non-credible, because they demand a radical reassessment of the prevailing conception of reality. Even though quantum mechanics has proved classical physics to be inadequate, classical metaphysics holds fast. The new concept of state, however, means that the quantum-mechanical portrayal is totally different to the classical portrayal, in which material phenomena are described by discrete particles moving in space-time. In spite of the abstract nature of state vectors, many of their features are however manifested in reality as concrete and observable phenomena.

4.2.1. The complex state vector, observables and properties

In quantum mechanics, the system that is being studied is described by a wave or state function which is dependent on the whole experimental arrangement. This function includes all the

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[496] Laurikainen 1973, 180-184. Laurikainen believes that the concept of space does not have a clear meaning in the realm of elementary particles since general relativity, a non-linear theory, is not compatible with linear quantum mechanics.

[497] Auyang 1995, 68. For example R. Penrose and J. Polkinghorne assume that physicists generally consider wave functions to be real.

possible states of the system, and these can be calculated to develop in a deterministic manner in a mathematical state-space. In a measurement situation, the quantum system is however ”projected” onto normal space and the result obtained is one of the many possible presentations of the system and a realisation of one of its possible values. For example, the system being investigated can, if required, be localised in a single position, but measurements naturally cannot provide knowledge about whether particles have positions other than those which result from specific interactions.

In classical physics, the state means a system’s space-time situation, its position and its velocity in space at a specific moment. Examination of the fundamental equations of quantum mechanics shows that quantum theory employs a definition of state that is quite unlike that employed by classical mechanics.[499] The state function in quantum mechanics does not bestow any specific position or momentum on particles.[500] It cannot be thought of as describing more a particle than a wave[501], and the state vector’s relationship to the classical concept of an object remains obscure. Also, the thought that an object ”owns” even its primary properties becomes a problem when no clear and observable properties can be attached to the wave function itself, only the possibility of different observable realisations in different interactive situations. Dirac characterised the new situation produced by quantum mechanics by saying that ”an observable introduces a set of basic states in which the characteristics of a state can be revealed.[502]

While all observables in quantum physics are represented by self-adjoint operators on the state space, not all self-adjoint operators represent observables. Among the infinitely many self-adjoint operators in a Hilbert space, physicists use no more than a handful.[503] In quantum mechanics, if the eigenvalue of an operator can be measured, it corresponds to an observable.[504] Since a state vector can be treated as a sum or organised source of different kind of observables, quantum mechanics is often presented as indicating that the different objects and phenomena which influence the macroscopic world are fundamentally indivisible and profoundly interdependent.

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[499] Nagel 1961, 306. The state-description employed in quantum theory is extraordinarily abstract. The so-called Psi-function does not lend itself to a intuitively-satisfactory non-technical exposition.

[500] Velocity does not have a clear role at the micro level and momentum cannot be considered to be classical, but the relations to energy are similar to those at classical level. Hodgson 1991, 258-260.

[501] When introducing students to the handling of quantum physics, they are told: “We have abandoned the notion of a wave packet as representing a particle. This notion was helpful to us in making the Schrödinger equation plausible, but now it is $\Psi(x,t)$ and its probabilistic interpretation that tell us where the particle is, without the particle being thought of as 'made up out of waves'." Gasiorovits 1974, 54

[502] Quoted in Auyang 1995, 20.

[503] Auyang 1995, 87.

Many of the problems of interpreting state vectors are connected with the fact that quantum characteristics are irreducibly complex. This is explicitly evident in the Schrödinger equation and other fundamental relationships such as commutation. If, as Sunny K. Auyang believes, state vectors depict real complex quantum objects, the complex nature of quantum-state space is neither an accident nor a mathematical convenience. The entire complex state vector is significant. Its meaning is destroyed if we try to separate the real and imaginary parts. Auyang believes that quantum objects and quantum properties really exist at the quantum level, and argues on their relationship with observed observables and their eigenvalues as follows:

> ”In classical mechanics a particles position and momentum assume defined values in certain coordinate system. The same holds for quantum systems. But there are differences. The state space of quantum mechanics has a richer intrinsic structure. The Hilbert space has a built-in metric structure embodied in the inner product which enables the quantum state to internalize coordinatization as a kind of relation among states. Thus quantum properties can assume definite values in bases or coordinate systems defined within the state space itself. The most interesting bases are associated with observables. The basis of an observable A constitutes a representation of a state vector.”[505]

Because of their complexity, quantum observables should not be confused with their classical namesakes. For example, quantum momentum has a richer structure than classical momentum and some observables such as spin have no classical counterparts. The quantum predicates of amplitude also describe characteristics more complicated than can be handled by the classical predicates of eigenvalues. A specific eigenvalue a_i , has the unique significance of being the one that can be found in experiments on a single system, but there are great objections to ascribing it as the property of a quantum system. The nature of eigenvalues conflicts with that of state vectors, which claim to be summaries of quantum properties; the one is real and the other is complex. A state vector also has its governing equation of motion, a specific eigenvalue that is determined by experiment does not. State vectors are not kickable within quantum mechanics: we cannot manipulate a quantum system to obtain a specific eigenvalue in an experiment. Only in special cases analogous to the eigenstates can a quantum system be "aligned" in such a way that a classical predicate becomes a good abbreviation.[506] Because of the difficulties, Auyang concludes that eigenvalues should not be considered properties of quantum objects. The explicit stipulation of some quantities that can be measured justifies the name “observable”, but

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[504] In principle for each possible observable can be constructed its own operator.
[505] Auyang 1995, 68, 73.
[506] Auyang 1995, 19, 80.

eigenvalues or spectral values are only parts of the structure of observables. Their relationship remains unexplained.

> ”Abstractly, the eigenvalues of an observable can be regarded as labels of the eigenstates. Physically the labels are realized in classical objects we can measure. How they are realized no one knows. Eigenvalues are analogous to symptoms of a disease, they indicate something that does not show up. Unlike amplitudes, the occurrence of an eigenvalue needs the extra condition of classical realization. Practically, an indicator is somehow triggered in measurements and experiments. Unperformed experiments have no results, but this does not imply that the quantum systems on which the experiment might have been performed has no properties.”[507]

In quantum mechanics, phases are also important. To describe a state more definitely we have to use representations which reveal that state's relations with other states. The relation is contained in complex relative phases which account for the peculiar phenomena associated with quantum mechanical interference. That is why we need complex numbers c_i instead of their moduli $|c_i|$ when expanding the state vector. The set of moduli is truly measured, but the relative phases are somehow destroyed in experiments; exactly how this happens we do not know. Measurements always return to real numbers into which complex numbers cannot be homomorphically embedded. It is like trying to squeeze a three-dimensional something into a two-dimensional plane: some damage is unavoidable. The reduction of a multi-dimensional quantum description to nothing more than the checking of attributes (eigenvalues) is not due to our clumsiness, the cause is more basic. It may be due to the fundamental limitations of our form of observation. Specific representations are necessary for us to acquire empirical knowledge of the objective world.[508] Humans clearly cannot investigate quantum states other than by individual coordinatization, which they themselves may influence:

> ”An observable coordinatizes the quantum world in a particular way with its eigenstates, and formally correlates the coordinate to classical indicators, the eigenvalues. An observable introduces a representation of the quantum state space by coordinatizing it. Within the representation a quantum state acquires a definite description in terms of amplitude. It realizes a general conceptual distinction of physical state and its specific representation. An amplitude is ascribed to the quantum system only with the choice of a representation, just as coordinates are assigned to a classical particle only in a coordinate system.”[509]

The indispensability of observables and the representations they introduce is apparent in quantum mechanics. The representation-free form of a state space M of a physical system is too

[507] Auyang 1995, 79.
[508] Auyang 1995, 74.

abstract and by itself insufficient for physical theories, since the theories must predict the behaviour of particular objects so that they can be supported by experiments. M, being a total abstraction from all particularities and observational conditions, is newer observed: observations are always of particular representations of M. What we observe in experiments is characterised by initial and boundary conditions that are expressed in coordinates, but to say that observables are conventional does not imply that they are phantasmal. Once an observable is chosen, its eigenstates that realize the coordinate bases are as physical as any other state, and the classical quantities that realize its eigenvalues are concrete. Thus the conventionality of representations does not lead to relativism. Quantum mechanics prescribes rigid transformation rules among the various representations that leave the quantum state invariant.[510]

An attempt can also be made to visualise the abstract relationship between quantum states and observables by employing the language used for wave functions. As has already been pointed out, in quantum theory the wave function of the system under investigation can always be presented as an expansion of the desired wave-types. In this way, different families of waves correspond to different physically measurable attributes.[511] A fixed spatial position is associated with a momentum wave. Momentum is associated with spatial sine waves, and energy is connected to temporal sine waves. Spin is connected to spherical-harmonic waveforms. Waveforms and the connection with their attributes tells us why some attributes are quantised and others are not. Quantised attributes are connected to restricted waveforms such as spherical-harmonic waves whose vibrations are limited to the spherical surface. Clearly, each possible waveform corresponds to some dynamic attribute which can, in principle, be measured. The number of different waveforms is infinite.

This can lead to the conclusion that quantum theory does not directly describe independent objects in space-time any more than it describes their enduring attributes. With the help of quantum theory, a desired object can be connected to a wave function whose form incorporates information about all the possible observable attributes of that object. Observable attributes are not however manifested without interaction or measurement. During measurement, the wave function is cut to the wave expansion of the desired attribute in which each term has its own amplitude. The square of this amplitude gives the probability that the value in question will be

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509 Auyang 1995, 85-86.
510 Auyang 1995, 87, 96.
511 Herbert 1985, 102. Quantum entities have two kinds of properties: static and dynamic. For example, mass, charge, and spin are static, while position, momentum and the direction of spin are dynamic.

reached if measurement is carried out. It is truly strange that real measurements reinforce the probabilities that quantum mechanics predicts.

Whether the abstract quantum-mechanical state function describes a real quantum object, a world of possibilities, knowledge of the observer or anything else, this mathematical construction connects concrete observations of real phenomena in many ways which are impossible to comprehend within the framework of reality provided by classical physics. These confusion-causing and difficult-to-interpret features of quantum mechanics are examined more closely in the following section.

4.2..2. Discontinuity and wave-particle dualism

In classical terms, the world was assumed to be made up of separate mechanically interacting objects which had different objective properties such as size, mass or velocity. In principle, these properties could be assigned any values, and changes in them from one state to another were believed to take place in a continuous manner through all the intermediate stages. The discovery that the interaction of matter and radiation was connected with a new universal constant, Planck's constant *h*, set a limit on the minimum size of any effect and at the same time made some atomic particle states discontinuous, i.e. quantised.

In quantum mechanics there is a certain probability that an electron in a hydrogen atom, for example, can be found in one position, and there is also a certain probability of it being in another position. Electrons no longer have orbits but physicists often speak of ”electron clouds” that are of different sizes and shapes. These configurations are known as quantum states.[512] Different states are associated with different energies. When an atom's energy changes, the electron makes a transition between two different states. In doing this, the atom emits or absorbs a light quantum (or photon), whose energy corresponds to the difference between the energy states. The atom's transference from one stationary state to another cannot however be visualised in space-time. The change is usually presented as taking place in a quantum jump, in which

[512] Morris 1997, 93. Subatomic particles are in general considered to be in mixtures of states. One can speak of the probability of a subatomic particle being in this or that state. Not only is an electron in many different places at once, it can simultaneously occupy an infinite number of different energy states.

internmediate states are impossible.[513] In micro-physics, we also encounter new quantised properties such as spin, charm and strangeness. Although these are properties whose conservation in particle reactions is confirmed, it is difficult to construct a clear understanding of their fundamental nature.

Arthur March, a German professor of physics, tried to conceptualise the ideas of the Copenhagen school on the foundations of quantum mechanics in a clear and careful manner. He reflected the new situation in his remark that any phenomenon that occurs in the micro-world consists of elementary processes or acts which, by virtue of natural law, cannot be analysed. Hence, the micro-world is by nature atomic not only in respect to matter but to events as well. We shall never know what happens in an atom during the process that leads to the production or annihilation of a photon. The emission or absorption of light as well as the scattering of a photon by an electron are examples of elementary processes or acts which resist any attempt to analyse them. We cannot therefore apply the principle of causality to these processes. The atomicity of events appears to us as a discontinuity in the course of events, and only probability relations exist between present and future.[514]

This situation can also be illustrated by saying that the wave properties associated with particles make the earlier deterministic space-time description impossible: particles are not only mechanically interacting objects that can be idealised as mass points. At the same time, waves make possible probability forecasts concerning atomic events.[515] Categories of reality previously illustrated using separate wave and particle metaphors now appear to be in some way linked. An clear and visualizible representation of the new connection between particles and waves or matter and radiation cannot however be found in the classical ”billiard ball” world. Particles are located at specific points, but waves spread throughout the whole of space. Also, quantum field theories cannot claim credit for visualisable clarity, through which the connection between waves and particles has anyway become increasingly clear. In quantum field theories, all elementary particles are considered to be quanta in the fields that they are connected to. For example, a photon is understood as a quantum in a electromagnetic field which mediates

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[513] This strange situation can somehow be visualised by using the simple example of the waves on a string. There are always some positions where the string is at rest. We can see how the wave-like properties of particles lead directly to ’energy quantization’ without solving the Schrödinger equaton. Hey and Walters 1987, 42-44.

[514] March 1951, 1-3 and March 1957, 47-50.

[515] Laurikainen 1993, 155.

electromagnetic interactions between electrically charged particles.[516]

The probabilistic structure of quantum mechanics incorporates the possibility that a particle can be found in locations that are absolutely forbidden to it in the classical world. In classical terms, there can be an energy barrier which separates one region of space from another so that particles below some energy threshold cannot move from one region to another. What is remarkable about quantum ’particles’ is that they do not behave like classical objects. There is a finite probability that they are able to ’tunnel through’ the forbidden region and appear on the other side. This ’barrier penetration’ or ’quantum tunnelling’ is responsible for nuclear fission and the burning of hydrogen in stars. In modern technology, it is a commonplace quantum phenomena that forms the basis for a number of electronic devices such as new type of microscopes.[517]

The developers of quantum mechanics were confused by the fact that atomic objects were described in some experimental situations as being particles and in others as being waves. In mathematical representations of a studied system, for example, an electron could be associated with a certain individual waveform whose form allowed the calculation of its position probabilities. When an individual electron is observed, it always appears as a localised particle. Groups of electrons are, on the other hand, usually considered to be cooperating with each other in making waves. In Young’s double-slit experiment, where an electron beam is directed through two thin slits, the diffraction pattern formed in the shade is similar to that observed when investigating the diffraction of light waves. The intensity distribution obtained can be explained by assuming that the waves passing through both slits interfere with each other. In the diffraction pattern formed in the shade, individual electrons strike in those places where waves diffracted through the neighbouring slits reinforce each other (are in phase), while places where the diffracted waves are out of phase remain dark.

The intensity distribution obtained from the double-slit experiment clearly differs from the patterns which result when the individual patterns obtained by opening one slit at a time are combined. When particles are allowed to pass through the two open slits one at a time, the diffraction pattern gradually built up in the shade is the double-slit interference pattern, not the pattern obtained by superimposing the patterns obtained by opening each slit in turn. In

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[516] Quantum field theories deal with two kinds of interacting fields. The quanta of matter fields are fermion-type particles and interactions or forces are transmitted by fields which consist of bosons. Particles and fields form one dynamic whole in which differentiation between force and particle is not significant.

[517] Hey and Walters 1987, x, 53-59. Treiman, 1999, 10.

circumstances where this experimental situation which demands a wave-picture has a particle-picture applied to it, the easy conclusion is to think that each individual electron which can pass only through one slit or the other must have advance “knowledge” of the existence of the other slit in order to be able to strike in the specific location allowed by that experimental situation. The basis for the coherence that is manifested in quantum-mechanical systems, i.e. cooperation between particles, is the superposition of wave functions or state vectors.

Wave-particle dualism means that the classical concept of particles must be abandoned. Electrons and other postulated elements are usually still characterised as ”particles”, but this characterisation is based on what are at best only partial analogies between the mathematical formalisms of classical and quantum mechanics. On the basis of present-day knowledge, it is impossible to say whether atomic objects are fundamentally particles, waves, a combination of these, or something completely different which cannot be addressed using classical terminology.[518] The illusion that the world is made up of separate objects resembling billiard balls which travel along specific orbits no longer works at the microscopic level, since particles resonate and interfere in the manner of waves. Consolidation of the concept of waves and particles in the same object is clearly impossible if one is not ready to abandon either the concept of particular independent objects, or the assumption of the primacy of the space-time description.

4.2.3. The principle of uncertainty and complementarity

One of the most significant experimental features of quantum mechanics is that all observables corresponding to operators do not commute with each other. Unlike classical variables, observables can be incompatible with each other.[519] These canonically-conjugated values of parameters cannot be defined precisely simultaneously. Also, since their probability distributions are interdependent, they cannot, without problems, be considered independent of one another.[520]

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[518] Selleri 1990, 107. Nagel 1961, 299, 304. Nagel points out that the words ’position,’ ’momentum,’ ’particle,’ and ’wave’ in quantum mechanics must be recognized as borrowings from classical physics. When these words are employed in the new context, they must be understood in terms of the restrictions placed on their use by the postulates of quantum theory.

[519] Auyang 1995, 16.

[520] Maalampi and Perko 1997, 103, 124.

The best-known example of this is Heisenberg's 1927 discovery of the limitation connected with the measurement of position and momentum. He demonstrated that, in principle, the position of a particle can be measured to any required degree of accuracy in quantum mechanics if a sufficiently-short wavelength is employed. In doing this, however, knowledge of the particle's linear momentum becomes increasingly imprecise. The Uncertainty relationship

$$x \; p \geq h$$

states the precision with which both position and linear momentum can be concurrently defined. Since the inaccuracy of the measurement result cannot be reduced below the magnitude of *h*, it is never possible to determine both properties accurately at the same time. The Principle of Uncertainty is not, as has on some occasions been interpreted, a consequence of unavoidable disturbance to the system resulting from the act of measurement. The question is that of a limitation in principle which is actually a consequence of formalism, one which cannot be solved by development of the measurement system employed. It is more possible to say that the uncertainty relationship follows from the system's internal ”inexactness”, a consequence of the nature of waves, or stated more precisely, a feature of reality which wave descriptions reflect. From the human observer's point of view, the uncertainty relationship naturally also manifests as a limitation on the accuracy of measurement. From the point of view of the system under investigation, the limitation can however be viewed as a guarantee given by nature that its spectrum of possibilities can never be reduced below a specific quantity. When the number of positions available to a system using a specific method of measurement is reduced, the values of momentum that are possible are automatically increased.[522]

[522] Herbert 1985. In general, when a certain wave shape resembles some fundamental wave form, it is easy to present it as a sum of these forms. The resulting expansion contains relatively few terms (minimum spectral width). If one desires to express a certain wave shape with the aid of very different waves, many terms are required (maximum spectral width). When two wave forms such as W and M are in a certain way opposites, their spectral widths obey the rule $\Delta W \, \Delta M > 1$.

Since it is not possible to accurately know both the position and linear momentum of a particle, it is also not possible to precisely define that particle's path. Knowledge of a path requires precise data concerning both the particle's position and its velocity at every point.[523] The objectivity of classical physics is based on knowledge of the path. Recognition of paths was a requirement for the idea that the studied system, or the
world, could be thought of as being describable exactly as it was, objectively and without any disturbing effect. When, in microphysics, this proved to be impossible, Einstein, for example, who adhered to the classical framework of description and the idea of a detached observer, judged quantum mechanics to be incomplete.

In classical physics, all observables commute and can always be assumed to have precise values. As a result, the question of the meaning of undefined or partly-defined operators never arose, and there were no problems related to the ontological status of the mechanical concepts: they were believed to be a true representation of reality. [524] When generalised Heisenberg Principle of Uncertainty implies that when properties appear together as a conjugated pair, part of the system's attributes always remain unknown. Since all the attributes and properties that it is possible to link to the system cannot be explicit (precise) at the same moment, the whole richness of a quantum-mechanical system cannot be revealed at any single moment. [525] In the light of the uncertainty relationship, it is possible to hold fundamental doubts whether dynamic properties even exist without the observer's influence. To observe specific attributes, it is necessary for us to measure them. Our choice of measurement system effectively forces the system into manifesting itself in a specific way. In this way, the existence of human actions changes the world in a way that it becomes possible to think that physics does not investigate nature as it is, as it actually exists: it examines nature as it presents itself to a human investigator.[526]

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[523] The Zeno's paradox discussed in antiquity can be seen as a kind of macroscopic analogy to the uncertainty relation. Zeno concluded that a flying arrow must at every moment be somewhere and that if it is in a certain position it cannot be moving. Even if the path of the arrow is divided intoan infinite number of small regions, the fact that two neighbouring points could be observed meant that motion could not be achieved. Nörretranders 207-214.

[524] Petersen 1968, 148.

[525] In quantum mechanics, energy and time are also linked. When one of the two is defined precisely, imprecision in the other cannot be avoided. This gives an 'explanation' for tunnelling. The energy of a particle may occasionally deviate. By borrowing energy a particle is able to proceed to a previously forbidden area. Greene 2000, 132-133.

[526] March 1957, 106-108.

In contrast to what is often claimed, Bohr and Heisenberg warned against interpreting the uncertainty relationship as nothing more than disturbance caused by measurements.[527] They stressed that the uncertainty relationship set up a limit beyond which our attribute-describing concepts do not work. This was not just a question which concerns the ambiguity of our observations or our knowledge because it signifies that specific mechanical concepts lose their accurate meaning in the microscopic world. They no longer appear as clear measurable magnitudes.[528] It is possible to speak about position and momentum, in accustomed way, only at the macroscopic level. If an attempt is made to define both of them with complete accuracy at the same moment, we are trying to get hold of something which does not exist. In quantum mechanics, even if *p* and *x* are called coordinates of ”momentum” and ”position”, the words are being employed in an unusual sense. In contrast to classical mechanics, quantum theory does not legislate about the usage of words stating that it is possible to establish both position and momentum with unlimited precision.[529]

At least in the beginning, Heisenberg believed that the consistent formalism of quantum mechanics was adequate for the explanation of atomic phenomena. The theory provided limits on what could be observed, and since classical concepts such as position and momentum could no longer be handled precisely, it was only necessary to accept that classical concepts no longer applied in the atomic field.[530] This interpretation, i.e. that the uncertainty relationship defines the restrictions on the scientific applicability of classical concepts, is supported, among others, by Victor Weisskopf, in whose opinion philosophical discussion regarding uncertainty within nature could have been be avoided if the uncertainty relationship had been named the “limitation relationship”.[531]

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[527] Their views are often misunderstood. For example Mark Buchanan (*New Scientist* 6 March 1999), when reviewing new results on entanglement which agree with Bohr’s and Heisenbergs assumptions, claims that they based their ideas on the wrong view that measurements cause disturbances.

[528] March 1957, 112-115.

[529] Nagel 1961, 301.

[530] Heisenberg when interviewed by T. Kuhn. See Folse 1985, 95.

[531] Weisskopf 1990, 49.

In contrast to Heisenberg, Bohr did not consider mathematical consistency to be the most important value. He wanted to achieve a deeper understanding of the uncertainty relationship and wave-particle dualism by believing that these features in some manner reflected the structure of reality. As will be described in greater detail in Section 4.4.2, Bohr wanted to hold on to classical concepts and he searched for new connections between them and reality by employing the idea of complementarity. He considered the uncertainty relationship to be a mainstay of the doctrine of complementarity, and thought that in the same way that descriptions of position and momentum in quantum mechanics are complete in themselves and modifiable to each other by employing Fourier transformations, classical descriptions and concepts such as the particles and waves employed in describing atomic systems are perfectly suitable in specific experimental situations. Simultaneous employment of such complementary type descriptions was not however possible, since quantum theory did not permit experimental situations in which both aspects of such systems could be defined exactly at the same moment. In this sense complementarity has a clear physical meaning.

Following a long discussions with Bohr, Heisenberg also recognised that even though our classical language does not work at the atomic level, we are not able to abandon it.[532] Even though the world is not divided into parts in the way we have learned to become familiar with on the basis of our experiences at the macro level, we do not have any better tool than natural language to describe our experimental observations. However, the uncertainty relationship did make clear the fact that the concepts of Newtonian mechanics were not, on their own, adequate for quantum mechanics, since the position and velocity of particles could never be known with absolute precision. At the same time, it became clear that all the attributes associated with a system in all its different situations could never be known at one time. The uncertainty relationship is also linked to the statistical predictions given by quantum mechanics. For example, the exact decay time of a radioactive alpha particle cannot be defined precisely because if it could be, alpha particles could not be also understood as waves leaving the atomic nucleus, something which can be experimentally demonstrated. Paradoxical tests of this type which expose the wave and particle nature of atomic matter compel us to be satisfied with the statistical conformity to laws.[533]

4.2.4. Non-locality and entanglement (Quantum co-operation)

[532] Folse 1985, s. 90-97.

In addition to conjugated variables, a new coherence or internal relationship between the parts of a system is manifested by non-locality. In quantum mechanics, particles which once belonged together but are now located far apart are correlated with each other, in a manner which traditional theories are not able to predict by presuming that reality consists of locally-interacting separated parts.[534] This holistic feature of quantum systems, which Albert Einstein criticised via his EPR paradox argument, has now been the subject of experimental confirmation. In the 1990s, experiments conducted on interference phenomena between different states of individual particles gave rise to increased discussion of non-localised entanglement.[535]

If a multi-particle situation can be recorded as the result of individual particle states, the quantum states of the particles are independent of each other. If this is so, each particle can be thought of as being in its own position in Hilbert space, and these states can then be measured without the measurement affecting other particles. On the other hand, if the states are entangled, a multi-particle state does not consist of individual particle states and a measurement which apparently concerns a single particle will actually affect the state of the whole system: measurement of Particle 1 followed by measurement of Particle 2 will not be the same thing as measurement of Particle 2 followed by measurement of Particle 1. The best-known example of entanglement is the two double-state particles which form an EPR pair.

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533 Heisenberg 1955, 25-27.
534 Omnes 1999, 228-230.
535 See Quantum Challenge.

In the EPR state, the wave function is formed out of the non-separable superposition of both particles. According to the formalism, the parts of the system are correlated and observing one particle has an instantaneous effect on the other particle, regardless of the distance that separates them. Objects which have once been interacted with are no longer completely isolated, they are internally connected with each other in a manner incomprehensible to classical physics. This new feature of quantum mechanics allows new options for example for the storage, transfer and handling of information. It is believed that superposition phenomena and entanglement can be exploited in quantum computers by coding information to two states quantum-mechanics systems, i.e. as quantum bits. In this conditional logic, a change in state of one bit is dependent on the state of the other and as a result of the operations the states of the quantum-bits become entangled. In quantum calculations, on the other hand, entanglement is also a severe problem, since if the quantum computer is not located in a totally isolated situation, a quantum computer and the state of its environment will be entangled by virtue of their interaction. In such a case, the quantum system would move from being a pure state to a mixed state and part of the information it contained would be lost.[536]

The Copenhagen group clearly recognized and drew serious attention to this novel holistic feature inherent in the world described by quantum mechanics. Bohr debated it for decades with Einstein, who did not accept Bohr's thinking that quantum mechanics required a radical renewal of the framework of description employed by classical physics and wanted to hold on the traditional objective, deterministic and localised
concept of reality. The result was a decades-long debate conducted at scientific conferences and in private correspondence.[537] Although the controversy concerned the consistency and completeness of quantum mechanics, its foundation was a difference in conceptions of reality.[538] During the dispute, a majority of physicists considered Bohr's position to be the more durable one, even though in Einstein's own time, his stubbornness had some justification. In the light of subsequent experimental work, the holistic features of quantum mechanics and their ontological implications are much harder to deny. Even today, opinion is however not unanimous about whose arguments won the day.[539]

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[536] The impediment resulting from decoherence typically grows in an exponential manner related to the size of the quantum system. For this reason, it is difficult to observe or build macroscopic quantum systems.

[537] The debate is discussed in more details in Section 4.1.1.

[538] Hooker 1972, 77-78.

[539] Beller and Fine 1994, 29.

Einstein presented the EPR paradox in 1935 in collaboration with his young colleagues Boris Podolsky and Nathan Rosen.[540] They presented a thought experiment which was taken to demonstrate that the statistical predictions of quantum mechanics did not address all the elements of reality, and thus the theory could not be complete. In simple terms, the EPR paradox can be presented as follows. Particles are being examined in an experiment which breaks them into two parts of equal size. In accordance with the laws of conservation of energy and momentum, the resulting particles fly in opposite directions at equally-great velocities. When either the position or momentum of one of the particles is measured, the corresponding property of the other particle becomes known. According to quantum mechanics, a system's properties do not have precise values before they are measured. Einstein considered that this assumption had to be incorrect as it would be absurd to presume that measuring one of the particles could instantly give birth to the corresponding property in the other particle.

Einstein's argumentation was not accepted by Bohr, who considered quantum theory to be complete and emphasised the indivisibility of quantum phenomena and the fact that the whole experimental system should taken into account.[541] Correlation phenomena between particles which had once belonged to the same system were understandable by thinking that the particles in some way also at a later
point in time were connected together. The problem was struggled over for a long time. There was no desire to abandon the requirement for classical locality, even though matching this to quantum theory had been problematical from the very beginning. In 1964, John Bell succeeded in casting new light on the EPR situation and presumptions of locality. He started from the traditional realistic assumption that a local objective reality existed and worked out a specific formula concerning the correlation between particles flying in opposite directions, something which experimental observations should confirm, if the initial assumptions were correct. When quantum mechanics gave different predictions for correlation, local hidden-variable theories and quantum mechanics could be tested against each other.

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[540] A more-detailed description of the paradox can be found, for example, in the introductory chapter of J.T. Cushing and E. McMullin (ed.) *Philosophical Consequences of Quantum Theory, Reflections on Bell´s Theorem* or in Bell's article *Indeterminism and Nonlocality in Mathematical Undecidability and the Question of the Existence of God* (Ed. A. Driessen and A. Suarez)1997, 83-93.

[541] For Bohr's account of the discussions, see Bohr 1949, 32-66.

Precise measurements of correlation were made by John Clauser and Alain Aspect, among others.[542] According to these, it became obvious that the results predicted by quantum mechanics were correct. This was a strong argument in favour of non-locality. Most authors commenting on Bell's theorem have adopted the view that the empirical violation of Bell's inequality has demonstrated that quantum mechanics is of necessity non-local.[543] For example, Abner Shimony says that quantum mechanics is undoubtedly a non-local theory when it treats correlated spatially separated systems. His view is that this does not demand modifications to the causal structure of space-time, but rather refining of the concept of an event and processes.[544]

If, however, one wishes to presume that the world is a classical one in accordance with the traditional view, a hypothetical mechanism should be added justifying an influence at a distance, in which a measuring instrument can instantly affect the readings of another measuring instrument.[545] Such models of the world are also possible, in the light of the experiments, where the objects involved are able to change their attributes as a result of influence by the environment. Since Bell's theorem is not based on quantum mechanics, it will presumably be valid even if quantum mechanics is replaced by a better theory at some time in the future. Such a future theory can be expected to contain some non-local features.

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[542] Clauser 1976, Aspect 1982.

[543] Stenger 1995, 121.

[544] Shimony1986,182.

[545] It has been suggested that influences exeeding the velocity of light or travelling backwards in time would transmit the signal but these kinds of model result in difficulties with theory of relativity and the principle of causality.

In the 1990s, when it became possible to make more accurate observations of individual particles and their quantum states, non-local phenomena associated with quantum systems once again became a subject of discussion. D.M. Greenberger, M.A. Horne, and Anton Zeilinger (GHZ) demonstrated the incompatibility of EPR's assumptions with quantum mechanics regarding only "perfect correlations". The GHZ theorem is even stronger than Bell's theorem since it works without resorting to an inequality.[546] In new experiments, the reality of the superposition of quantum states has been clarified. It is possible for particles to be put into non-local states in which they can be in several energy states at one and the same time. In such a case, it can be said that they as if possess several different identities.[547] The probability amplitudes of the states always interfere with each other when the particles can, in principle, follow different paths. Every attempt to establish which trajectory a particle is actually following destroys these delicate interferences.[548]

These recent results on quantum coherence are still often described as unexpected and counterintuitive[549], but they would not have surprised the Copenhagen group. Bohr stressed the uniqueness and indivisibility of different experimental arrangements and saw that this implausible non-locality is clearly anticipated by the formalism of quantum mechanics even if the results are difficult to understand within the customary framework of mechanically-interacting individual particles. A special form of quantum mechanical co-operation are the lasers. The emitted photons in a laser beam are all in phase - they are coherent and travel in the same direction. This is possible because the photons are 'bosons' and plenty of them can be in the same quantum state. The 'matter-like' particles - fermions - usually cannot occupy the same quantum state. If an atom, however, contains an even number of fermions they can behave like bosons. For example, liquid helium can undergo a Bose condensation at low temperatures and show remarkable 'superfluid' behaviour.[550]

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546 Pliska 1997, 102.
547 Haroche 1998, Buchanan 1999.
548 Buchanan 1999, 28.
549 S. Haroche, "Entanglement, Decoherence and the Quantum/Classical Boundary." *Physics Today*, July 1998.
550 Hey and Walters (1987) 109-118.

Phase entanglement associated with quantum waves, something not observed in normal three-dimensional waves, has often been described by applying the idea of multi-dimensional space. Non-local correlations become understandable if particles or states observed in three-dimensional space are thought of as being different projections of a certain waveform which belong to the multi-dimensional space.[551] On the other hand, the multi-dimensional configuration spaces required to depict a wave function are evidently the main reason why wave functions are not generally taken to be real objects.

4.2.5. Indeterminism, irreversibility and the measurement problem

Classical physics presupposed that one can always in principle determine the state of a physical system to any desired degree of accuracy by measuring certain quantities. Measurement was thought of as simply revealing some objective fact concerning the world to a detached observer. Measurement either caused no disturbance to the system being examined, or the effect of the disturbance could be controlled.[552] However, as humans could not obtain direct observations of atomic phenomena, some type of experimental equipment was required which interacted with the system under investigation. In quantum mechanics, when a system of exceedingly small mass is under consideration, the state of the object is disturbed by the measuring process in an unpredictable way and the state loses its determinacy relative to other quantities.[554] Interactions always take place through changes in energy and momentum. The minimum quantity of energy that can be exchanged is a single quantum, and when states are quantised, interaction signifies that the state of the system will change in an unpredictable manner.

The fact that interaction between the measuring apparatus and the object is inevitable implies that the state of a system cannot be measured without being changed by the process of measurement. The nature of this ”disturbance”, the unpredictable statistical impact on the system somehow produced by the measurement

[551] Herbert 1985, 168-170. For example, David Bohm and Sunny Y. Auyang have emphasised multi-dimensionality.
[552] For example, measurement of length did not disturb the object and the error resulting from the measurement of electric current was calculable.

[554] March 1951, 1.

instruments, has been difficult to understand and conceptualise. The Copenhagen group described it as something inherent in nature, something that could not be overcome by better instruments or observation techniques. Because of it, interaction between the measuring instruments and the object under observation could no longer be either neglected or totally controlled. When referring to this phenomena, members of the Copenhagen group often spoke of it as quantum mechanics demonstrating the calamity of the causality principle, or of the "failure" of space-time descriptions. Philosophers of science have with good reason often criticized these unclearly stated and often annoying claims relating to the foundations of physics.[555]

Physicists familiar with mechanical determinism were not perhaps fully conversant with the terminology of the philosophy of science, or simply did not know the long and twisted history of the causality problem; that the word ’causality’ is in fact used to designate three principal meanings.[556] Even for philosophers, it is by no means easy to answer the question of whether quantum theory entails restrictions on determinism or on causality, because the answer depends not only on the definition of both of these terms but also on the interpretation of quantum theory that is chosen. It is, however, a common view that quantum mechanics drastically restricts the Newtonian form of determinism, according to which all physical processes boil down to changes of position of the point masses in space-time. Quantum theory incorporates a statistical component which cannot be eliminated. It is indeterministic in the important sense that its state-description is associated with a statistical interpretation and that its predictions are based on statistical assumptions. The theory naturally does not sweep out causes and effects, but it somehow alters the rigid causal nexus among them.[557]

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[555] For example Nagel 1961, 298-303.

[556] In short, causation means a causal connection in general and the causal principle states the form of the causal bond, whereas causal determinism or causalism asserts that everything happens according to a causal law. Bunge 1959,3-4.

[557] Bunge 1959, 14-15. Nagel 1961, 308.

Disturbance caused by measurement and the statistical predictions of quantum theory are connected to the already discussed discontinuity, which according to the Copenhagen group's way of thinking could be interpreted as indicating that any phenomenon which occurs in nature consists of some kind of elementary process which, by virtue of natural law, cannot be further analysed. The Copenhagen group were convinced that if quantum mechanics is correct, we will never know what happens in atom during the process that leads to the production or annihilation of a photon. The emission or absorption of light as well as the scattering of a photon by an electron are examples of elementary processes which resist any attempt to analyse them. In consequence, we cannot apply the principle of causality to the process, and it therefore appears to us as a discontinuity in the course of events.[558]

A consequence of the uncertainty relationship is that measurement possibilities in the quantum field are more restricted than in the classical one: canonically conjugated observables can only be measured within the limits that the uncertainty relationship allows. If an experimenter decides to measure a single property accurately, he loses the possibility of obtaining knowledge about other properties of the system. Since the measurement of one property affects the possible values of other properties, it is not possible for any measurement to be repeated.[559] Following each measurement, the distribution of future possibilities is changed. Bohr emphasised the fact that in quantum mechanics, measurement has an individual and irreversible character. Irreversible changes must also take place as a result of measurements in macroscopic experimental setups in order for humans to conclude that a measurement has even occurred.

Since any observation consists of an indeterminate interaction between object and measuring apparatus, it is also impossible to determine the exact initial state of the system. Without exact knowledge of the present, exact prediction of the future is impossible. This fact also implies the essentially statistical nature of quantum mechanics. Only probability relationships exist between present and future, and in quantum physics the concept of chance plays a role for which the methods of classical physics allow no room. Quantum mechanics considers it to be an established fact that in the observable world, something is at work which can be designed only as chance.[560]

[558] March 1951, 1-2.
[559] Kothari 1988, 18-22.
[560] March 1951, 3.

This does not, however, mean that quantum mechanics maintains complete indeterminism. The laws of quantum mechanics suffice for determining the probabilities of finding the system in a given state at a future time. We know something about the future but in many respects we do not know it exactly.[561] The probability of each possible event can be calculated on a theoretical basis. The observables of quantum theory are statistically predictable, but, except in pure cases, quantum mechanics is not able to predict with certainty what values a given variable will assume upon measurement - for example which transition will happen in an atom or which nucleons in a specific radioactive sample will decay in the next 60 seconds. If the subject of research is a large number of systems with the same initial conditions, the distribution of their possible final states is predictable. Quantum mechanics can be taken as a statistical theory[562] which, when stripped down to its very basics, deals with either one measurement of an infinite number of particles or an infinite number of measurements of a single particle.

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[561] March 1951, 9-11.

[562] Quantum mechanics is different from classical statistical mechanics as the latter is a deterministic theory. Statistical mechanics includes the assumptions of classical particle mechanics but its state-describtion is defined in terms of statistical state variables. In quantum mechanics, the ”positions” and ”momenta” are not the self-same traits of particles which in classical mechanics are subject to precise numerical determination. The Psi-function of quantum mechanics employs a definition of state quite unlike that employed in classical mechanics. Quantum theory is ”indeterministic” in the important sense that its state-description is associated with a statistical interpretation and that its predictions are based on statistical assumptions. Nagel 1961, 290-291, 305-308.

Even if, at first sight, chance appears to be the very negation of determinism, it should be noted that chance also has its laws, and accidents emerge from pre-existing conditions. Games of chance do not follow the Newtonian type of law but follow statistical laws instead: they are statistically determined. On such a basis, it can even be argued that chance is not alien to determinism. Chance may in fact be a peculiar type of determination, because the principle of lawfulness does not require that every individual phenomenon should always occur in exactly the same way. Universal lawfulness is not committed to a specific form of determinism such as causal determinism or mechanical determinism. It is consistent with individual exceptions, with occurrences in a given low percentage of cases.[564] Bohr highlighted the fact that the determinism of classical physics was only an idealisation suitable for addressing situations at the macroscopic level whereas Wolfgang Pauli was fond of saying that quantum theory is indeterministic and that individual events "slip through" the net of physics.

While predictability is often taken to be a symptom of causality, or causation is even defined in terms of predictability, this may be unwarranted. Predictability is an epistemological category dependent on our knowledge, whereas causation is a mode of behaviour of things in the real world, an ontological category.[565] The common equating of causality with predictability is linked to the problem concerning measurements in quantum physics. In classical physics, the process of measurement could be described objectively from an external viewpoint by comparing the result yielded by measurement to a space-time portrayal or a model created by theory. Quantum theory, on the other hand, does not generate a model for the process of measurement. When the theory is applied to both the measuring apparati and to microscopic objects, the final state of the system will be a superposition of state vectors. This does not, however, represent a definite observable state. The final state should be a so called mixed state, but no transformations map initial pure states into final mixed states. The theory is thus not able to describe how it is possible to proceed from the uncertain and non-classical quantum realm to the stable and separable world of everyday experience.[566]

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[564] Bunge 1959, 13-14, 23. If chance has a place in the framework of determinism in the general sense, quantum theory does not lead to the bankrupty of determinism. Bunge sees as a widespread misconception that causality is regarded as necessarily mechanistic and that, conversely, mechanism necessarily entails causality. The mere existence of the Platonic and Aristotelian systems shows that causality need not be mechanistic. Mechanistic philosophy from Galileo to the Newtonians restricted causes to forces contrary to the richer but chimerical forms of causation imagined by Aristotle and his innumerable commentators. In actual fact, contrary to the causal system of Aristotle in which every motion requires a cause, Newton´s principle of inertia is openly non-causal and can be seen as a restricted version of the principle of self-movement. Bunge 1959, 107-110, 116.

[565] Bunge 1959, 326-327.

[566] Murdoch 1987, 113.

By assuming that theory corresponds to reality and that the observer is external to the object of research, physicists have traditionally assumed that a 'complete' theory such as classical or quantum mechanics should be applicable to microscopic objects as well as to experimental setups. Physicists have tried many ways of establishing substantive criteria for classicality within a quantum framework in order to provide a better treatment of classical characteristics. These include superselection rules, decoherence effects, systems with infinite degrees of freedom and generalised observables. Most distressingly, none of these appears to be satisfactory; and results lead to inconsistencies that cannot be resolved in an obvious way.[567] It is confusing that a theory which is founded on empirical evidence and which as an abstract formalism concentrates on predicting the results obtainable by measurement, is not able to provide an unambiguous description of how measurements should be handled within quantum framework. An increasing number of physicists have begun to suspect that this open problem of measurement may have far-reaching consequences for the possibility of recognizing an objective reality in physics.[568]

According to Instrumentalist thinking, the theory should not be expected to yield direct answers to questions of what type of world we live in or how the world behaves when measurements are not taking place. On the other hand, a realistic attempt to understand reality and interpret the theory might be able, at its best, lead to us reassessing our ideas about the ontological and epistemological relationship between human beings and the nature in which we exist, which we manipulate by our actions and describe in our theories. It is no accident that the measurement problem has become a central question in the debate concerning the interpretation of quantum mechanics and that the ideas concerning measurement and its significance are widely divergent. This subject is discussed in greater detail in Section 4.3.6.

4.3. The interpretation of quantum mechanics as a manifestation of change in the conception of reality

The birth of quantum theory resulted in consternation among several experienced physicists, and as a consequence, they found it necessary to question many of their earlier beliefs concerning reality. For example, in the opinion of Sir James Jeans (1877-1946), the universe began to be more reminiscent of a great thought than a great machine, and Sir Arthur Eddington (1882-1944)

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567 Auyang 1995, 82.
568 Mittelstaedt 1998, ix, 103.

saw that it had become clear that research in natural science was not targeting concrete reality, its descriptions only touched a symbolic world of shadows.[569] Both the theory of quantum mechanics and its first and still most generally accepted interpretation, the so-called Copenhagen interpretation, were shaped in the same environment of astonishment. In the 1920s, under the direction of Niels Bohr (1885-1962), the Copenhagen Institute collected together young talents such as Werner Hesienberg (1901-1976) and Wolfgang Pauli (1900-1958), who were, in the light of new experience, ready to re-evaluate the whole of the tradition of describing reality that had been dominant since the turn of the modern era.

The international and openly interactive atmosphere at Copenhagen, the ”Copenhagen spirit”, attracted many researchers for longer or shorter periods. By 1930, some 60 physicist from 17 countries had visited the institute[570], in which the revolutionary theory of quantum mechanics and its interpretation were developed hand in hand. Interpretation signified a radical departure from both determinism and the idea of humans as detached observers, things which had become familiar cornerstones of research in natural science. They were replaced by statistical laws and a reality partly dependent on choices made by the observer, in which the behaviour of microscopic objects was dependent on the experimental system employed.[571]

The founding fathers of the Copenhagen interpretation, who were also largely responsible for the construction of the theory, were convinced that quantum theory could not be satisfactorily interpreted and understood within the prevailing mechanistic and deterministic framework of classical physics. They proposed profound revisions to our ontological and epistemological approaches to reality. The ideas of Niels Bohr in particular represented a radical reconsideration of traditional metaphysics. In Bohr’s framework of complementarity, the role of the human observer and his position in reality is understood in a new way that completely reconstructs previous objective and dualistic approach based on the ideas of Descartes.

Bohr’s radical approach was challenged in many of the post-Copenhagen interpretations of quantum mechanics such as David Bohm’s causal interpretation or the many-worlds’ interpretation, both of which, even when conceptualizing a new world-view, aim to maintain familiar metaphysical presuppositions of determinism, reductionism and the detached observer.

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[569] Wilber 1985, 8,128. Quotations are based on books by Eddington (*Nature of the Physical World*, Macmillan 1929) and Jeans (*The Mysterious Universe*, Cambridge University Press 1931).
[570] Pais 1985, 8.
[571] Pagels 1986, 87.

Philosophers of science have often perceived these later interpretations as Realistic and in contrast, the basically Realist tendency of the Copenhagen group is ignored, and their ideas are often seen as either Positivist or Anti-realistic. Even if this label has some credibility when these ideas are considered within the classical paradigm of science, the Copenhagen group did not consider themselves to be Positivists. Against the wider perspective of natural philosophy, they can be seen as true seekers for wider understanding.

The Copenhagen group were explicitly attempting to understand the nature of reality. They abandoned the classical conception of reality but not because of Positivism. They realized that quantum mechanics implied changes to previous metaphysical presuppositions. From the Copenhagen point of view, the interpretation of quantum mechanics was not a question of Instrumentalism or Phenomenalism or even of Realism, it was simply a new conception of reality. In the light of their wider viewpoint, later interpretations appear as futile attempts to return to classical metaphysics by postulating unfounded auxiliary hypotheses. These post-Copenhagen interpretations can be seen in Kuhnian terms as efforts to hold onto a "normal science", i.e. classical metaphysics, even when new evidence actually demanded entirely new approaches.

From the long-sustained nature of the debate concerning interpretation, it is possible to conclude that philosophers were not very much better prepared than physicists to deal with the profound paradigm change that was being proposed. The Copenhagen group’s attempt to transcend the earlier framework of reference would have demanded a fundamental re-evaluation of familiar examination and classification categories, but philosophers were usually satisfied with an analysis based on their previous concepts. It was disclosed that the thinking of the Copenhagen group included Realist, Anti-realist, Kantian and Positivist features, but by using these conventional definitions and classifications, philosophy of science is not able to arrive at a position concerning natural philosophy in which the significance of the Copenhagen thinking can be evaluated within the context in which it was being argued. Even though, for example, investigation of Bohr’s doctrine of complementarity within different frames of philosophy of science cast light on his concept and was helpful in understanding it better, it would be more fruitful to examine the thinking of the Copenhagen group using the themes discussed within the western philosophy of nature and the corresponding metaphysical background.[572]

Correct conception of the matter has been difficult, because traditional theories of the philosophy of science have also been formulated within the classical paradigm of science and they attempt to hold onto the ideals of objectivity shaped by the theories of classical physics. By the familiar strategy of avoiding metaphysics, or forgetting their own metaphysical starting points, science and the philosophy of science attempt to investigate the world objectively, from an external viewpoint. As a research objective, detached intelligence forms a representation of the world whose formation is specified only by empirically observed regularities and logical rules. For example, the basic idea of empiricism is that science can only be objective if it is regulated by factors which can be examined in an independent manner, free of human influence, anthropomorphism and all normative judgements.[573]

The almost century-long debate concerning the interpretation of quantum mechanics has not yet led to a common view of whether quantum theory requires a renewal of the metaphysical foundation for describing reality. Even the question of whether the theory requires an interpretation cannot be replied to in an unambiguous manner not dependent on the assumptions adopted by a particular approach to the philosophy of science. There is however general agreement that the degree of interpretation of the theories can change. Physical theories should always be at least in part interpreted in order for being of any use in research. The minimal instrumental interpretation of quantum theory links the formalism to the possible experimental results with the assistance of quantisation and statistical algorithms.[575] All users of the theory are unanimous about how the system and operator are connected to the world of observations, but there are differing views concerning the need for an interpretation of the wave function - the most important term in quantum theory.

Theories which lack a comprehensive interpretation do not increase our understanding of the world. According to the realistic approach to scientific philosophy, physics has the specific task of explaining the structure of the world that surrounds us. Realists want to know why a theory predicts the correct results, i.e. which of the world's features does it reflect? With the help of an interpretation, an abstract theory can be used as some kind of map of reality. It provides a general framework of reference which helps us to understand the nature of new phenomena by employing already familiar concepts and analogies that belong to our world of experience.

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[572] Fo more concerning Bohr's interpretation, see Kallio-Tamminen 1994, 52-81.
[573] Hooker 1987, 202, 206. This kind of ideal situation was best available in classical astronomy. In general terms, the empirical method implies measurements and human intervention.

[575] Redhead 1987, 44.

Problems in interpreting quantum mechanics are closely connected to the foundations of our conception of reality and world-view. As the Copenhagen group saw, quantum mechanics offers much empirically based material which supports their radical attempt to break free of classical descriptions of reality. The new features of the theory discussed in the previous chapter of this book are inexplicable when they are examined against a background shaped by the mechanistic-deterministic conception of reality. The relationship between theory, interpretation and reality is however a complex tangle of problems. The same phenomena can be explained in several different ways, and definite ontological or epistemological conclusions cannot be drawn on the basis of physical theory. A comprehensive, empirically verified theory can, however, substantially restrict the number of alternatives that can be taken seriously. All attempts to interpret quantum mechanics require major changes to the world-view formed at the turn of the modern era. Their different aspirations and starting points imply that the solutions suggested significantly differ from one another.

4.3.1. The Copenhagen group's reconstruction of the classical frame of reference

The fundamental work on developing quantum mechanics carried out at Niels Bohr's institute in Copenhagen is clearly the result of close interaction between several people. The most important shapers of the interpretation can be considered to be Niels Bohr and Werner Heisenberg. The ”silent influence” of Wolfgang Pauli in shaping the interpretation is clear[576] and the impact of Max Born cannot be forgotten. According to Heisenberg's description, he himself was essentially the mathematician, Pauli was the critic and Bohr was above all else the philosopher emphasising complementarity and the epistemological lesson provided by quantum mechanics.

Even though everyone involved knew they were handling matter of great depth and philosophical significance, the interpretation was never worked up into a systematic presentation, and not a single scientific conference devoted solely to the interpretation was ever held. Under closer examination, the viewpoints and differing emphases of the physicists who participated in development of the interpretation have been seen to be widely divergent[577]. However, the Copenhagen group had a common and an important starting point. All of them believed that

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576 Laurikainen 1985.

577 Among other material, personal correspondence is also available for detailed analysis.

quantum mechanics required a radical renewal of earlier ways of thinking, and each of them was striving, for their own part, to understand and analyze the new and unexpected situation resulting from the failure of the conception of reality which had been dominant for more than 200 years. According to Pauli, renewal of the conception of reality was the most important task of the age. Even though he was the only one of the Copenhagen group who was clearly searching for a new ontologically orientated model in the spirit of traditional system-building philosophy[578], none of the developers of the interpretation showed any interest in questioning the primary goal of such an enterprise.

The Copenhagen group were very well aware that the objective description of reality in classical physics had become inadequate since wave-particle dualism made it impossible to clearly separate matter and fields from one another, the principle of uncertainty limited the possibilities of obtaining a precise knowledge of a particle's mechanical state or trajectory, and measurement appeared to be interactive, so that because of the quantum of action the possible results and the future behaviour of the system could not be analysed in an unambiguous manner. The collapse of determinism was a surprise which not a single physicist had apparently expected.[579] Even though indeterminism and objective chance had been a subject of much discussion in the 1800s in connection with theories of probability, physicists clearly believed that statistical laws were reducible to underlying deterministic events. Philosophers such as C.S. Peirce (1839-1914) were better equipped to rejected the doctrine of necessity. He based his logic of inductive reasoning on statistical stability believing in a universe in which laws of nature are at best approximate and evolve out of random processes.[580]

When the ideas of classical mechanics were incapable of explaining new experimentally observed phenomena, the Copenhagen group realised that they would be forced to abandon physicists' earlier attempts to describe natural phenomena as completely deterministic and observer independent events taking place in space-time. The circumstances turned them into philosophers almost against their will. They did not lack the courage to move outside the area of their own specialities and search for new solutions and orientations in those fundamental

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[578] An outline of Pauli's ideas will be given in Section 4.3.5. For more detail, see i.a. K.V. Laurikainen 1988 and 1997.

[579] March 1957, 14.

[580] Hacking 1990, 200-215, Popper 1972, 212-213. Popper appraises Peirce as one of the greatest philosophers of all time. Peirce was the first post-Newtonian physicist and philosopher who dared to adopt the view that to some degree all ”clocks” are ”clouds”. In his book, Hacking presents a thorough examination of how determinism was subverted by the laws of chance. For early 17th-century ideas about probability, induction, and statistical inference, see Hacking 1975.

questions which have been pondered within natural philosophy since ancient times. As philosophers, however, there are several reasons for considering them to be no more than amateurs. They did not know the traditions of philosophy, and their handling of conceptual analysis certainly did not shine. They did not even write down a systematic and comprehensive presentation of their thinking concerning the interpretation of quantum mechanics. On the other hand, the Copenhagen group had something without which even the best philosophy remains ungrounded. They had an experimentally based certainty that the description of nature employed by classical physics was no longer adequate, and a justified view of the matters in which a reappraisal was required.

Max Born's question ”How is it possible to speak of an objective world when the atomic world cannot be manifested without account being taken of the observer and the whole measurement situation?”[581] is characteristic of the starting points employed by the Copenhagen group. Since it did not agree with either classical realism or mechanical-deterministic space-time descriptions, interpretation was often outright thought of as being Positivist. The Copenhagen group, however, wanted to explicitly understand and explain the apparent paradoxes that quantum mechanics brought with it. Since the framework of classical physics had been revealed as being too narrow, they did not just content themselves with the situation declaring that all frames of reference contained unnecessary metaphysics. In the light of new knowledge, they were ready to re-evaluate the fundamental character of reality. Born's realism was revealed in his response that ”only theoretical physics is true philosophy, which also has the ability to further deeper knowledge and understanding of the world”. Physics had revolutionised the basic concepts of time, space, causality and matter, and it was now able to teach us a new way of thinking such as complementarity.[582]

Heisenberg, who emphasised the mathematical methods, is generally considered to be the most Positivist of the developers of the Copenhagen interpretation. According to his own crystallisation, quantum mechanics raises two fundamental groups of problems: ontological questions concerning the nature of matter or even further, the ancient Greek question of how the manifold phenomena associated with matter can be understood with a single principle, and the epistemological question of objectivisation, which, especially following Kant, has been current: how far is it possible for us to be objective about our observations concerning nature, i.e. in

[581] Born 1983, 50.
[582] Born 1968, 48.

defining the observation of phenomena as an objective proces that is independent of the observer?[583] Heisenberg did not himself accept the thinking that the Copenhagen interpretation was positivistic in any way. He considered a Positivist approach based on mathematical logic to be too narrow. It was not suitable for a description of nature in which the employment of imprecisely defined words and concepts was unavoidable. While Positivism considered an observer's sense perceptions to be elements of reality, the physical basis of the Copenhagen interpretation was the objects and processes which could be described using classical concepts.[584]

Bohr also believed that the "phenomena" studied by physicists were born in interaction with what we call reality. He understood observation as physical interaction between the system being investigated and the equipment being used to make the observations, and did not accept the thinking that the only thing being dealt with is sense experiences. Concerning the relationship with Positivism, he said "I can readily agree with the Positivists about the things they want, but not about the things they reject. ... Positivist insistence on conceptual clarity is, of course, something I fully endorse, but their prohibition of any discussion of the wider issues, simply because we lack clear-cut enough concepts in this realm, does not seem very useful to me - this same ban would prevent our understanding of quantum theory."[585] The Copenhagen interpretation does not therefore in any way demand a defence of the simple statement that "what cannot be observed does not exist". Supporters of the interpretation are only bound to the thought that that which can be observed certainly exists and about that which we do not observe we are still free to make suitable assumptions in order to overcome paradoxes.[586]

The problem of objectivisation led Bohr and Heisenberg to problematise the nature of language and mathematics. They did not believe that humans had an access to language which would be suitable for describing reality at all levels and which would automatically correspond to the structure of reality. The conscious acceptance that methods of description are inadequate does not however mean that reality itself must be rejected. Even though humans cannot obtain direct

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[583] Heisenberg 1958, 4.

[584] Heisenberg 1958, 85. Heisenberg 1962, 22.

[585] Heisenberg 1971, 207-208. Henry Folse, a philosopher of science, has often stressed that Bohr should not be interpreted as a positivist or a phenomenalist. H. Krips also believes that Bohr and Heisenberg were not anti-realists in the metaphysical sense. Krips 1990, 1.

[586] Von Weizsäcker 1980, 183-184. The statement concerning the certain existence of the observed should not be taken as naïve empiricism forbidding the theory-ladenness of observations. In the light of new knowledge, observations can be interpreted in a new way.

observational knowledge of atomic reality, or objectify macroscopic observations in such a simple way as is classically assumed, we do carry out realistic investigations into existing processes and are able to shape inter-subjectively valid scientific knowledge on the basis of observations we have made. In this way, the Copenhagen group preserved the realistic basic starting points employed by classical physics, according to which humans can, step by step, form an ever more truthful concept of the world. Achieving this target did however required abandonment of the basic presupposition of classical physics approach, i.e. that the whole of reality can, without exception, be described as observer-independent phenomena that can be treated in an objective and intuitive manner in space-time. In spite of its ”common sense” illustrative character, the mechanistic way of thinking, in which reality is considered to be made up of separate parts and objects for research, was considered to be inadequate.

Discovery of the quantum of action meant that the centuries old tradition of an objective description of nature had to be renewed. The illusion of a predictable autonomous external world broke down at the micro level. In our inquiries, we do not meet nature as it is, as an independent objective reality. Quantum mechanics does not allow for the possibility of making observations without reference to the observer or to the means of observation and thus we are investigating nature as it appears to us; in our examination we should be aware of our own influence in shaping reality. Werner Heisenberg connected this problem to the indisputable fact that natural science is formed by men. He supposed that natural science does not simply describe and explain nature as it is, but is part of the interplay between nature and ourselves, describing nature as exposed to our method of questioning, which means that when investigating nature, we also encounter ourselves.[588] Niels Bohr often declared the same thing by saying that humans are not just observers but also actors on the stage of life. The reality that we examine is also subject to our influence.

Failure of the familiar objective way of examining nature led the Copenhagen group into philosophically inaccurate and badly chosen utterances, such as the claim that research does not reach nature as it is, only as mere interaction between it and the observer.[589] This does not however make the Copenhagen interpretation significantly subjective, it rather means that humans do not have an absolutely external monitoring point from which it is possible to observe the world as it is. Sometimes, Heisenberg expressed the new situation by saying that the

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587 Heisenberg 1955, 18-28.

588 Heisenberg 1955, 18-21. Heisenberg 1961, 12-13. Heisenberg 1962, 81.

589 March 1948, 15-16.

mathematical equations of natural science no longer describing nature, but only our knowledge of it. In saying this, he did not mean that we only address our own thinking and that our portrayal of nature could not via further knowledge evolve.

The Copenhagen group saw that the illusion of an observer independent external world adopted at the turn of the modern era fell apart when the observational events and the system being investigated are interwoven (entangled) at the microscopic level. It was no longer possible to speak in an unproblematic way about atomic particles without also considering the measurement situation . When waves are observed in one situation and particles are observed in another, the thought that the most fundamental level of reality consists of material particles moving in space-time becomes a problem. The concept of an ’object’ at the microscopic level becomes obscure. According to Heisenberg, the question of whether particles ”as such” exist in space and time could no longer be constituted in such a form, because it was necessary for us to conclude the particle’s behaviour from those events which occurred when it was in interaction with some other system like another microscopic entity or a macroscopic measurement device. Descartes’ division into *res cogitans* and *res extensa* and the world’s old division between objective events in space and time and, on the other hand, the mind or soul in which these events are reflected, was no longer a suitable starting point for an understanding of modern science.[591] When different situations produced different phenomena, human beings were not only passive observers but, by manipulating the boundary conditions, they also designed or shaped the distribution of obtainable outcomes. This was something that Descartes could not have attained. It made sharp separation between the world and the I impossible.[592]

The Copenhagen group adopted the probability interpretation of the wave function presented by Max Born, in which the square of the wave function gave each point a probability that a particle could be observed at given position. Unanimity on a more accurate characterisation of the wave function could not however be achieved. Born himself thought that the wave function was in some way connected with reality, while Bohr took it more as a mathematical device which gave a symbolic portrayal of a microscopic world that could not be observed. For his part, Heisenberg speculated that the wave function addressed some world of potential possibilities, while Pauli linked the wave function to the psychic side of reality as some kind of irrational or creative element. On occasions, the wave function was presented as portraying nothing more than our

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591 Heisenberg 1955, 12, 21.

592 Heisenberg 1962, 81.

knowledge of reality, an interpretation emphasised by K.V.Laurikainen, who was well acquainted with Pauli's thoughts in particular.[593]

Even though the concept of the ontological nature of the wave function remained obscure, the Copenhagen group agreed that the wave function makes quantum mechanics a holistic theory. In an experiment involving 'similar' and 'similarly-prepared' particles, the state function combines individual events into a whole. Individual particles have the property of behaving statistically in the way described by the wave function, and the wave can only be demonstrated by using a very great number of 'similar particle events'. They believed that this was an expression of the very essence of reality and that there was no reason to expect that this feature would be eliminated by a future development of the theory. The new physics was essentially statistical by nature. The classical concept of causality was inapplicable and for human beings, the world was not totally predictable. Pauli in particular stressed statistical causality and statistical laws as the most characteristic feature of quantum mechanics.[594]

At first, Bohr used to say that "causality is not valid in microphysics" but avoided the phrase after 1957 when the Soviet Academian V.A. Fock visited Copenhagen and pointed out that there are laws even in microphysics although they are of a different kind to those of macrophysics. From the very beginning, Bohr, however, emphasised that causality must be generalized to the 'framework of complementarity'. In practice, this generalization means the idea of statistical or probabilistic causality.[595] Bohr believed that statistical laws and complementarity were linked to the fact that the particle description and wave description had to be associated with one and the same object. This fact implied that the concept of 'object' was obscured at the microscopic level and that the classical space-time description became unambiguous.

4.3.2. Niels Bohr's epistemological lesson and the framework of complementary

Bohr emphasized the epistemological lesson given by quantum theory and considered his doctrine of complementarity in an obvious way resulting from the new situation encountered in

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[593] When criticising realism, K.V. Laurikainen often used the statement that natural science only describes our knowledge. He saw that by interpreting matter waves (i.e. the state function of quantum mechanics) as describing our knowledge of reality, the paradoxes of quantum theory disappear. The unpredictable reduction of the state-function happens only in our consciousness as our knowledge of the situation changes. Laurikainen 1997, 36-37.
[594] Laurikainen 1997, 37, 40-41.
[595] Laurikainen 1997, 40.

physics. As a philosopher Bohr was to a great extent *”sui generis”*, of his own kind, a researcher forced by quantum physics into contact with the most fundamental questions concerning knowledge and objectivity. This can be taken as both his strength and his weakness. Since Bohr was not well acquainted with academic philosophy and he lacked clear philosophical models,[596] he had to create his own original interpretation in order to explain the new experiences. It has been said with justification that the philosophical power of Bohr’s thinking was not so much on scholarship as on the sharp and acute intuition with which he figured out profound matters.[597] On the other hand, without the support of philosophical tradition he was not capable of exploiting all the already developed tools of thinking, or convey his viewpoint to other researchers in the clearest possible and unequivocally understandable manner.

Bohr’s thoughts have divided both physicists and philosophers to a quite astonishing degree. On one hand he is viewed as a radical innovator and creator of synthesis who pushed forward the complete renewal of the classical physics frame of reference, whose dynamic philosophical power and the ability of this to influence development of our world-view came from its solid empirical foundation.[598] On the other, for example, Sir Karl Popper stated that ”Bohr was a marvellous physicists but a miserable philosopher, who had introduced subjectivism into physics”.[599] Philosophers of science analysing Bohr’s thinking have discovered Positivist, Pragmatist, Kantian and Realist features. Different starting points and different approaches, combined with the sparseness of his presentations and their openness to different interpretations have produced the absurd situation that all 20th-century schools of thought have considered Bohr to be both their opponent and their ally.[600] Even though there are elements in Bohr’s philosophy which can support both Realism and Anti-realism, his thinking as a whole cannot be classified as fitting any of the accepted schools of scientific philosophy. Most appropriate for Bohr is to be classed as a significant natural philosopher who attempted a profound renewal of the foundations

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596 Favreholdt 1992, Pais 1991, 24, ja Honner 1994, 144-148.

597 Pais 1991, 5. When asking A. Pais to be his assistant, Bohr explained that co-operation could only succeed if Pais understood that Bohr was a dilettante who had to approach each new problem from the viewpoint of complete ignorance.

598 For example Hooker, Murdoch and Feyerabend have stressed the durability of the physical foundation of complementarity. At the very least, Favreholdt, Folse, Hooker and Plotnitsky consider that complementarity is intended to replace the classical framework.

599 Horgan 1998, 36. The following statement appears in a recent biography of Bohr: ”When Bohr extended his principle of complementarity into philosophy he really made a fool of himself.” Strathern 1998, 89.

600 Folse 1985, 18. For his part, Bohr thought that philosophers are strange people who have been led astray. Philosophers did not attach enough weight to observation and were not prepared to learn important things from experience. One reason for Bohr’s disappointment was probably Jörgen Jörgensen, an influental Copenhagen philosopher who said in his lectures in the 1950s that Bohr’s ideas were completely wrong. Faye 1991, xv. Pais 1991, 421.

of the conception of reality adopted at the turn of the modern era.[601]

Physicists generally acknowledge Bohr's authority as a Nobel prize winning physicist and developer of the atomic model. Also, the Copenhagen interpretation and the concept of complementarity are usually referred in standard introductory books on quantum mechanics, even if these texts almost systematically avoid the problems in interpreting the theory. In general, however, the philosophical content of Bohr's thoughts are not made any more explicit, and many physicists, starting with Bell, have understood his way of thinking in an incorrect manner[602]. Since Bohr did not make an attempt to understand the nature of reality within the limited framework of the classical paradigm of physics, many physicist now consider his arcane thinking and interpretation as having corrupted subsequent generations of physicists. The propagator of a clarification in the concept of reality has begun to be seen as a scapegoat for the long unresolved problem of interpreting quantum mechanics.[603] Even in works which deal with the interpretation, many blatant misconceptions concerning Bohr's viewpoints are commonplace. For example, against obvious evidence Roland Omnes claims that Bohr accepted the projection postulate concerning measurements, and that his authority thus led research in a wrong direction. Also, according to David Deutsch, Bohr supported the idea that consciousness was a kind of causal factor which reduced the state function.[604]

Bohr's background gave him a sound basis for what he was to do. He was born into a respected Danish academic family and throughout his life, enjoyed unreserved support and encouragement from those close to him. To entice the developer of the atomic model back to Denmark, thus with Copenhagen University offered the 30-year-old Bohr a professorship. The Danish state and private associations soon established the Institute for Theoretical Physics, and as a director of his own research institute, Bohr was able to invite his own choice of researchers and continue his own research work in stimulating and productive interaction with these individuals. Bohr's public activities involved a steady procession of accolades. Even during his time as a student, he received the gold metal of the Danish Science Academy for his research into the oscillating surface tension of liquids. This was followed by the Nobel prize for his research into atomic

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[601] For more details see Kallio-Tamminen 1994.
[602] Arkady Plotnitsky in his presentation at the conference "Towards a science of consciousness" in Skövde in Sweden 7-11.8.2001.
[603] Bohr's views are criticised, for example, in Bub 1974, 45 and Deutsch 1997, 327-328. According to Bub's analysis, Bohr was a remarkably-successful propagandist.
[604] Omnes 1999,155-157. Deutsch 1997, 327-328. Bohr does not need the projection postulate, with or without consciousness, and nowhere does he present this kind of idea. Murdoch 1987, 126. Bohr's thoughts concerning the measurement problen are discussed in Section 4.3.6.

structure and emitted radiation, his appointment to the nobility and to many positions of trust in influential international organisations such as the Atomic Energy Commission.

At school, Bohr was said to have been interested in many other subjects in addition to mathematics and natural science. In general he managed well, but writing essays was a source of difficulties as the young Bohr did not learn to handle the wide range of subjects in an suitably balanced and superficially cursory manner.[605] Within his family circle, this was taken as evidence of the wish to be absolutely precise and logically consistent that he had shown ever since he was small. This characteristic was reinforced during his first year at university when Bohr, who was participating in a compulsory course by Harald Hoffding on the history and logic of philosophy, discovered an error in Hoffding's textbook, already translated into several languages, and was allowed to help to correct it for the second printing.[606]

When preparing his thesis on the theory of electrons in metals (1911), Bohr began little by little to become aware of the limitations and difficulties of classical physics. In his speech of acceptance after receiving the Nobel prize in 1922, he pointed out the limitations and weaknesses of quantum theory which acutely troubled him. Gradually he began to show an increasing interest in philosophy and epistemology realizing in the course of his research work that the question of the fundamental nature of reality could no longer be taken as being given *a priori*. Physicists could not know in advance what type of world they were investigating. In his complementarity approach, Bohr tied the foundations of portraying reality to the interaction between man and nature and the inter-subjective descriptiveness of experience. The detached observer became an active operator in evolution, interacting with the environment and shaping it by the choices made. Natural laws became laws invented by humans, but not in a subjective sense. His approach urges us to see that both our objective manner of describing reality and our whole language are metaphorical, familiar ways of perceiving the world.[607] The primary task of physics becomes the development of methods of organising human experience, and the offering of possibilities to test the central conceptual foundations and dimensions of natural language.[608]

Bohr's philosophical texts are considered to be difficult to understand. The same cannot be said about his clear articles connected with physics. Bohr obviously handled physical problems using an analytical approach which was easer to communicate on paper, while his intuitive view to

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[605] Rozental 1967.
[606] Favreholdt 1992, 16-18.
[607] Gregory 1988, 96.

philosophical matters was more difficult to capture in written form. Bohr wrote, or more often dictated, his texts many times. The statements resulting from this endless polishing and finishing are reminiscent of tiny universes of meaning which attempted to say everything at one and the same time.[609] In particular, the process of writing the Como lecture, in which Bohr first published his thoughts on complementarity, was long and painful. He never wrote a complete book, but presented his philosophical thoughts in condensed essays and public lectures which were later collected into three different volumes. In these, the same subjects were handled over and over again from slightly differing viewpoints. The following paragraphs are a collection of Bohr's thoughts on language and complementarity based on his own texts.

The character of language

A subject to which Bohr paid considerable attention was the extent to which humans are bound to language in their search for knowledge. In particular, he searched for an answer to the question of why describing observed phenomena using classical concepts[610] led to the use of descriptions which appeared contradictory, even though, since consistent mathematical theory guaranteed the consistency of the portrayal of quanta, no real incompatibility could in fact exist. Bohr understood language as a means to approach and analyse nature and our experiences of it which had evolved over time. With the help of language, we are able to orient ourselves to our environment.[611] Words entrap us, but they are at the same time a network with which we can aim at achieving an ever-clearer picture of the world and our place in it. It is my opinion that language can also, according to Bohr, be considered to be a kind of theory of the world. It works because it is anchored to our everyday experience. On the other hand, the language we use also implies a familiar macroscopic world. It tacitly incorporates everyday assumptions about the nature of the world which suit the macroscopic environment we are living in, such as, for example, the assumption that the world consists of isolated objects and the drawing of a clear distinction between subject and object.

The image of reality offered by classical mechanics appeared rational as it was based on the well-defined and idealised use of concepts and pictures which were familiar from everyday life. The new physics has, however, extended the coverage of these concepts well outside the region

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608 Bohr 1963, 2, 10.
609 Nörretranders 1991, 225.
610 By "classical concepts", Bohr means the intuitively-understandable concepts used both in ordinary language and in classical physics.
611 Bohr 1948, 88.

in which they can be experienced and on which they are founded.[612] Its theories deal with areas which are not touched by our everyday experiences and direct observation. In such investigations, we cannot without problems maintain that our language ”corresponds to reality” as was thought in the circles of classical physics. The theory of relativity and quantum mechanics tackled inadequacies in classical language.[613] These theories revealed structures in the world that ”normal” language could not address. The area in which certain concepts are universally applicable turned out to be limited. The theory of relativity demonstrated that the classical concept of space and time was only suited to the description of a world in which speeds were small compared to the velocity of light. At the same time, the discovery of quanta revealed that the theories of classical physics were idealisations, useful only at the macroscopic level where effects are so large that quanta can be ignored.[614]

Even though the area of applicability of classical concepts has been shown to be limited, we are, according to Bohr, tied to both our classical language and our classical methods of description. In portraying new and strange areas we have to be satisfied with the images and concepts that we recognise. When experience is extended far beyond everyday phenomena, objective or common inter-subjective description can only be maintained if we adhere to classical language, the use of which guarantees consistent inter-subjective communication.[615]

> Det är inte endast så att kännedomen om verkningskvantums odelbarhet och bestämningen av des värde beror av en analys av mätningar som grundrar sig på klassiska begrepp, utan det ar fortfarande endast användningen av dessa begräpp som betingar sambandet mellan kvantteorins symbolik och erfarenheternas innehåll.[616]

Bohr drew a clear distinction between a theory’s mathematical formalism (its symbolic scheme) and the intuitive description offered by classical concepts. But mathematics was also a language for Bohr. The definition of its symbols and operations is based on the simple and logical use of normal everyday language. Because it avoids the references to conscious subjects which slip through in everyday language, mathematics is well suited to objective description and consistent definitions. It is appropriate for the expression of relationships where verbal communication is unclear or clumsy.[617]

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[612] Bohr 1958, 69.
[613] Bohr 1939, 25 ja Bohr 1963, 59.
[614] Bohr 1958, 70.
[615] Bohr 1958, 67.
[616] Bohr 1967, 19.

Even though mathematics is a language, mathematics alone will not do. Pure mathematics is not physics, which is able to tell us something about reality. Both the theory of relativity and quantum mechanics are based on comparison of the results of measurements, and the use of classical language when handling this material is essential, even though, in principle, it is unable to deal with the revelations brought by both relativity theory and quantum mechanics.[618] Without a common language, one already employed in classical physics, research would lack a common foundation according to which everyone would comprehend, for example, the experimental equipment used or the results obtained in the same way. Classical language is an indispensable communication tool, because knowledge has to be based on meanings which we can understand in a common manner.

Bohr’s claim that we must also hold on to classical language when depicting the new areas revealed by quantum theory was not immediately accepted even in Copenhagen circles. Wolfgang Pauli believed that the problems of interpretation would be solved if the inadequate concepts were replaced by new ones that could be used to create a new visualisable model of reality. It was Werner Heisenberg’s opinion that we no longer knew the meaning of ”wave” or ”particle” and that like heat or pressure, ”space” and ”time” were only of significance when dealing with a large number of particles.[619] Bohr’s attitude to models that visualised observations was one of caution. Even though he employed such models in his own work, he strove at the same time to keep in mind both the limitations and the deceptive nature of all types of descriptive and analogical models. For example, according to Bohr, portrayal of the wave function, even though it was real, meant that the act of visualisation had to be abandoned. He did not believe that any single visualisable model should be given the status of being more realistic than abstract mathematical formalism.

Since Bohr did not consider it possible to build an visualisable ontological portrayal of reality on the basis of quantum mechanics, his position could be interpreted as being Anti-realistic.[620] For his own part, however, he was a maximal Realist. He saw that we do not have the tools required to provide a single ”true” picture of the microscopic world. Since the abstract and symbolic depiction given by quantum theory was neither visualisable or directly understandable, we are forced to reflect the formalism by using concepts and analogies that are based on direct experience appropriate at the macroscopic level. By interpreting our experiences of atomic

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617 Bohr 1963, s.60
618 Bohr 1939, 25.
619 Hendry 1984, 64, 114.

objects with the help of natural language, we do however end up with descriptions which appear incompatible. In this situation, Bohr viewed complementarity as the only possible way of achieving an objective approach, one in which apparently contradictory phenomena could co-exist within a consistent framework. Complementarity descriptions can be thought of as complementing each other in order for us to understand complex reality.

Complementarity

Complementarity is Bohr's central concept, he considered it to be his greatest gift to humankind and continued to develop it until the end of his life. Interpretation of the concept is however often experienced as difficult: even if on one side there is a clear content which arises from a physical foundation, on the other, Bohr adapted his thoughts concerning complementarity to different situations in a fairly free manner. Henry Folse may be correct in his suggestion that many of the misconceptions about complementarity follow from attempts to clarify it as nothing more than an internal principle of quantum theory. It is approached from the classical frame of reference, even though it is intended as a replacement for this earlier framework.[621] Also C. Hooker has argued that Bohr was striving with his concept of complementarity to discover an internally-consistent and understandable "rational generalisation" of classical physics.[622] Understanding Bohr's objectives has not been easy, since his clearest statement of his demands for change in the fundamental principles of portraying reality was presented in statements such as the following:

> The classical physical description is an idealisation of limited applicability. In proper quantum processes, we meet regularities which are completely foreign to the mechanical conception of nature and which defy pictorical deterministic description.[623]

> The notion of complementarity is called for to provide a frame wide enough to embrace the account of fundamental regularities in nature which cannot be comprehended within a single picture.[624]

On the other hand, in the context of the whole of Bohr's thinking, the radical interpretation of complementarity is quite logical and follows almost inevitably from his ideas concerning the character of language and the indivisibility brought by the quantum of action. A consequence of

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[620] Mackinnon 1994, 290.
[621] Folse 1985, 18.
[622] Hooker 1991, 499, 502.
[623] Bohr 1958, 85.
[624] Bohr 1963, 12.

this indivisibility resulting from the quantum of action is that a portrayal of the world in quantum form cannot any more be presented using a visualisable mechanistic-deterministic model.[625] In specific experimental situations, atomic objects have to be represented in the form of waves, in others they have to be represented as being particles. It is not necessary, however, for atomic objects[626] or the target of a particular investigation to be either a particle or a wave, even though these are the only familiar images which we can use at the macroscopic level to describe the phenomena observed in different experimental situations. As the information yielded by complementary experimental situations and portrayals also includes the influence of the experimental setup, our observations do not have to concern some independent properties of microscopic objects, only phenomena which appear as result of their interaction. Complementary phenomena cannot be directly internally contradictory for the reason that the experimental systems always require one or the other to be excluded. From the viewpoint of complementarity, the apparent inconsistencies were completely removed.[627] Complementarity is not therefore connected to any contradictions in reality, it results from the limitations of the employment of mechanical models and classical language.

In an interactive situation, the observer is considered as an extension of the equipment being used in the examination of phenomena. In such a situation, the observer cannot give an objective external view of how a particular process advances and can only obtain knowledge about the world by participating in its processes. When describing the experienced process to others, the observer must, however, separate subject and object from one another, thereby separating him/herself from the wholeness of reality. Portrayal is thus a consequence of an experiment and is bound to it. The best-possible portrayal cannot therefore attain the whole of reality without residuals. The method of portrayal employed by complementarity addresses a certain part of the whole in different situations and from different perspectives. Even though our descriptions are coloured by our previous observations and language, they are not imaginary constructions, they refer to real phenomena.

Bohr presented his thinking on complementarity for the first time in 1927 at a conference in

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[625] Bohr 1958, 5 and 41.

[626] Bohr regularly speaks about atomic objects instead of speaking, for example, of properties related to interactions or relations between atomic objects and measurement equipment, or of the actualisation of possibilities contained in wave functions.

[627] Bohr 1958, 59.

Como.[629] At this occasion, in addition to presenting wave-particle complementarity, he also discussed the complementarity between visualisable time-space description and causal[630] description. Development of the classical system can be portrayed in a causal manner in time and space. Particles move along specific paths under the influence of specific forces in a fully-predictable manner. Quantum theory, however, demonstrates that every observation happens at the cost of losing the connection between the system being investigated and its future development.[631] Since we cannot exclude the effects of the observation process in the world we are attempting to describe, the self-evident assumption of classical physics concerning simultaneous causal space-time description is impossible. In atomic systems, the measurement of position and the measurement of momentum or energy both require equipment that excludes the possibility of investigating the other property. Experimental equipment which makes it possible to locate an atomic object causes uncontrollable changes in that object's momentum or energy, on the conservation of which the possibility of causal description is based. And vice versa, if dynamic conservation laws are used when describing a system, it will be necessary to abandon the precise definition of location.[632]

Bohr's view of complementarity permits the traditional causal description when the phenomena being observed are at the macroscopic level and independent of the observer. At the microscopic level, this qualification does not apply. When examining the context-dependent and indivisible phenomena described by quantum theory, the behaviour of objects is not independent of the observer. Indeterminism cannot therefore be avoided and physical description is returned to a more-general portrayal using complementarity.[633] The mechanical models of classical physics, in which all events can be encapsulated in observer independent objects moving in space-time, are only capable of addressing idealisations useful at the macroscopic level. The indivisible or individual features connected with quantum theory are not therefore just alien to classical theory, they are incompatible with the whole concept of causality.[634]

Information obtained from complementary systems of investigating cannot be combined in a single portrayal by using common images and concepts. Even so, each image and concept

[629] Bohr 1967, 46-74.
[630] Bohr used the notion of causality in a restricted manner. When using it, he largely meant mechanical determinism.
[631] Bohr 1967, 16.
[632] Bohr 1958, 90 and Bohr 1963, 62.
[633] Bohr 1958, 41 and Bohr 1939, 25
[634] Bohr 1948, 313.

represents essential aspects of the information concerning that object.[635] Complementary phenomena represent regularities which the classical, single-picture description suitable for causality cannot attain. They are mutually completing but at the same time mutually exclusive. Together, they provide all the knowledge of atomic objects available from the experimental system being employed.

> ...the impossibility of combaining phenomena observed under different experimental arrangements into a single classical picture implies that such apparently contradictory phenomena must be regarded as complementary in the sense that, taken together,they exhaust all well-defined knowledge about the atomic objects. Indeed any logical contradiction in these respects is excluded by the mathematical consistency of the formalism of quantum mechanics, which serves to express the statistical laws holding for observations made under any given set of experimental conditions.[636]

Complementarity does not therefore in any way indicate a limitation of quantum mechanical descriptions, it should be taken as a rational generalisation of the idea of causality.

Complementarity is closely connected with a change in the position of the observer. Classical physics adopted the viewpoint of Cartesian dualism in which an immaterial and knowing subject investigated world events as if it were completely isolated. To Bohr, the observer was quite clearly a part of reality. The wholeness of humans is both part of reality and a shaper of it, both audience and actor at one and the same time. Immersed in the world, people do not have complete knowledge of the fundamental nature of reality or a comprehensive external view of its full extent. We can only strive to understand and participate in the phenomena that we encounter to the best of our ability.

4.3.3. The relationship between complementarity and eastern philosophy, Pragmatism, and Kantian categories

Connections with eastern philosophy have been pointed out in Bohr's complementarity.[637] According to the Indian professor D.S.Kothar, the core of the in-depth ethical and spiritual insight brought forth by Upanisadism, Buddhism and Jainism is the same as Bohr's

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[635] Bohr 1963, 26.
[636] Bohr 1963, 25.

complementary way of approaching the problems of life and existence.[638] Bohr rejected the traditional ontological approach to natural philosophy. Even the division between subject and object appeared to him to be more a question of situation-specific expediency than a fundamental ontological starting point. Strongly generalising, it is possible to say that in eastern philosophy, the world is not usually examined as it is revealed in isolated things and events, but as an unbroken whole, part of which is the human observer.[639] In Taoism, reality is thought of as transcending the limits of normal language and logic. Since the structure of nature is not the same as the structure of language, every attempt to detach from the world and portray it in an objective manner leads inevitably to an imperfect description of reality.

Bohr's philosophy has echoes of eastern philosophy and there is reason to believe that he read ”Tao te Ching” in his youth.[640] When the Danish state honoured Bohr, he chose as his coat of arms the yin-yang symbol which depicts the balance and unity of the opposites. Bohr also often brought out the fact that the lesson of atomic theory, i.e. the inadequacy of the idealisations of classical physics, also led to epistemological problems similar to that which thinkers such as Buddha and Laotse encountered when attempting to balance our position as both observers and actors in the great drama of existence.[641] He also repeated the paradoxical-sounding statement according to which the antithesis of each profound truth is also a profound truth, even though the antithesis of an ordinary truth cannot be defended.[642] This thought is in agreement with dialectic Janeian Syadvada logic.

Bohr did however warn against incorporating mystic material into scientific methods of approach. His starting points were empirical, logical and fully in accordance with the western scientific tradition. Bohr resigned from the view that complementarity would include any mysticism foreign for natural science. Complementarity was a consistent generalisation of the classical concept of causality and the framework was needed as soon as the behaviour of the object was not independent from the act of observation.[643]

Understanding the central features of complementarity does not require eastern philosophy.

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[637] For example Hooker and Honner have noticed parallels in Bohr's views concerning the difficulty of drawing a line between subject and object, and in his manner of encapsulating the human being into language, to eastern philosophy. Hooker 1972, 207, Honner 1994, 141-142.
[638] Kothari 1985, 325.
[639] Capra 1983.
[640] Favreholdt, 1992, 37.
[641] Bohr 1958, 19-20.
[642] Bohr 1958, 66.

Bohr's thinking is fittingly enlightened also in the current debate within philosophy of science concerning realism and pragmatism. Several researchers have seen Bohr's viewpoint as becoming in many respects close to Pragmatism.[644] Like Bohr, Pragmatists do not make a clear division between the subject and external reality, and they highlight the role of humans and their actions in creating truths. To Pragmatists, question of ontology also remain in the background and is connected with epistemology and values as they ask which kind of method of talking about reality is meaningful and possible from a human viewpoint.[645]

Complementarity clearly has points of contact with the thoughts of Nelson Goodman and Hilary Putnam, according to whom the world can be investigated as an open and inexhaustible reality which humans can always approach from new viewpoints. The faces of the world can then always be viewed in a new way, and no language, viewpoint or system of concepts can exhaust the unlimited aspects of its unending abundance.[646] With the help of mathematics, however, Bohr evaded the threat of Relativism that is linked with Pragmatism. Complementary ways of description allow us to visualise phenomena which are, in principle, consistent with descriptions employing mathematical formalism.[647] Max Born expressed things by saying that complementarity is applicable to two different aspects of a single physical situation. They are both useful by providing an intuitive understanding of the situation which however can only be properly understood with the aid of the mathematical theory.[648]

To Bohr, Pragmatism however was no starting point at all. He did not weaken the traditional realism of physics, in which objective knowledge was believed to correspond to the absolute structure of reality, for either pragmatic or positivist reasons. He did not think that humans should ignore the reality which lies behind their observations, or that he could invent theories which served only his needs. Bohr had to bind his theory to human practice for more Kantian[649] reasons. For humans, the adoption of a complementary method of portrayal is unavoidable

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643 Bohr 1958, 27.
644 Those who stress the pragmatist features of Bohr's philosophy often claim that he was influenced by Kierkegaard, William James or Harald Höffding. David Favreholdt, who relies on extensive research material, strongly contests their influence. Favreholdt 1992, 62. When Bohr became acquainted with James' ideas, he noted their similarity to his own and referred to them in an almost regular manner after 1936.
645 Pihlström 1977, 139.
646 Pihlström 1997, 182.
647 See further Kallio-Tamminen 2004.
648 Born 1968, 105-6.
649 Bohr has been considered to be a pragmatic Kantian (Folse 1994, 121.) or a developer of Kant's doctrine on the basis of the quantum revolution (Hooker 1994, 155-182). Many researchers such as Honner, Keiser and Chevalley have found similarities between Bohr and Kant, even though Bohr makes no reference to Kant in any article or letter, and all his rare statements concerning Kant's critical philosophy are negative.

because we are fettered by our forms of observation and language. We simply do not have tools at our disposal which can encompass the whole of reality in a single picture or model. Reality simply cannot by captured in this way. Bohr did not however remain a prisoner of Critical idealism, since he believed that the human conception of the world could be developed and made better step by step.

Bohr took a critical attitude to the Kantian concept that humans are irrevocably bound to *a priori* observational prerequisites and categories of understanding. Even though time, space and causality are natural and unavoidable methods of structuring the chaos of observational material offered by the senses at the macroscopic level, research could, according to Bohr, reveal the limits to usage of even these basic terms. The abstract formalisms and theories of science shall however be interpreted, and hence normal classical language, coloured as it is by the world of phenomena and observational prerequisities, can be said, in Bohr's interpretation, to be searching for a similar role to that which Kant's *a priori* observations played in his philosophy. As the range of experience exceeds by far the dimension of everyday phenomena, a common objective description which will be available to all can only be preserved by holding on to classical language, the use of which guarantees consistent inter-subjective communication.[650]

In microscopic physics, however, humans gain knowledge which is not bound to everyday language or *a priori* causal space-time description. This is knowledge which Kant would obviously have considered it impossible to acquire. In interpreting this knowledge, we are of course forced to employ classical language because we cannot understand reality by using nothing but our conception of quantum theory. Since, according to the new knowledge we have gained, the area of application of what was earlier considered to be a universally-applicable concept has proved to be limited, we can learn to use language in a complementary manner. Complementarity provides a frame wite enough to embrace the account of fundamental regularities of nature which cannot be comprehended within a single picture.[652]

It is unlikely that Bohr believed that we are categorically bound to our classical language, as has sometimes been proposed. Even if we are trapped in the net of our language, it is a network that can be developed step by step in accordance with new experience. In Bohr's thinking, Kant's strict categories, which were a prerequisite for our observations, became gradually changing and

[650] Bohr 1958, 67. Bohr 1967, 19.
[652] Bohr 1963, 12.

dependent in experience. The essential idea, however, was preserved. In every historical situation we are bound to our own structure, capabilities, language and theories, and we investigate the world through the spectacles that these provide. Our observational and communicational capabilities, and the level of knowledge we possess, unavoidably shape the picture of reality that we obtain. Bohr saw that description could not be used as a direct bridge from theory to independent of reality. Whatever the actual character of the atomic world, it was not visualisable with the help of classical models which required an observational environment independent of the influence of the observer.

Generalisation of the concept of complementarity

Bohr is said to have developed the idea of complementarity as a result of his father's influence. His father was a physiologist. At the time when mechanistic and reductionist explanations were believed in, Bohr the elder defended teleological explanations. He did not consider these different methods of explanation to be contradictory, just complementary. Investigating the mechanism of an organism required that it be killed, which made research into living things impossible and vice versa. Circumstances in which the other form of description could be used shut out use of the other method of description.[653] Whether he was influenced by his father or not, the younger Bohr started little by little to notice that complementarity was new only in physics, in which, because of the quantum effect, phenomena could no longer be investigated as being fully isolated from the measuring device. He saw the complementary method of description as something traditionally used in areas where taking account of the conditions in which phenomena occurred had been essential from the very beginning.[654]

Physical description had to be generalized by complementary approach when the assumption that physical systems could be investigated in a manner which was independent of the observer had been shown to be an simplified idealisation. At the same time, complementarity generalised the question of whether nature was fundamentally deterministic or indeterministic. According to Bohr, causal descriptions were only possible when the phenomena being handled were independent of any influential interaction with the observation:

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[653] Powers 1982, 133.

[654] Bohr 1963, 60, 78 ja 93. As the state function is a solution of the Schrödinger equation which fulfils the boundary conditions corresponding to the experimental situation, 'circumstances' in quantum mechanics are defined by the experimental arrangements which appear as boundary conditions. Laurikainen 1997, 40.

> The view-point of complementarity allows us to avoid any futile discussion about an ultimate determinism or indeterminism of physical events, by offering a straightforward generalisation of the very ideal of causality, which can aim only at the synthesis of phenomena describable in terms of a behavior of objects independent of the means of observation.[655]

Victor von Weisskopf tells that Bohr illustrated complementarity by referring to a Cubist painting displayed in his house, which depicted people in many apparently inconsistent ways. The whole represented many different aspects of a person at one and the same time and all the different perspectives were necessary if the object being portrayed was to be ”come at” in a many-sided way. According to Weisskopf, Bohr wanted to say that there were many different apparently contradictory ways of classifying human experience. A sunset could be examined from a physical point of view by thinking about the passage of light and why the sun appears to be red, or the combination of colours could be marvelled at from an aesthetic point of view. In the same way, a Beethoven sonata could be examined as a vibration in the air or as a spontaneous musical and emotional state. All the complementary methods of handling experience increased the significance of a phenomenon, while the other methods, when studied from the viewpoint of a single isolated approach, could be considered to be weak and badly-defined. Poetic statements are not reasonable in scientific description, and psychological arguments are not reasonable in a neurophysiological context.[656]

Quite clearly, whenever we are describing phenomena from which our own influence or interpretation cannot be isolated, the same situation can quite reasonably be outlined using different complementary frames of reference. When, for example, the portrayal of a specific person by a wife, a foreman and an adversary appear to be contradictory, all the honestly expressed descriptions should in the spirit of complementarity be taken as true representations of the separate viewpoints which complement each other. Nevertheless, even all such descriptions taken together are hardly likely to exhaust the countless possibilities that are linked to possible manifestations of the target in different situations. Consequently, the portrayal that for whatever reason appears as truth to some must be seen as a product of historical and context-bound circumstance. Fundamentally, the formation of descriptions and comparisons between them can be seen as a personal and ethical challenge faced by each human individual.

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655 Bohr 1939, 25.
656 Weisskopf 1990, 66, 325-328.

In his later essays, Bohr applied his thinking on complementarity to research into philosophy, biology, psychology and culture. For example, in spite of their apparent contradictory nature he saw free will and determinism, or brain processes and consciousness, as essentially complementary methods of portrayal which completed each other. Also, strict justice and compassion formed a complementary pair, and depended on each individual's free choice of the framework within which they examined, for example, an individual case that conflicted with general norms. Professor D.S.Kothar has told of Bohr's wish expressed in personal conversation that complementarity would one day become part of every human individual's upbringing. It could help people to see that apparently incompatible concepts and viewpoints are not inevitably contradictory. Understood in greater depth, they could clarify each other and help in seeing the harmony that is the background to different human experiences.

In essence, the idea to replace traditional objective approach with a complementary description which is linked to a new conception of the relationship between subject and object. Bohr did not principally want to say that classical language does not address the whole truth of reality, he rather wanted to challenge the traditional assumption that humans are able to examine natural events in an objective manner from an external viewpoint. For example, he rejected the traditional Kantian division according to which science investigated the world of phenomena in an objective manner while religion was linked to the subjective domain. According to Bohr, the relationship between science and religion could not be examined on the basis of objective and subjective experience:

> "Religion uses language in quite different way from science but I myself find the division of the world into objective and subjective side much too arbitrary. The fact that religions through the ages have spoken in images, parables and paradoxes means simply that there are no other way of grasping the reality to which they refer. But this does not mean that it is not a genuine reality" ... "The developments in physics which have shown how problematic such concepts as 'objective' and 'subjective' are a great liberation of thought. Even if we have to distinguish between the objective and subjective side the location of the separation may depend on the way things are looked at; to a certain extent it can be chosen at will. Science and religion could be seen as different forms of complementary descriptions which though they exclude one another, are needed to convey the rich possibilities flowing from man's relationship with central order."[657]

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[657] Heisenberg 1971, 87-89.

4.3.4. Later attempts to interpret quantum mechanics by returning to the classical frame of reference

In later interpretations of quantum mechanics, Bohr's call for a fundamental reassessment of physics' customary methods of investigation has been forgotten. These interpretations have not proposed changes or alterations in starting points as deep as was the case with the Copenhagen interpretation, they have typically sought new ontological models in which the metaphysical background presuppositions of classical physics such as Determinism, Reductionism and the isolated detached observer can continue to be maintained. In particular, the idea in the Copenhagen interpretation of an active observer, one whose examination and measurement of nature influences the development of the process, has proved hard to accept. Developers of later interpretations have continued to view nature as mechanical and objective and have been unwilling to countenance a situation in which human aspirations and intentions have any influence on the process of shaping reality.

The traditional starting point for later interpretations has led to the postulation of different auxiliary hypotheses and to many incredible consequences such as the assumption that there are many parallel universes. If the cost of accepting these is considered worth paying, it is possible to attempt to hold on to the traditional approach and the presuppositions of the familiar mechanistic-deterministic paradigm. These developments suggest that even an entire conception of reality can be saved by different auxiliary hypotheses in the same way that such hypotheses can be used to save an individual scientific theory. Assessment of the degree of simplicity and credibility of these different models and interpretations represents a challenge for which it is even more difficult to present clear responses and criteria than when weighing-up the correctness of an individual theory.

Supporters of hidden-variable theories attempt to return quantum mechanics to being a classical and deterministic theory by assuming that its apparently statistical nature is the result of us being unable to recognise all the factors that affect the behaviour of a particle. This interpretation rejects the idea in the Copenhagen interpretation that the wave function provides a complete description of a system: i.e. that all systems which are described by the same wave function are in the same state and physically identical. If this were so, why, for example in the double-slit experiment, do identical electrons which are in the same state behave in different ways? Why does an electron strike the screen in one position and not the other? Supporters of the hidden-operator theory are not satisfied by the explanation that randomness in nature is a fact. They consider it more natural to assume that the question is only one of human ignorance. The wave function does not provide a complete portrayal of an individual system because it does not contain information which brings out the differences in hidden parameters. If the values of variables were known, the behaviour of an individual particle would be exactly predictable and quantum mechanics would revert to being a normal classical and deterministic theory in which measurement would be no more of a problem that it has been earlier.

This hope raised by the hidden-variable interpretation was however dashed by measurements carried out when Alain Aspect was testing Bell's inequality.[659] According to these experiments, local and realistic hidden-variable theories led to incorrect predictions. The presumption of independent reality or locality must obviously be rejected. Usually, supporters of hidden-variable theories prefer to abandon demands for locality and add to the world some mechanism for influence at a distance, which allows a particle in one location to obtain instantaneous information about a measurement being made on a particle in another location. Traditionally, this influence at a distance has been taken to be an absurd and impossible form of faster-than-light signalling. The abandonment of locality is not compatible with the theory of relativity. It also signifies radical change in the aspiration to a classical physics world-view. Some researches have suggested that in addition to locality, also separability, the idea that the identification of a system does not require that it be ontologically limited to a specific location, could be abandoned.[660]

In their desire to preserve the universe as completely deterministic and independent of human influence, some supporters of hidden variables have been ready to propose that it is Super-deterministic, i.e. that people carrying out experiments are unaware of the fact that the choices they are making are actually predetermined. If free experimentation is rejected, the whole issue of non-locality can be solved in many ways. The supporters of physical hidden variables attempted to return to scientific determinism by postulating, for example, velocities greater than that of the speed of light and particles that move backwards through time[661], while for their part,

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[659] Aspect 1982. Bell 1964. Presumably, Bohm's clear hidden-variable interpretation (1952) which was non-local inspired Bell to think more carefully about these questions, even though the Copenhagen interpretation already stressed the indivisible and holistic features within quantum mechanics.

[660] Folse and Howard 1987 in *Philosophical Consequences of Quantum Theory, Reflections on Bell´s Theorem*. Ed by J.T. Cushing and E. McMullin.

[661] For example, John Bell has supported the idea about a coordinator or ether through which something can move faster than light. Davies and Brown 1989, 55-58.

metaphysical determinists complete the deterministic world by hypothesising some external factor which makes selections in those individual events where it is possible to be several outcomes. Wolfgang Pauli accepted scientific indeterminism, but his archetypes can be interpreted as representing Metaphysical determinism.[662] In his ontological interpretation, David Bohm assumed Scientific determinism, but moved on by postulating entities in reality which can be interpreted as representing Metaphysical determinism.[663]

Bohm's causal interpretation

David Bohm studied physics at Berkeley in United States under J. Robert Oppenheimer. When Bohm finished his studies, he became a Princeton professor and clarified his thinking on quantum theory by writing a textbook on the topic. Bohm's *Quantum Theory*[664] is loyal to the Copenhagen interpretation and is valued by students as a simple introduction in plain English to the mechanics of quantum calculations, as well as for its unusually detailed discussion of the reality question. In 1951, Bohm tangled with American political reality when he refused to testify against his teacher before Senator McCarthy's Committee on Un-American Activities. He lost his job at Princeton, moved to Brazil and finally settled at London's Birkbeck College.[665]

Even though he held to the Copenhagen interpretation in his textbook, Bohm later began to have doubts about Bohr's approach that implied a farewell to micro-reductionism or the view that classical ontology could be reduced to some form of micro-ontology. He did not accept the Bohrian presupposition that both the classical level and classically describable measuring apparatus are necessary conditions for it being possible to say something unambiguous about quantum systems. For Bohm, the basic issue was ontology, not determinism. In 1987, Bohm said that after having written *Quantum Theory* in 1951 he still felt that he did not understand quantum theory. Bohm saw the theory of relativity and quantum theory as accentuating the indivisible

[662] Niiniluoto 1984, 123-124. On many occasions, Niiniluoto has criticised Pauli's metaphysical determinism and the ideas of K.V. Laurikainen, who has committed himself to the advocation of Pauli's interpretation of quantum mechanics in Finland.
[663] Bohm in the 1950s can be seen as a dialectic materialist who thought that both determinism and intererminism are aspects that can be found in each context. In his *Causality and Chance in Modern Physics*, Bohm presents a world-view in which hierarchical levels and qualitative infinity in nature are important. The totality of the universe could then also be seen as 'self-determined'. Bohm was clearly fascinated by the thought of the world as ”creatively self-determined” and by using concepts such as ”generative order” etc. he aimed to do away with mechanical determinism.
[664] Bohm 1951.
[665] Herbert 1985, 48-49.

wholeness of the world. The necessary wholeness of the quantum world led Bohm to the new notion of unbroken wholeness, which denies the classical analysability of the world into separately and independently existing parts. He saw quantum wholeness as a fundamentally new kind of togetherness, undiminished by spatial and temporal separation.[666]

In contrast to the mathematical proofs by Von Neumann and the generall -accepted expectations of the Copenhagen group, Bohm succeeded in constructing an ontological ”ordinary reality” interpretation of quantum theory for the electron[667] in the 1950s, and he subsequently completed his hidden-variable theory working in cooperation with Basil Hiley. In Bohm’s interpretation, the wave function is written in polarised form and placed in the Schrödinger equation. This results in two equations, the second of which includes the formula for energy conservation in which a new item, quantum potential, is placed alongside classical kinetic and potential energies. Quantum potential differs from classical physical potential in that it does not depend on the strength of the wave function, only on its form. In Bohm’s model, the electron is a particle[668], having at all times a definite position and momentum. In addition, each electron is connected to a new field and is equipped with a real wave, the so-called ”pilot-wave”, which guides its movement according to a new law of motion. With the assistance of this internal structure, particles are able to ”understand” the information contained in the field and they can be thought of as moving along precise trajectories. For example, since their pilot-wave explores the structure of the field like a radar beam, particles can know in advance whether one or both of the double slits are open. As quantum potential depends on the overall structure of the system, it changes its form instantly when changes occur in the surrounding environment. In this way, non-local connections present no problems for this interpretation. Also, distance does not weaken quantum potential in the way that it does normal fields, since quantum potential depends on form.[669]

In Copenhagen circles, Bohm’s model was generally taken as a return to the narrow approach of the mechanistic method of portrayal, even though an understanding of quantum mechanics

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[666] Pylkkänen 1992, 62. As already stated, the Copenhagen Group also highlighted the holistic nature of the wave function.

[667] Bohm´s specific example of the hidden-variable theory agreed precisely with conventional quantum mechanics in all its empirical predictions. Bohm did not submit his theory to the apparently-harmless, technical assumption-related additive properties assumed for the way that observables are dependent upon hidden variables , which von Neumann had employed in his ’proof’. Polkinghorne 1990, 56-57. Associating relativistic Lorenz-invariance with Bohm’s theory cannot however be achieved without problems.

[668] The notion of particle becomes blurred when an electron, for example, is regarded ”as an inseparable union of a particle and a field.” Bohm 1990, 271. As discussed in the next chapter, the field even has some ”mind-like” properties.

[669] Herbert 1985, 49. For more about Bohm’s interpretation, see for example Stenger 1995, 106-110, 127-130 or Bohm and Hiley 1987.

would require a rational broadening of the earlier way of thinking. According to Pauli, Bohm's hypothesis was ”old goods which had been dealt with long ago” [670]. For a long period, Bohm abandoned development of the hidden-variable theory and at the beginning of the 1960s he started developing a new ontological conceptual frame of reference for physics founded on the concept of implicate order. According to the implicate order model, the world is a multi-dimensional indivisible whole whose parts have internal relationships with each other. Non-causal connections between particles can be explained by what we see as separately influenced particles being three-dimensional projections of the same events in multi-dimensional space. The implicate frame of reference is a better fit than Bohm's earlier ideas with Copenhagen thinking when dealing with, for example, questions concerning electronic trajectories.

In the 1980s, Bohm returned to the hidden-variable theory, and working with Basil Hiley, developed an ”ontological interpretation” in which the central concepts were ”objective wholeness” and the already-mentioned ”active information”. In this multi-level framework, in which form informed matter in a specific way, biological and psychological phenomena and the question of the relationship between mind and matter could be approached in a new way. Mental processes no longer had to be reduced to the quantum level, since Bohm suggests that in certain ways, the activity of information at the quantum level is similar to the activity of information in ordinary human subjective experience. He uses the similarity as a basis for his mind-matter theory which is discussed in more detail in the following section 4.3.5.

Even though Bohm's theory of hidden variables is almost classical and mechanical at the microscopic level, his ontological interpretation differs radically from classical physics, something that Bohm himself emphasised. In its entirety, the model does not lead to complete predictability or observability, nor is it possible, even in principle, for people to either know the whole of multi-dimensional and multi-layered reality in the way that Laplace's demon did, or have the ability to predict all its events. Some of Bohm's successors appear to make a clearer attempt at classical metaphysics and realism than Bohm himself. In recent years, one of the alternatives that has arisen in the discussion concerning the interpretation of quantum theory has been so-called ”Bohmian mechanics”, in whose circles Bohm's 1952 ”hidden variables” interpretation is being further developed.

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670 Pauli refers to de Broglie's matter-wave-hypothesis. Pauli's earlier criticism played a part here in the fact that de Broglie abandoned the theory and only returned to it following Bohm's satisfactory response. The reaction of the Copenhagen Group can also be seen from the viewpoint provided by the sociology of science. 'The ruling elite' did

Bohm did not fear metaphysical re-evaluation and in many situations, his view concerning the basis of reality can provide more practical propositions than for example the Copenhagen interpretation.[671] Because of his ontological approach, Bohm was not however capable of re-evaluating the position of the external observer or seeing the limited area of application for the ontological model he had created. In practical terms, the Bohmian model does not provide events in the microscopic world with anything more than statistical forecasts in the way that quantum mechanics does. It is also not possible to test the existence of quantum potential since this depends on the amplitude of the wave function obtained from the Schrödinger equation, and a particle's initial values cannot be defined to a greater degree of accuracy than is set by the limits of the uncertainty relationship.

Physicists have traditionally avoided postulating artificial structures of a type which theories do not absolutely require and whose existence cannot in principle be tested. Even though it is impossible to completely avoid the incorporation of metaphysical material into theoretical interpretation, the incorporation of such material into physics results in problems. Natural science has achieved great victories by avoiding speculative metaphysics and placing its trust in the experimental method.[672] Bohr moved the development of his interpretation forward by cautious evaluation of the correctness of earlier metaphysical assumptions and their tenability in the light of new knowledge. If the quantity of metaphysical postulations allowed within physics increases, the number of possible world models can clearly become infinite, and we do not have empirical ways of selecting which of them are believable. Even though Bohm's model can be assessed as being unnecessarily metaphysical, the drawing of a line between physics and metaphysics cannot however be carried out in an unambiguous manner.

The many-worlds interpretation

In the many-worlds interpretation, the universe is thought of as containing an infinite number of parallel universes. Are these to be viewed as redundant metaphysical digression, or does

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not want to consider an alternative way of thinking. See for example Cushing or Beller.

[671] It can be argued that Bohm's model is useful when, for example, making interference experiments with biomolecules. The Copenhagen interpretation does not offer proper tools to deal with the border areas between the quantum- and classical levels.

[672] The history of science shows that hypotheses such as quantum potential which are based on empiricism and a working formalism have often promoted science –probably more often than a positivistic 'denial' which avoids speculating about anything that lies behind observations. Hypotheses are required if the assumed new phenomena are to be tested.

quantum theory directly offer its own mathematically elegant interpretation, as supporters of this interpretation maintain? The many-worlds interpretation was presented by Hugh Everett, John Wheeler's doctoral student, in 1957 and it has subsequently enjoyed strong support, among others from Paul Davies and David Deutsch. It arose in the context of cosmologists wrestling to apply quantum mechanics to Einstein's general theory of relativity.

The attractiveness of the many-worlds interpretation is often taken to be its ability to solve the measurement problem - it is not necessary to handle observational and measurement situations in a different way to other interactive influences, since the artificially-viewed projection postulation is simply forbidden. Always when the theory predicts many possible results, all possibilities given by the state function can be fulfilled, since reality can branch into different worlds in every interactive situation. For example, if a measurement situation has five possible results, the measuring equipment and system are developed into five quantum systems which differ from each other only in the results shown by each of the measurement systems. Bruce de Witt describes the situation as one in which each quantum transfer that takes place in each star, in each galaxy, in each corner of the infinite universe, splits our earthly world into an uncountable number of copies.

All interactions in Everett's super-real world are of the same kind: two systems come together, get correlated, and start to realise all their mutual possibilities. When the wave function is assumed to represent reality itself, not just probability, every event that can happen does happen in some corner of reality. When interacting, systems reveal all their mutual possibilities. Every little ”could be”, no matter how improbable, is given its time to shine. While such a universe differs radically from a clockwork mechanism, it cannot reveal anything truly surprising or consciously alterable, since all events unavoidably follow from its own automatic progression. Everett's model attempts to portray reality in the classical manner – in an objective way from the outside - and he is able to treat measurement devices and measurement acts fundamentally in the same way as all other devices and acts. Strictly speaking, however, there are no real measurements in Everett's super-real world, only correlations.[673]

In the many-worlds interpretation, people are in principle handled in the same way as other objects. In some worlds I can accomplish things, or rather I am able to implement my greatest hopes, while others contain my most awful dreams. Even though the super-reality postulated by

[673] Herbert 1985, 173-175.

the interpretation could be supplied by an almost unlimited amount of material for the actualisation of all possible worlds, people being chosen for specific worlds cannot obtain knowledge of other worlds, and do not have contact with their copies that exist in other worlds because the interpretation excludes any interaction between worlds. This state of affairs also prevents any testing of the many-worlds interpretation. The branching of worlds remains an unfounded auxiliary hypothesis with the help of which an attempt is made to preserve the traditional assumption of a fully-observable reality which is independent of human activity. Even though some type of visualisable portrayal of the world can be given, this interpretation does not allow people to know the whole of reality or to predict development in the known world.

Neither David Bohm's nor the many-worlds interpretations have, in spite of a long-drawn-out and vigorous debate, received very much support from physicists. More interest has been generated by the interpretation developed by physicists such as Murray Gell-Mann, James Hartle, Griffits and Roland Omnes who have been working to develop a more-sophisticated and palatable interpretation of quantum mechanics which does however continue along the same line, i.e. avoiding references to an observer. Their interpretation grows out of Feynman's version of quantum mechanics and the many-worlds interpretation, and attempts to make the quantum-to-classical transition a smooth one. The various incarnations of this new interpretation are known as Post-Everett quantum mechanics, Alternative histories, Consistent histories or Decoherent histories. Alternative or Consistent histories differ from the many-worlds interpretation in that every allowed history does not actually occur. Decoherence arises naturally by the interaction of physical bodies with their environment. Much of this new interpretation remains under development and is the subject of intense debate.[674]

In spite of the prolonged discussion of interpretation and many different attempts, a successful reconciliation between quantum physics and the mechanistic-deterministic framework for reality shaped by classical physics has not been achieved. From the viewpoint of the Copenhagen group, the discussion can be generally characterised by saying that up until now, the lessons of quantum theory have not been taken seriously, and that every possibility of holding on to earlier ontological and epistemological starting points has been used.[675] More attempts have been made to avoid Bohr's thinking than to develop it further. Many physicists have, like Bell, considered talk about the reassessment of the concept of reality and the inadequacy of the generally accepted

[674] Stenger 1995, 176-187.

concepts as being too bizarre and romantic. The conclusion to be drawn from the discussion of interpretation and its direction are that the classical frame of reference, the familiar "horizon of understanding", has had a powerful influence on shaping physicists' ways of thinking when they are interpreting quantum theory. They have wanted to believe that humans are capable of portraying the world in an absolute, objective and preferably deterministic manner, and essentially exclude their presence from the investigation of reality.

Preservation of the classical assumptions for as long as possible has been sought after, even though it leads to empirically unfounded assumptions concerning quantum potential or multiple worlds. Also, many of those who have not wanted to postulate additional structures in the world often cling almost unconsciously to many of the presumptions of classical metaphysics. It appears that they would rather relinquish the whole interpretation of quantum-mechanics and deny the need for a better understanding of reality than give up the ideals of classical objectivity. Researchers taking a critical attitude to speculation can, in the name of Positivism, dismiss the whole idea and conception of reality. To Positivists, it is enough that theory predicts the correct result. The question ”Why?” is unnecessary. Instrumentalist oriented supporters of statistical interpretation can avoid the apparent paradoxes of the new physics by being content with statistical laws and prohibiting the handling of individual events.[676]

The need for a fundamental change of paradigm is sometimes also disputed by denying that there are any real problems concerning quantum theory. Metaphysics or any further interpretations are not required as the theory works well and predicts the correct results.[677] Another typical method of approach is a resort to mathematics. Specific interpretations are not believed to be necessary since reality effectively reveals itself in mathematical form. The nature of reality becomes, via mathematics, as understandable as it actually can be. An adequately tested mathematical theory and reality essentially become one and the same thing. It is considered unnecessary to ponder what complex values or multi-dimensional spaces actually manifest, or whether the new relationships and dependencies in reality addressed by mathematical theory could perhaps be portrayed in some other way. It is believed that the deeper nature of the universe cannot be understood by anyone unable to use mathematical language and that it will never therefore be

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675 K.V. Laurikainen believed that the strong tendency since the 1950s to seek a more-realistic interpretation was a result of the materialistic conception of reality among the generation educated during the war or immediately after it. Laurikainen 1997, 38.

676 For a concise presentation of different interpretations, see Kallio-Tamminen 1990, 1993.

677 For example Weisskopf in his article “Foolish Questions”.

concretely understood.

If someone does not, because of the advent of quantum mechanics, wish to abandon the familiar metaphysics which is taken as self-evident, no-one and nothing can force them to do so. Our experiments at the normal macroscopic level do not appear to offer tools for an intuitive understanding of the portrayal of the world of quantum mechanics, and because of their long history, the assumptions of classical physics concerning reality appeal to our common sense. When examining the discussion concerning the interpretation of quantum mechanics from a historical perspective, it is however surprising that the metaphysical assumptions involved are not discussed in a clearer, more explicit manner. In spite of the almost complete change in the concept of matter, discussion concerning the interpretation of quantum mechanics has not dealt to any great extent with the nature of objects and their properties, or the relationship of humans and their language to these. Even the Copenhagen group did not present the ontological, epistemological and cosmological origins or consequences of their interpretation of quantum mechanics in a particularly clear manner.

Even though fundamental metaphysical assumptions are difficult to verify directly in an experimental manner, they are neither arbitrary nor inconsequential. The roots of science lie in metaphysics. The relative infrequency of philosophically ambitious attempts at interpretation should not however be surprising, since familiarity with either metaphysics or the history of natural philosophy is seldom connected with the use of quantum mechanics and a good command of formalism. In-depth and wide ranging interpretations are unlikely to result without sufficient background material. It is however surprising that in their discussions of the interpretation of quantum mechanics, physicists have, in addition to traditional material causes, also begun to make reference to human consciousness. The most interesting task employing quantum theory has been the search for new ways of thinking which would allow the transcending of Cartesian substance dualism.

4.3.5. The concept of consciousness in discussions concerning the interpretation of quantum mechanics

The concept of consciousness entered the vocabulary of physics in the 1920s as a result of the quantum mechanics measurement problem when John von Neumann, an eminent Hungarian mathematician, questioned the traditional idea of the detached observer by presenting as a solution to the measurement problem the projection postulate, according to which only one of the many possibilities included in wave functions could be realised in a measurement situation. As will be explained in more detail in the following section 4.3.6., von Neumann did not provide any clear explanation for his projection postulate, but Fritz London and Edmund Bauer soon suggested that reduction of the wave function was not perhaps a straightforward physical process, but that its occurrence demanded the consciousness of an observer. Consciousness somehow collapses the wave function. Reduction of the state function only occurred when the observer somehow became conscious of the measurement result.[678]

The idea that consciousness somehow made it possible for the quantum reality which included superpositions to manifest following a measurement in the familiar classical world was advocated at a later point in the discussion of the interpretation of quantum mechanics by, for example, Eugen Wigner and J.A.Wheeler, according to whom ”an elementary phenomenon is a phenomenon only when it is an observed phenomenon.”[679] Their viewpoint can be viewed as an argument supporting subjective idealism in the traditional discussion concerning the psycho-physical problem. In this way of thinking, consciousness was presumed to be an entity independent of matter and it did not need to conform to the laws of quantum mechanics. Consciousness is viewed as a more important factor than matter in shaping the appearance of the observable reality.

Quantum mechanics does not however offer any evidence for the thought that mind can directly affect matter. No-one can even predict what experimental results will be yielded by a specific measurement situation, to say nothing of the fact that they might be able to consciously bring about the desired result. Idealists can try to get around this problem by appealing to supernatural influences such as God, the spirit of the world, or Pauli’s archetypes, to whom quantum-mechanical indeterminism allows the possibility that they, without humans being aware of the fact, choose the desired result from what to us appears to be a wide range of random possibilities.

In my view, this idealistic way of approaching the nature of mind and matter or their interaction does not disclose anything more than the materialistic models which draw on classical physics and attempt to reduce spirit to matter. In spite of centuries of pondering, Reductionist

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[678] Herbert 1985, Murdoch 1987, 126-127.
[679] J.A. Wheeler in Jahn (ed.) 1981, 1, 91.

materialism or Idealism have not proved able to solve the psychophysical problem raised by Cartesian dualism, even though the interaction of matter and consciousness can be taken, in a fundamental way, as a precondition for everything we do. Since quantum mechanics bestows on matter the assumption that the world of physics is not emptied in the familiar deterministic particle-mechanics reality, the question of the relationship between mind and matter can, on this basis, be evaluated within a wider frame of reference. It is not necessary to attempt to understand every event in nature by reducing phenomena to separate particles moving in space-time.

Suitably interpreted, quantum mechanics could offer a foundation for both matter and consciousness. Bohr speculated about quantum processes taking place in the brain in the 1930s, and Wolfgang Pauli and David Bohm, when interpreting quantum mechanics, viewed reality as in some sense psychophysical. Even though their ontological models differed, both men stressed the unity of the physical and psychic sides of reality. They did not wish to reduce spirit to matter any more than they wished to reduce matter to spirit, they can rather be viewed as in a certain way seeking for a return to a non-Cartesian monistic and organistic conception of reality.[680]

In the 1950s, Wolfgang Pauli, who had taken part in the development of the Copenhagen interpretation, developed his views in an ontological direction. In the manner of Pythagoras and Kepler, he concentrated on the mysterious power of mathematics in physics. It directed the researcher as if it was some kind of higher power, and this fact provided Pauli with material to speak of a universal cosmic order which was manifested in both natural laws and the operation of our psyche. In cooperation with C.G.Jung, Pauli postulated that cosmic archetypes reminiscent of Plato’s ideas are present in the background to mind and matter.[681] The compatibility between our concepts and our sense observations is based on the same cosmic order and the archetypes coordinate both people’s internal and external worlds. The collective unconscious comprised everything that can potentially become conscious.

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[680] To interpret the idea of psychophysical reality as representing objective idealism does not do justice to either Bohm or even to Pauli, who did not want to deny the fundamental reality of the lawful material world. According to Paavo Pylkkänen, Bohm realised the failure of substance dualism, was dissatisfied with both reductive materialism and reductive idealism, and tried to formulate a different, non-dualistic and non-reductive way of thinking about the relationship between mind and matter. Pylkkänen 1992, 36. Pauli also considered that both physics and psychology are of equal importance when one is trying to describe reality and solve the psychophysical problem. Laurikainen 1994, 167.

[681] Laurikainen 1994, 150-151, 162, 168. Through archetypes, Pauli found a connection to the cosmic order he knew so well in the physical world. He also studied Kepler’s ideas concerning archetypes and considered that Jung and Kepler used the concept in a similar meaning which had been influenced by neoplatonism. In a state of contemplation, the soul could remember structures in the world of ideas which could be viewed as the thoughts of God.

Pauli emphasized, in the same way as Heisenberg, that the situation we meet when analysing observations in quantum mechanics forces us to abandon Cartesian dualism. In particular, Pauli was critical of the idea of psychophysical parallelism created on the basis of this dualism. Parallelism remains a foggy spiritual cloud in western thought because it still is without scientific motivation, and also because, over the last few centuries, it has resulted in a sharp distinction being made between natural sciences and humanistic sciences as well as between science and religion. For Pauli, the complementarity of quantum mechanics provided a model for approaching the psychophysical problem. He thought that physical and psychic phenomena are mutually complementary in the same way that the wave description and the particle description are complementary in atomic theory. Both are manifestations of an abstract transcendent whole that is not describable within the framework of any rational theory.[682]

Pauli's sketchy attempt to outline a psycho-physical reality can be criticised from many directions. In his model, Pauli to some extent actually explained away the new freedom discovered in nature. The world as he portrayed it was neither completely random nor did it give humans real freedom, since the archetypes could affect test results and lead development in any direction they desired, for example via the experimenter's subconscious mind. When it appeared that physical laws no longer determined the results of individual experiments, the traditional objective way of thinking perhaps pushed Pauli into searching for metaphysical causes. The ontological way of approach he was targeting is unavoidably problematical when talking about phenomena which cannot be directly observed. Even though the psycho-physical problem obviously vanishes if reality is postulated as psycho-physical, the more accurate portrayal of such a postulated metaphysical reality remains a problem. David Bohm did not speak about archetypes, but instead drew attention to the active information and implicate order present in reality.

Bohm notes that the quantum wholeness brought out in his idea of quantum potential is reminiscent of the wholeness usually associated with living organisms. The whole may be said to organise the activities of the parts in a way that is not obtained by putting together the parts of a machine. His notion of active information begins to resemble the domain of mind and suggests a rudimentary mind-like behaviour in matter, since for Bohm, the essential quality of mind is just some kind of activity of form rather than of substance. Active information is simultaneously physical and mental in nature and accounts for the inseparability of the mental and physical sides

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682 Laurikainen 1997, 30-31, 84.

of experience in any situation. Moreover, distinction between the mental and the physical is relative in the sense that what appears as mental in one context may be seen as physical in another, more subtle context. There is no unbridgeable gap or barrier between any of these levels because at each stage, some kind of information provides the bridge.[683]

In addition to Bohm and Pauli, John Eccles, David Hodgson, Roger Penrose, Euan Squires, Henry P. Stapp and Danah Zohar have, among others, subsequently attempted to understand consciousness phenomena using a framework formed on the basis of quantum mechanics. For example, Stapp and Zohar have hypothesised that the wave function directly describes the real world of which people are also a part. Stapp exploits Werner Heisenberg's thinking concerning the actualisation of potential possibilities and hypothesises that the world is by its nature more idealistic than material. In this way, human consciousness is naturally integrated within it. Consciousness is part of a global process which cannot be fully understood but which actively creates and shapes the universe.

Zohar takes wave-particle dualism as her starting point and links consciousness directly to the wave aspect of reality. Matter and consciousness arise from the same quantum reality and each of them presupposes the existence of the other. Through consciousness, the wave side of reality, we are in deeper contact with our environment than was supposed by the objectivising particle-mechanics way of thinking. Via the wave aspect, quantum systems are able to enter one another and can, in certain circumstances, even share the same identities. Different variable wave configurations also contain alternatives whose employment may result in the birth of a new and changed world.

The above examples show that many researches have argued for the relevancy of quantum mechanics in questions concerning consciousness phenomena. The participation of physicists in the handling of these matters has also been the subject of extensive comment. Their speculative models suited to quantum mechanics are not necessarily fully coherent and consistent, and many of the suggested physical-physiological hypotheses[684] are certainly open to criticism. The new ways of thinking take a vigorous stand on fundamental ontological questions, but more precise

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683 Pylkkänen 1992, 36-44. Bohm 1980, 1989 and 1990.

684 For example Zohar thinks that consciousness is a coherent quantum phenomenon based on the Bose-Einstein condensate which arises in organic tissue. Penrose has suggested that the physical basis of quantum consciousness is microtubules located in brain cells.

analyses of the nature of reality are usually left uncompleted. These ways of thinking are often said to represent Idealism, Pan-psychism or Materialism, either by the presenters themselves or through an external appraiser's interpretation. In my opinion, these traditional classifications are, in all cases, more or less problematical since their concept of matter in these discussions has drifted so far away from the classical idea of matter. If, for example, the ideas by Roger Penrose and David Hodgson are taken to represent Materialism, then Materialism has undergone a decisive change of content. Both men stress such non-algorithmic abilities of human beings as understanding, drawing conclusions by analogy, making choices and qualitative comparison and evaluation of wholenesses that are traditionally often regarded as spiritual. It is their opinion that a mechanically based computer does not have these capabilities, and that a mechanical metaphor is not of great benefit when attempting to understand them.

When viewed from the customary frameworks of dominant research, general claims presented on the basis of physical results can easily appear amateurish or too speculative. Most workers in artificial intelligence and neuroscience remain unconvinced by Penrose's assertion that the human mind cannot be simulated by a machine.[685] The models presented are, however, interesting in many respects. They include convergent features, for example the world is generally viewed as a developing or changing system and human beings are not detached observers but belong to the same reality and shape it by their actions. Clear points of contact with many of the central ideas in the history of philosophy can be found in these ways of thinking, even though the models and arguments presented have not really appeared dazzling to those who are acquainted with traditional metaphysical systems of philosophy.

It is certainly true that both Spinoza's pantheism and Leibniz's parallelism are more beautiful and comprehensive systems of thought than either Bohm or Pauli's psycho-physical propositions. Rather than making comparisons, it is however important to see that the new physics offers the possibility of further developing the attempts of the great system builders in order to gain a better understanding of our place in reality. Both Spinoza and Leibniz rejected Descartes' dualism and the nowadays generally accepted Materialism. They believed that the human soul or spirit also belonged to a lawful reality. It is however difficult to combine freedom of the mind to a world described by deterministic laws of matter. New methods of approach drawn up on the basis of quantum mechanics might offer new hypotheses concerning the

[685] Stengers 1995, 279.

connection or interaction between domains that are usually taken as psychic and physical.[686] The explanation of conscious phenomena within a scientific world-view will receive more space since quantum mechanics allows solutions which remain outside the familiar ontological categories of traditional ways of thinking. For example, via the concept of quantum state or the re-definition of matter [687], physics could have much to offer in the handling of psycho-physical problems.

Familiar ontological and objective approach is however unlikely to be capable of providing exhaustive solutions to questions concerning the relationship between mind and matter or man and nature. We do not have the tools which would enable us to choose between, for example, Pauli's archetypes, Bohm's active information and implicate order, or the innumerable other models of reality which have already been presented or which could be postulated in the future. Mind and matter can be integrated into the same reality without adopting massive ontological standpoints. Bohr rejected traditional ontological and objectivising methods of approach and stressed the fact that quantum theory was the ultimate theory of reality shaped by man. It is something more general and trancendent to thinking that touches mind and matter and it can offer a foundation for both. Bohr noted that according to science, there was ”no reason in saying that there is no reason in the universe” [688]. To him, speaking about mind and matter is just a way of dividing and describing the wholeness of reality in a manner which we are able to comprehend. Humans are immersed in the same wholeness whose structure and operation they attempt to describe in comprehensive and coherent way. [689]

The philosophical path of deep conceptual and metaphysical revisions that was taken by Bohr and the Copenhagen Group is not being nowadays followed in physics. The basic

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[686] In my opinion, the psychophysical problem which has so troubled modern philosophy does not, in Bohm's model, enjoy a clear solution that would preserve free will. The many dimensions or layers of reality, or the idea that information guides matter, do not guarantee that a relative freedom of mind could be united with material reality which is assumed to be deterministic. Instead, Bohm clearly understands that human beings are also somehow formed by the new information they receive from either the external or internal world. Some kind of ”material factor” restricts the forms our thoughts can take. Rather than this being the result of 'active information', logic could be proposed as such a shaping field.

[687] In the terms used by Plato and Aristotle, matter as such is an abstract and plastic material which evolves when connected to different kinds of form.

[688] Bohr 1958, 66. Even if Bohr avoided ontological standpoints, he clearly regarded humans as a psychophysical whole and part of reality. He believed that the conscious mind was connected to living organism and speculated already in the 1930s that some kind of quantum processes take place in the brain.

[689] Ultimately D. Bohm also expressed the view that talk about ”levels,” ”mind,” and ”matter” is vague, because they are referring to a single underlying process. There is no fundamental distinction between subject and object, the whole of life is intertwined in the whole of multi-dimensional reality. Pylkkänen 1992, 44.

presuppositions and objective ideals of classical metaphysics are simply taken as givens. Confidence in abstract mathematics has often been connected to Instrumentalism, which naturally does not result in improved understanding concerning the nature of reality. This attitude does not however satisfy Realists, who wish to achieve a deeper understanding of the nature of reality. Since quantum mechanics has not been reconciled with the classical concept of reality after a debate that has now lasted for almost a hundred years, there is good reason to take seriously the thought that the description according to classical physics which has worked well for more than two centuries and attained the status of a paradigm must be considered inadequate. Rather than wasting time looking backwards, now is the time to concentrate on what we can learn from the current situation and on how to move forward. As quantum mechanics cannot be reconciled with the concept of reality adopted by classical physics, it offers material in the light of which better methods of portrayal can be sought. Creating a new conception of reality requires both physicists and philosophers. So far, competing models for the Copenhagen interpretation have been mostly been presented by physicists who usually strive to investigate and explain what exists. This starting point already includes a presupposition which philosophers can avoid. For example, in Heidegger’s opinion, it is more profound to examine what existence is than to examine what actually exists.

Physicists have not been eager to study the philosophical foundations of quantum physics. It has not been seen as necessary since research has moved ahead like a train. Perhaps alarmed by the prospect of falling off the train, the great majority of physicists have hurried to adapt the theory to new problems and phenomena, to solve practical problems.[690] Quantum mechanics has been successfully adapted to different sorts of problems, but the measurement problem and the question concerning the nature of reality, i.e. its more accurate characterisation, have remained unresolved. In the midst of all this frantic activity, a philosopher has good reason to take a closer look at the landscapes in which the journey is taking place, to assess the durability of the route being taken, and to consider whether the expected destination is a reasonable one. What do the indeterminism, non-locality and problem of measurement in quantum theory really tell us about reality and our place in it? Plato and Aristotle would certainly have been able to exploit knowledge of the strange behaviour of tiny building blocks of matter in their debate with the Atomists, and Kant would have shaped his strict categories in quite another way if the theory of relativity and quantum mechanics had been known in his day.

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[690] Enqvist 1998, 147.

The physicist-philosophers in Copenhagen clearly saw the inadequacy of the mechanistic-deterministic approach employed in classical physics and their thinking succeeded in making many of the new features and paradoxes connected with quantum theory more understandable. The thoughts of the Copenhagen group on the need for a renewal in our concept of reality have become no less topical as decade succeeds decade. Quite the reverse, we are perhaps more ready than ever to understand that physical realism no longer requires us to think that a single particlemechanistic model represents fundamental reality, and that objectivity necessarily means the same as independence of the human observer. Using the Copenhagen interpretation and above all Bohr’s method of approach as a foundation, even the notorious measurement problem of quantum mechanics can be illuminated in a new way.

4.3.6. The measurement problem and the position of the observer

As discussed in Section 4.3.5., the theoretical treatment of measurement in quantum mechanics has been problematical. Abner Shimony has described the conceptual problem of the reduction of a superposition as a "small cloud" in contemporary physical theory in which the laws are otherwise completely independent of the existence of minds. He anticipated that our present intellectual discomfort would be compensated if this difficulty eventually provides some insight into the mysterious coexistence and interaction of mind and matter. "Small clouds" in an otherwise highly successful theory have often been precursors of great illumination.[691]

The accepted viewpoint among physicists is that because quantum mechanics is a comprehensive theory concerning reality, it should be applicable in equal measure both to the object being investigated and to the measuring apparatus. While the universality of quantum theory is taken for granted, physicists have not, however, been able to reach a consensus concerning measurement. When the measuring apparatus and the object being investigated are handled as quantum mechanical systems, the measurement result is a superposition of state vectors which, according to the generally accepted interpretation, is not an observable state. The final result of making measurements should be to obtain a so-called mixed state, but the transformations necessary to convert a pure initial state into a mixed final state do not exist.

In spite of this fundamental problem that the formalism brings with it, there is no desire to

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[691] A. Shimony, "Role of observer in Quantum Theory." *Ann.Jnl.of Physics,* vol 31, (1963), p. 773.

abandon the traditional objective way of treating measurement. The problem of reconciling non-classical quantum states with values for classical properties remains. Quantum mechanics provides no substantive or causal relationship between the two classes of characteristic. The mathematical equations of motion describe in detail the development of quantum states describing individual systems, but the observed eigenvalues are statistical. In a measurement situation, non-classical quantum states are generally thought of as somehow being ”reduced” or ”collapsed” to classical ones.[692]

For example, Peter Mittelstaedt, a physicist who has carried out a great deal of research into the measurement problem, accepts the assumption of the completeness of quantum mechanics in his recently published book: ”Once the universality of the theory is taken for granted, it is obvious that quantum mechanics can also be applied to experimental setups which are used as measuring apparatuses.” Even if the main theme of the book is the idea that quantum mechanics is valid not only for microscopic objects but also for the macroscopic apparatuses used for quantum-mechanical measurements, Mittelstaedt is forced to admit that the problem of the objectivisation of measurement results leads to inconsistencies that cannot be resolved in an obvious way. He concludes that this still open problem has far-reaching consequences for the possibility of recognising an objective reality in physics.[693]

It is as difficult for Mittelstaedt as it is for everyone else to understand why the objectivisation of measurement has not succeeded. Contrary to the customary presupposition, the "complete" theory appears unable to generate a model for measurement. This is, however, something that Bohr already anticipated in the early days of quantum mechanics. As, for example, Henry Krips has noted, Bohr disputed the common requirement that quantum theory should generate a model for the process of measurement.[694] Bohr saw that a description of the measurement process for quantum quantities would have to be carried out in classical terms and rejected the idea that these classical descriptions should in turn be reducible to quantum theoretical descriptions. To Krips, the reasoning behind the choices made by Bohr remain vague and Bohr’s ideas do not convince him. Krips concludes that while generation of the model is of course not necessary, quantum theory must be able to provide such a model if is to be 'complete'. Like many others, he is afraid that Bohr’s solution would lead to the loss of completeness in quantum mechanics.

[692] Auyang 1995, 22, 82.
[693] Mittelstaed 1998, ix, 103.
[694] Krips 1990, 106.

Correct understanding of Bohr's thoughts concerning the measurement situation does however require a more far-reaching reassessment of the concept of reality and its theoretical depiction. Bohr did not believe that the dilemma could be solved using the traditional objectivising framework of thinking in the way that Krips and Mittelstaedt appeared to anticipate. Bohr constantly highlighted the fact that the discovery of quanta indicated that all phenomena could not be divided into separate parts. Since the object being examined and the measuring apparatus cannot be isolated from each other in an unambiguous way while interaction is taking place, the system that is being investigated cannot be considered as being closed. Even the observer - as an extension of the measuring apparatus - cannot be isolated from the situation. It is for this reason that the classical objective treatment of measurement process is not possible.[695]

> "The very fact that in quantum phenomena no sharp separation can be made between an independent behaviour of the objects and their interaction with the measuring instruments, lends indeed to any such phenomena a novel feature of individuality which evades all attempts at analysis on classical lines, because every imaginable experimental arrangement aiming at subdivision of the phenomenon will be incompatible with its appearance and give rise, within the latitude indidicated by the uncertainty relations, to other phenomena of similar individual character.[696]

We observe different phenomena in differing contexts whose unambiguous treatment demands portrayal of the whole of the experimental system being employed. In classical terms, measurement simply means that the properties of the object being examined are compared to the properties of another system operating in the measuring apparatus. In the quantum region, comparisons cannot however be made without interacting with the system being investigated and the measuring apparatus therefore has its own intrinsic influence on the phenomenon. This leads to the point that the presumption in classical physics that measurement does not disturb the system being investigated, or that the degree of disturbance caused is always controllable, must be abandoned. The properties of atomic objects cannot therefore be spoken about without taking account of the manner in which the observations were obtained. Since the measuring apparatus defines the conditions in which a specific phenomenon can be observed, and since the influence of the measuring apparatus cannot be clearly isolated from the behaviour of the undisturbed object, we cannot obtain direct observational knowledge of the independent properties of objects in the microscopic world.[697]

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695 Bohr 1963, 2, 52, 61, 90, 92. Bohr 1948, 313.
696 Bohr 1939, 19-20.
697 Bohr 1939, 19. Bohr 1963, 6. Bohr 1967, 50.

For example, an observer can, using a suitable form of experimental apparatus, measure the precise location of an electron, or can use another type of equipment and obtain from it a precise measurement of the electron's wavelength. In both events, the choice of experimental apparatus defines whether particle or wave properties are observed. The observable nature of the electron is essentially defined via the greater wholeness of the measuring device. By looking in different ways we receive different answers. In itself, however, each measurement is neither inaccurate or unclear.[698] For this reason, according to Bohr, observation in quantum mechanics *per se* differs in no way from the situation in classical physics, even though humans shape the world by their actions and choices, the case of whether or not someone becomes conscious of a certain result in a specific measurement situation or not, will not effect on the shaping of observed reality.

A measurement situation makes a deterministically developing ”closed” system which would obey the Schrödinger equation into an ”open” one. During an interactive process, the system made up of the observing equipment and the object are not in any definable state, and cannot be subjected to any form of analysis before the interaction has ceased and a new ”closed” system has formed in which the measuring device has settled into one of the states that we can read. This thinking of Bohr's concerning the unavoidable influence of the environment is similar in nature to that of supporters of the decoherence model. Bohr however goes further in seeing that even separating subject and object cannot be achieved in an unambiguous way while interaction is proceeding, because the division between the experimental equipment and the observer as an extension of it is not an absolute one.[699]

According to Bohr, the difficulty of objective observation in microscopic physics can be compared to the psychological problem of self-awareness. The observed subject can be part of the content of its own consciousness, but the possibility of observation does however require that part of the subject remains external to the content of the investigating consciousness. This in turn requires a moving or relative rather than an absolute division between subject and object. However, consistent description of our experience is based on the clear separation of subject and object. When we wish to communicate our internal or external observations, we have to make a theoretical distinction, a cut, and detach ourselves from the world we are investigating and portray it as independent. Classical physics mixes this abstract portrayal into reality by believing that it can separate subject from object and investigate and measure the external world as an

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[698] Wheeler refers to the same situation when explaining measurements to Horganille: “Not until you start asking questions, do you get something… The situation cannot declare itself until you have asked your question.” Horgan 1998, 82.

independent system.[700] For his part, Bohr saw that quantum mechanics demanded change in the whole of classical physics' causal space-time description.[701]

Observations concerning the atomic level cannot be objectivised in as simple a manner as was thought in classical physics. Bohr saw that humans observing the microscopic world are bound to a macroscopic measuring device and are only able to observe phenomena which are dependent on the measurement system. Our description of the quantum world is unavoidably based solely on the macroscopic properties of the measurement equipment and the observation of permanent marks formed therein, which must be directly definable in either everyday language or on the basis of the terminology used in classical physics. The quantum features of phenomena are revealed in the information which can be derived from atomic objects on the basis of these observations.[702]

Since the results of measurement are based on stable evidence such as the dots left by photons or electrons on a photographic plate, measurement requires irreversible physical or chemical reactions, and at the most fundamental level this reveals the irreversible nature of observation itself.[703] This implies that qualitative change in reality can be brought about by human activity. The course of so-called objective reality is actually changed in the different processes which follow from our divergent choices and actions. Choices related to different kinds of measurement methods and apparati are part of our irreversible activity. Bohr actually said that in the framework of complementarity, the idea of universal predestination should be replaced by the concept of natural evolution.[704]

Bohr's starting point was that man does not have an external point of observation from which he could view the world as it is. To him, the purpose of measurement is not to check a value of some pre-existent quantity but rather to obtain information and knowledge about reality by participating in its processes. When the system under study is not unambiguously separable from the measurement apparatus during the measurement process, the system is not closed and, accordingly, human impact on the observed reality does not create any physical problem. When seeking knowledge, humans are tied to experiences in the macroscopic world and the device

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[699] Bohr 1958, 73, 90, 101.
[700] Bohr 1958, 27.
[701] Folse 1985, 68-70.
[702] Bohr 1963, 3-4. If reality is described by a reversible theory, it cannot change or develop in a qualitative manner because phenomena must be similar when proceeding forwards or backwards in time.
[703] Bohr 1963, 25, 61 & 92.
[704] Bohr, 1958, 81.

used for measurement defines the conditions in which a phenomena occurs. The basis for physical interpretation and theory are concrete changes in the measuring devices which can be described in classical terms. These are things that must be assumed as starting points and it is not necessary for theory to explain them.[705] The lack of a clear mental model concerning measurement does not have to mean, as Mittelstaedt concluded, a deficiency concerning reality. Neither does it mean a lack of completeness in the sense that quantum theory could not be considered to be universal.

The understanding of measurement in different interpretations

As measurements are the foundation for any physical theory, it is no surprise that the question concerning the proper interpretation of quantum theory also culminates in the measurement problem. The conflict between Copenhagen and post-Copenhagen ways of approaching reality and positioning human beings within it can be illustrated in their different treatments of the measurement problem. In general terms, the Copenhagen interpretation emphasises the presence of the observer in physical processes[706], while the post-Copenhagen interpretations have attempted to retain classical ideas concerning measurement; i.e. the ideals of detached observer and objective description. It should, however, be kept clearly in mind that the Copenhagen interpretation has dealt with measurement in two completely-different ways - even though both of them emphasise the role of the observer.

In 1932, John von Neumann tried in his orthodox theory of measurement to find a traditional objective solution to the problem by introducing the concept of the collapse of the wavefunction. Simply stated, this postulate says that measurement causes an abrupt and irreversible transformation in which a pure state turns into a mixture of states. Development of a quantum mechanical system could, therefore, happen in two different ways and measurements should be treated differently from all other interactions in nature. Von Neumann did not provide any clear explanation for his projection postulate, but the concept has subsequently led to idealistic and

[705] This point can also be expressed by saying that whereas classical physics tried to explain material objects with atoms, Bohr tries to explain atomic phenomena using macroscopic objects which have permanent marks created and observed in them.

[706] In a way comparable to that of Bohr, Heisenberg writes "In quantum mechanics, the departure from the classical ideal of objective descriptions has been radical... naturally it still makes no difference whether the observer is a man, an animal or a piece of apparatus, but it is no longer possible to make predictions without a reference to the observer or the means of observation. (To that extent, every physical process may be said to have objective and subjective features.) Heisenberg, 1971, 88.

subjectivistic interpretations which incorporate the suggestion that consciousness somehow collapses the wavefunction.

Von Neumann carried out careful research into where the reduction (i.e. collapse) of the wave function could be located. He divided the measurement chain into tiny parts and realised that the line between the object and the measuring device was movable. In this way, his projection postulate could be adapted to an object, a system consisting of an object and a measuring device, or an even wider system which includes the sense organs and brain of the observer. Somewhat against his will, Von Neumann was led to conclude that perhaps the best way to understand collapse is if the line is drawn between consciousness and the brain. Utilizing this, Fritz London and Edmond Bauer soon added the proposition that reduction of the wavefunction was not perhaps a physical process, but one which required the consciousness of the observer. Collapse of the wavefunction always occurred when the observer became conscious of some measurement result.[707]

Von Neumann's measurement theory is usually taken as part of the Copenhagen interpretation, even though Bohr rejected the subjective projection postulate and regarded the common attempt to create a model of measurement in terms of quantum theory as wrong. Von Neumann's reduction postulate is assumed in several textbooks on quantum mechanics, even though it is commonly believed that talk about collapse, reductions or jumps can, by the standards of physics, only be metaphorical.[708] Even if there is no evidence that any kind of collapse really takes place, avoiding the use of these metaphors when attempting to provide an objective model concerning measurement has been difficult. A consequence of the projection postulate is that measurement is considered to represent the state of the system being investigated immediately after measurement takes place, while classical measurement is thought of as revealing properties as they were prior to the measurement event.[709]

Bohr did not accept Von Neumann's method of approach, on the basis of which it was easy to end up embracing Subjectivism or Idealism[710]. Bohr was silent on the question of the collapse of the wavefunction. He did not accept the common requirement that quantum theory should

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[707] Herbert 1985, Murdoch 1987, 126-127.
[708] No textbook on quantum measurement exists. The projection postulate is seldom covered in standard quantum textbooks. These omissions show that a substantial account of the relationship between amplitudes and eigenvalues is not required for a working understanding of quantum theories. Auyang 1995, 82.
[709] Murdoch 1987, 122-126.
[710] John Bell also noticed that Bohr rejected projection postulate and subjectivism. Bell 1997, 99.

generate a model for the process of measurement. Neither did he believe that traditional treatment of the measurement problem was possible. For Bohr, quantum mechanics demanded rejection of the whole idea of the causal space-time description of classical physics.[711] When it is not possible to create a visualisable model of the microscopic world, neither is it possible to give a clear description of how to proceed from the microscopic level to classical reality. Classical language is not able to provide an exhaustive model of the measurement process. By taking the normal macroscopic physical world as a given, Bohr's method of approach is however completely realistic. By demanding that the measuring device should be treated as a classical system, not an quantum object, Bohr avoided the whole measurement problem, since in practice, the superpositional state of a macroscopic measuring device cannot be differentiated from a mixed state. The artificial projection postulate is unnecessary and measurement yields values which do not dependent on human observation.[712]

Von Neumann's method of approach, which also examined the measuring device as an object, attempted to examine external reality objectively from the outside in the same way as within classical physics. Bohr saw this objective space-time ”description” or ”model” as an abstraction from which human influence had been unconsciously shut out. Like classical physics, Von Neumann's approach was not capable of questioning either the reliability or the limitations of the ontological model being employed: unable to see that a single observational model cannot address the whole richness of reality, it could not, in a ”static” model, take note of the real ontological influence of human activity on the shaping of reality.

Even though later interpretations have generally challenged von Neumann's projection postulate, in their handling of measurement situations they have, as von Neumann did, attempted to portray it in the traditional external and objectivising way. According to the ideals of classical metaphysics ”mechanical” carried with it the connotation of being capable of being imitated in a mechanical model. According to this ideal, it was hoped that measurement would only reveal, in an objective manner, the values of specific attributes of the system undergoing measurement at a specific moment in time without making reference to observer. Measurable properties were presumed to exist in an objective way at all times just as in classical physics: the world stayed the same whether it was observed or not.

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[711] Folse 1985, 68-70.

[712] Murdoch 1987, 112-115. The question of whether measurement yields a value that the system being measured had before measurement took place is problematic, since there is a change in the world as a result of measurement interaction.

Supporters of the hidden-variable interpretation believe that if the values of the hidden variables could be identified, quantum mechanics returns to a normal classical and deterministic theory. In this way, measurement would be as unproblematical as it had been previously. In Bohm's non-local causal interpretation, in which particles are presumed to travel in reality in the manner required by quantum potential, observation is not required to cause any collapsing of wave-packets. For example, in the case of an electron, the form of its quantum potential tells it what is happening in its environment. Quantum potential is not dependent on distance and changes instantaneously when a measurement is made on the other side of the world. In this way, an electron can ”know” in advance what sort of measurement event it is being subjected to and can behave in the manner that such a situation demands.

Bohm did not explicitly presume that measurement would influence events in the world, but the state of the world does however change as a consequence of measurements, since the form of the quantum potential changes. Human activity has an influence on the shaping of the world, but the question of the nature of that influence or human free will does not enjoy a clear answer when Bohm reduces all events happening in the world to a multi-dimensional reality in such a way that many of the different phenomena which appear distinct to us are in fact just three-dimensional projections of one and the same event in multi-dimensional reality. Obviously, by attempting to view reality as deterministic, Bohm considered man to be determined by fields of active information and rejected the existence of free will and conscious choices.[713]

Hugh Everett also believed, in the manner of von Neumann and Bohm, that the whole world could be represented in a single objective quantum description. In the many-worlds interpretation, every possibility is in fact realised in every situation where there is a choice of experimental outcome. Thus the troublesome collapse of the wave function can be ignored, and a measurement device can be handled as an object in the traditional manner. The consequence of a measurement situation is not the collapse of a superposition, it is rather that in each interaction, the whole world including the measuring equipment and observer branches into parts which differ from one another only in terms of the result of the one measurement. Talk about classical measuring apparatus or the role of an external observer is simply brushed away as there is no

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[713] When dealing with mind-body interaction Bohm however does not try to reduce consciousness or freedom of will to quantum level. Quantum level is somehow intermediate between delicate implicate levels and the manifest particle level. When dealing with delicate levels, Bohm also use the concept of 'creative intelligence or insight' which is something else than a mechanical process.

room for their separate existence in the all-embracing picture of the cosmos.[714]

In a specific sense, Everett preserved the classical physics idea of an external objective observer capable of describing the whole world from a position outside it. However, in this model the world also seems to change drastically as a result of human activity. As a consequence of different choices of measurement arrangemants, the world is divided into different kind of branches even if an observer who is trapped in one world cannot, in principle, obtain any knowledge about other branches or even make predictions about the future of the world in which they are present. If a Laplacian demon, somehow positioned outside all worlds, would be capable of viewing a real super-reality in which all possibilities are realised and at the same time differentiated into their own universes, it could not calculate their future development if human activity was not also completely predictable in advance.

Even though the many-worlds interpreters and hidden-variable interpreters attempted, in principle, to preserve classical determinism and predictability, this is, from the human point of view, pointless, since humans cannot anyway know all branches of the universe or exact starting values for the hidden variables. In these attempts, people are usually placed within a completely-deterministic world which they cannot however know and whose future development they are unable to predict. The world is more or less a machine and man becomes its deterministic object. Also, the presumption made by London and Bauer about consciousness collapsing the wave function neither restored free will to humans or returned the situation to one of classical predictability. Even if they are conscious, people do not obtain the measurement values they require, and the use of consciousness in this connection is just as good an explanation as *anima mundi*, an archetype or God who can also be presumed to be secretly selecting the results that they desire.

Bohr stressed the fact that humans do not have a completely external view-point from which they could view the world ”as it is”. According to him, quantum descriptions could not be incorporated into the classical world without leaving some residuals. Both Bohm and Everett experienced problems in employing classical and objective ideals when trying to present a clear ontological model of a world actively influenced by man. Clearly, the totality of human activity and free choices cannot be included an ontological portrayal of the world given from an external viewpoint, at least as long as such a world is assumed to be essentially classical. This is however

[714] Polkinghorne 1990, 67. Actually, in connection with many worlds, one should not speak about measurements

the most common direction from which most subsequent approaches to the measurement problem have been made. Even though attempts to solve the measurement problem differ widely from one another[715], they usually attempt to preserve both the universal objective description and the external position of the observer while at the same time trying to find a ”natural” ontological explanation for collapse of the wave function.

In the later approaches, the fact that in large bodies the phases of the wave function from different parts of the body are mixed with each other has been presented as a solution to the reduction problem. When the phases are sufficiently random, the wave function can be thought of as collapsing of its own accord. The cause for the mixing of phases has been presented as both heat phenomena and other irreversible processes which can leave measurable traces. Supporters of the decoherence theory think that since macroscopic systems have to be employed, unavoidable events involving interaction with the environment can result in very rapid mixing of the phases in the quantum system under examination. While phase mixing is clearly connected with measurement situations, there is no unanimity about whether its extent is sufficient to cause collapse.[716]

In his time, Erwin Schrödinger attempted to reconcile the viewpoints of Bohr and von Neumann by using the explanation that macroscopic measuring devices are fundamentally quantum objects. Schrödinger did not wish to divide the world into two separate parts: quantum reality and classical reality, as it appeared that Bohr was doing.[717] He wanted everything to be fundamentally portrayable in the form of quantum-mechanical waves. In practice, however, macroscopic particles could still appear to be classical, since the quantum influences are so small that the human eye would not be capable of noticing their infinitely small effects. Schrödinger did however encounter problems as a result of this thinking because it is easy to point out examples where quantum-level phenomena could have macroscopic consequences. The best known of these examples is the paradox of Schrödinger’s cat.

In this dramatic thought experiment, the cat is placed in a closed box with a bottle of poison, and

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but of correlations which realise all their mutual possibilities.

[715] Different attempts to solve the measurement problem. See for example Healey 1998, 52-87.

[716] The mingling of phases eliminates part of wave phenomena. Interference disappears but diffraction, for example, remains. The uncertainty relationship also holds for waves whose phases are random.

[717] Bohr’s epistemic distinction should not be thought of as ontological. Macroscopic quantum phenomena such as superconductivity and superfluidity can be observed, and also entanglement refers to the fact that the classical idea of distinct and independent objects does not address the whole truth.

a radioactive source is connected to it in such a way that the random decay of a nucleus will break the bottle with the result that the cat dies. When the situation is being examined, the probability of the bottle being broken is 50 per cent. This kind of system is described in quantum mechanics with a state that contains these two possibilities. If the macroscopic cat can be portrayed as a quantum system, it is then an undefined state of the superposition of a living and a dead cat until, as a result of the projection postulate, observation reduces it to either one state or the other: it either dies or is fully alive. From this unbelievable result Schrödinger concluded that quantum phenomena do not extend to macroscopic bodies and that Bohr's demand for two separate levels was justified.

As Bohr clearly observed, the measurement problem is linked to fundamental ontological and epistemological assumptions. One question in the measurement problem is whether a measurement situation can be objectively described from an external viewpoint by giving a universally applicable objective description in quantum mechanical terms, so that the measuring device can also be handled in a quantum-mechanical manner. Another question is whether collapse of the wave function is necessary or unnecessary. Bohr did not believe that objective portrayal of the whole measuring situation from an external viewpoint is possible. According to quantum mechanics, a classical solution of the type in which the whole of the measuring situation can be examined objectively from an external viewpoint and in which measurement merely passively reveals the already existing values of quantum-system attributes cannot actually exist. To Bohr, the classical macroscopic world really existed ”as it is” and with the help of experiences obtained from it we can attempt to also understand atomic phenomena. To him, rather than being objects, measuring devices were extensions of the senses.

The Copenhagen group were not afraid to say that measurement changed what already existed, and that measurement arrangements had an influence on the types of properties or attributes could be actualised in the world. The Laplacian presumption that humans can, in principle, examine all of the happenings in reality from a ”God's eye view” perspective without having any effect at all on the deterministic processes of the world, had been shown to be incorrect. This kind of approach to the measurement problem in quantum mechanics is not however generally accepted or considered to be adequate.[718] Bohr's adherence to classical measurement devices and the consequent difference in describing the macroscopic and microscopic levels was essentially

[718] Bohr's ideas are perhaps not known very well. For example, Omnes criticises Bohr for pressing on with the projection postulate, even though Bohr did not have any use for it.

an epistemological solution to the measurement problem while the problem quite often is experienced as being more an ontological one. Physicists want to know the point at which the transfer from the quantum world to the classical world takes place: at what point do identical quantum systems start to produce macroscopically observable differences, i.e. where does possibility become actuality and when do dynamic attributes appear?

Bohr’s answer, that the transfer from the quantum level to the classical level takes place within the measuring device was not considered adequate. He was considered to be doing nothing more than hiding the problem from view, since humans cannot monitor events within a measuring device. Correctly understood, Bohr’s solution does not however exclude attempts to use decoherence or other physical phenomena to achieve more precise ontological explanation and understanding of the measurement situation. His method of approach does not prohibit attempts to portray the situation in a more exact way. Just the opposite, we are always free to interpret and explain our experiences, as long as we are not cowed into being too speculative by postulating, for example, archetypes or branching universes. Thoughts of decoherence resulting from environmental causes include the same ignorance as the statistical causality emphasised by the Copenhagen group. Processes occur in the world which humans are unable to predict. No attempt to solve the measurement problem provides an answer to the question of why a measuring device yields the result which is obtained from it.

Correct understanding of the effect of an environment obviously requires the perception of a change in the role of the observer. Humans are also part of the environment of the process that is being examined. Attributes that appear during measurement are not necessarily just internal properties of the system being investigated, they may rather be relationships between the system and the measuring device which are dependent on the whole of the experimental setup. Measurement does not passively reveal the already existing attributes of a quantum systems, but it changes the probability distribution for future events as well as what actually exists. Through the choice of measurement system and their own actions, humans can to some extent influence which properties or attributes are finally actualised and are manifested. Both measurement and changing of the world take place when a mark is created in the measuring device.

Bohr did not argue very convincingly for his central claim concerning the necessity to use classical terms and macroscopic experimental equipment. On the other hand, if he was correct in saying that the simultaneous description of space-time and causality is only possible in classical physics, his assertion that a quantum-mechanical measuring device must be described in classical terms has, for example in Von Weisäcker's opinion, consequences for inevitability. Since the description of phenomena provided by classical physics is not completely accurate but only a good approximation and the portrayal provided by quantum mechanics is better, research should be carried out into when a quantum mechanics system can address features which we would consider classical. The qualification could be that the system is an appropriate measuring device. The minimum stipulation that a system can operate as a measuring device could be that irreversible changes may take place within it. Such a system cannot be in a pure state, it is in a mixture of states. In this way it can be seen that Bohr's claim is obvious: the measuring equipment must be described in terms which are appropriate for a measuring device. In the form into which it has developed as a result of history, classical physics can be described as an approximation to quantum physics which is suitable for the handling of objects which can be observed as completely isolated. Mind, which observes nature using classically describable instruments, cannot comply with natural laws i.e. quantum laws, unless it describes nature in a classical manner.[719]

Bohr rejected both the earlier particlemechanistic ontology and the Cartesian assumption of a detached and objective observer able to provide an absolute and universally applicable description of reality. Abandoning the traditional classical physics assumption of an independent observer and accepting the thought that measurements change the world naturally do not imply Anti-realism or Subjectivism. With his approach, Bohr questioned classical metaphysics in a deeper and more fundamental manner than Bohm or Everett, who attempted to hold on to the ideal of a detached objective observer. Their interpretation is usually taken as Realistic, even though the ontological viewpoint they adopt forces them to postulate auxiliary structures in the world which are both unbelievable and unnecessary. Such Realism remains a prisoner of the classical way of thinking in the same way as teachings based on von Neumann's reduction postulate, in which the observer's consciousness is assumed to collapse the wave function and

[719] Von Veizsäcker 1980, 185-187. Also Don Howard (1994) assumes that by classical description Bohr means description which uses mixed states. Thus the distinction between classical and quantum description that is drawn by the use of pure and mixed states already implicitely exists in quantum formalism. Murdoch also believes that a necessary condition for observability is that the measuring instrument employed is so massive that interference can be ignored, and that superpositions cannot be in practice distinguished from mixed states. On this basis, Antonio Dannieri, Angelo Loinger and Giovanni Prosperi have suggested a detailed explanation for the physical process of measurement. They reject von Neumann's projection postulate because the process is not sudden or uncontinuous. Murdoch 1987, 114-115.

thus create both the different objects that are observed and their dynamic attributes.[720] In Bohr's way of thinking, it is not necessary for measurement to be handled in a different way to other interactions. As with all macroscopic systems in which irreversible marks can be created, humans themselves can be viewed as measuring devices.[721] Through the processes of encounter, humans can both influence the way in which the world changes and they can change themselves.

4.3.7. The representation of physical reality by Bohr and Einstein

In investigating the changes brought about in our concept of reality by quantum mechanics it is not possible to ignore the dramatic and widely publicised debate between Niels Bohr and Albert Einstein. The dispute between these great twentieth century physicists about the interpretation of quantum mechanics, our conception of reality and the nature of physical description has been compared to the dispute between Newton and Leibnitz at the turn of the modern era. In what follows, an attempt is made, using their different methods of approach, to cast some light on the basic themes whose clarification is needed in order to solve the current crisis.

In 1920, on the first occasion when they met, Bohr and Einstein made a deep and very positive impression on each other[722], and throughout their lives each maintained great respect for the other. By 1924, however, their different epistemological viewpoints and differing intuitive insights concerning the nature of reality resulted in them occupying opposing scientific positions. The proper, decades long dialogue between Bohr and Einstein at conferences, through articles and in personal correspondence began at a conference in Solvay in 1927.[723] It was the first occasion that they both attended after Bohr had presented his interpretation of complementarity.

Einstein had been influential in the development of quantum theory since its very beginnings, but after 1925 he no longer participated directly in its formation and concentrated on the search for a unified theory. Heisenberg's matrix mechanics and Schrödinger's wave mechanics were

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[720] Neither subjectivism nor idealism offer proper solution to the problem of collapse. As consciousness is not able to affect matter directly, the reduction of the wave-function should happen somehow unconsciously. Also, the reduction of the wave-function cannot be observed from an external viewpoint and the observer remains a prisoner of his own consciousness.

[721] Presumably the formation of our psychic structure could also be described in quantum-mechanical terms. See also Section 5.3.

[722] Letters in *N. Bohr, Collected Works* Vol. 3, p. 634.

[723] Pais 1991, 230, 316-320.

appreciated by Einstein, and he wrote about both theories in favourable terms, recommending their creators for the Nobel Prize. In contrast, he considered Born's statistical interpretation and relativistic quantum theory to be worthless. Writing to Max Born in December 1926 he expressed doubt about whether quantum mechanics, in spite of it being so very influential, was actually "the real thing". An inner voice told him that regardless of its good sides, quantum theory did not carry us any closer to "the secret of the Old One… who does not play dice".

Einstein never accepted Bohr's complementarity interpretation. Writing to Schrödinger in 1928 he described Heisenberg's and Bohr's thinking as intelligently fabricated philosophy or a sedative religious cushion which believers found it difficult to dispense with.[724] After the dramatic encounter between Einstein and Bohr which took place in Brussels 20-25 October 1930, Einstein gave up trying to show that quantum mechanics is logically inconsistent. In the second, American phase of the thirty year struggle between the two men, Einstein tried to show that quantum predictions are inconsistent with any reasonable idea of reality. Bohr's answer, in effect, was "We have to revise our idea of reality".[725]

If quantum theory is complete, the laws of nature are statistical, something that Einstein, who was searching for laws of nature which were fully symmetrical, objective and deterministic, was never able to accept. He did not wish to jettison traditional continuity and causality but presented new thought experiments in which he attempted to show that Bohr's interpretation of quantum mechanics was incomplete. The best known of these was the EPR paradox presented in 1935 and described in Section 4.3.4. of this thesis. Bohr succeeded in defending his point of view by emphasising the indivisibility of quantum phenomena, the necessity of taking account of the whole experimental situation, and complementarity. The continuing divergence of Einstein's concepts was however a source of acute discomfort to him. Bohr is known to have engaged in discussion with Einstein in his mind until his death. Even though Einstein focused his powers on the search for a unified theory, he never ceased pondering quantum theory and its interpretation. He once said to his friend Otto Stern that he had spent a hundred times longer thinking about the quantum problems than he had about the general theory of relativity.[726]

Even though the discussions between the two men, which were in essence a dispute about the completeness and consistency of quantum mechanics, did not usually directly touch basic

[724] Pais 1991, 320.
[725] J.A. Wheeler in Jahn (ed.) 1981, 87.
[726] Pais 1982, 8.

ontological and epistemological questions, Bohr's and Einstein's different concepts of the position of the observer, the nature of physical description and change in the world are, in my opinion, central ones when attempting to assess the tenability of their views. In Bohr's thinking, these themes, traditionally kept separate, are seamlessly interwoven.

The position of the observer

Einstein continued the Newtonian and classical physics' tradition of attempting to describe the world in an objective manner from an external viewpoint. When Newton combined earthly and cosmic phenomena in his theory of gravity, he also divided the world into two parts in a new way. There was the world in which we live and we die, and a world revealed by science which was ruled by absolute laws and in which there was, in principle, no space for human activity. Even though these two worlds are combined in practice, they have been in theory completely separate.[727] Newton's laws did not assume the physical existence of an observer. The "knowing subject" was usually thought of as a non-physical mind which can observe and describe the world "as it is" and not influence it when doing so.

In his theory of relativity, Einstein discovered a general and invariant theoretical description which in principle allowed us to overcome the obstructions of our occasional position as observers. As with relativity theory, quantum mechanics can be understood as offering a general theoretical portrayal of all the possibilities connected with different events. On the other hand, Einstein did not reckon that in the theory of relativity, the observing subject cannot be treated as completely external. Since absolute time and space do not exist, specific events can only be handled when it is known in which system the observer is located and to what his observations are being compared.[728] Bohr placed emphasis on the position of the observer. He focused attention on the logical affinity between the theory of relativity and quantum mechanics in matters related to an observer, something that demanded a renewal of conventional ideas concerning physical reality.

Bohr pointed out that relativity theory brings with it the constant velocity of light and quantum mechanics' Planck constant. As the speed of light is finite, space and time cannot be separated from each other in an unambiguous way without recourse to the observer, and Planck's quantum

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[727] A. Koyré in Prigogine ja Stengers 1984, 35.

of action requires that the object and the measuring device are dependent on each other.[729] According to these constants, human activity is bound to physical laws and restrictions, to the human's own ”light cone” or chosen experimental situations. For example, it is not possible for an observer to send a signal that travels faster than the speed of light, nor to communicate outside the observer's own ”light cone”. Relativity theory restricts an observer to a being tied to no more than a single location at any point in time, therefore relativity theory assumes that the observer belongs to the world which they are investigating.[730]

Even though, as a result of relativity theory, it is no longer possible to propose the existence of an all-knowing observer who can address the whole world from a single point, it is however possible to propose the existence of a supreme mathematician who can construct an equation which provides a complete portrayal of the whole of nature.[731] Bound to physical laws and restrictions in their lives and in their activity, humans could, in their descriptions, overcome these limitations and employ reason to reach the eternal and timeless world. Einstein maintained his belief in classical physics' objective, independent and invariant description. The human intellect could discover absolute truth. Believing that theory can address the objective structure of reality, Einstein trusted, for example, that a quantum systems always have a specific observer-independent state of reality that can be described using the language of physics.[732]

In their portrayals, both classical science and Einstein attempted to go behind the world of phenomena and reach a world that could be addressed by eternal and timeless logic, one which has fascinated philosophers since Plato's time. Bohr, on the other hand, remained quite clearly (as did Aristotle) in our own world. He did not believe that humans can describe the world properly from an external viewpoint. All our descriptions are limited projections of the world which we influence[733], and through the gathering of knowledge we increasingly shape our environment. We are engaged in a continuing dialogue with reality. Immersed in the world, Bohr's human cannot be a ”spy” who can disappear without leaving any traces.

To both classical physics and Einstein, scientific objectivity meant that subjective elements, the

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[728] Faye 1991, 73.
[729] Bohr 1939, 25.
[730] Prigogine ja Stengers 1984, 218.
[731] Prigogine ja Stengers 1984, 218.
[732] Mackinnon 1994, 291-293. Einstein did not believe that there was any logical method of discovering those universal laws from which the structure of the cosmos could then be deduced in a logical manner. In searching for proper theories he trusted intuition.
[733] Bohr also believed that mathematical theory best reaches reality. When interpreting it, we are however tied to our macroscopic experience.

influence of the observer, could be eliminated from theories. For his part, Bohr did not believe that the influence of a conscious subject could be removed from the process of description: he created a wide general rationalisation from the experience that was then available.[734] According to classical assumptions, improved theory resulted in more-accurate representation and the unconscious manifestation of human-centredness could be eliminated, but Bohr's objectivity came to mean inter-subjectivity and unambiguous communicativity. To him, the history of science appeared to be the understanding of our concepts and experiences with an ever-increasing degree of finesse. The observer's metaphysical independence of the world being investigated is seen as a requirement for the separability demanded by Einstein.[735] In contrast to classical physics, however, quantum mechanics appears to prohibit separability: two systems which have interacted at an earlier point in time are described in a combined state, even though the systems are widely separated from each other.

Since quantum theory did not completely satisfy the ideals of classical physics regarding description, it was Bohr's opinion that generalisation of the whole of the earlier classical framework of description, the one familiar from its use of causal space-time description, was required.[736] In his framework of complementarity, Bohr viewed human being as being conditioned by their experiences: they were not equipped with language suited to all levels of reality. Bohr did not believe that by using language developed to portray the macroscopic world, humans would also be able to shape a ”correct” visualisation of the microscopic world. On the other hand, he was of the opinion that even though we do not have any guarantee of the efficacy of language or its true correspondence to the world, we can, step by step, through our experiences and the use of complementary models, compose an ever-improving portrayal of the world that we influence.

In his unified theory, Einstein was clearly searching for a model which could once again overcome the doubts raised by quantum theory concerning the influence of humans. Obviously, both measurement and observations should, in the final analysis, form part of this theory in some way, and we would have to be able to portray our own activity from an external viewpoint in an absolute manner. This was something that Bohr considered to be impossible. Humans are bound to and dependent on the whole world system at a fundamental level. According to his son, Bohr even doubted whether science and mathematics would some day discover ”The Answer” (a

[734] Hooker 1991, 507.
[735] Howard 1994, 206.
[736] Folse 1985, 222.

Theory of Everything, TOE). He felt that the search for the ultimate theory of physics might never reach a satisfying conclusion, since as physicists sought to penerate further into nature, they would face questions of increasing complexity and difficulty which would eventually overwhelm them.[737]

The nature of physical reality and the status of mathematics

The Copenhagen group focused their attention on the fact that a notable feature of physics at the beginning of the twentieth century was the increasingly abstract nature of theories. The usefulness of quantum formalism was demonstrated before it was provided with interpretation in everyday language. Everything that measurement could acquire from a system being investigated was contained within the wave or state function, but this mathematical construction itself did not appear to have any clear counterpart in observable reality. As the significance of mathematics increased, the concept of the nature of matter became more abstract. Elementary particles were not eternal and unchanging. Rest mass changed to energy in collisions and kinetic energy became mass in pair formation. The form of allowed material structures appeared to be specified on the basis of laws of conservation and fundamental symmetries of nature. The Copenhagen group concluded that the increased immateriality (*entstofflichung*) of elementary particles meant that the concept of dead matter in our world-view was replaced by a kind of interplay of forms. The first step in this direction had already been taken by the theory of relativity in its equivalence between mass and energy.[738]

Heisenberg suggested that the world was going through the same type of change that took place in antique times when the atomist teachings of Leucippus and Democritus were replaced by the ways of thinking employed by Pythagoras and Plato, in which form was a more important factor than matter. Even though the final shaping of a situation could not yet be achieved, Heisenberg felt able to express his belief that Plato’s philosophical concepts were more suitable for addressing reality than proposals made by the antique Materialists. Also, the Aristotlean terms 'form and content' or 'form and substance' were given new meaning since the elementary particles of modern physics were neither eternal or unchanging particles of matter, but abstractions in the same way as Plato’s regular elements consisting of triangles. In Heisenberg’s view, elementary particles were different forms in which energy could be manifested. The result

[737] Horgan 1998, 83. Bohr’s son told this to Wheeler whom Horgan interviewed.

of a collision was not an object but a form which energy could take and which we then observed as being a material object. In this way, the most important aspect of research into nature ceased to be a material object and became mathematical symmetry. Energy was not just the force which kept everything moving, it was like fire in the philosophy of Heraclitus – the fundamental substance out of which the world is made.[739]

Max Born also emphasised mathematical forms or structures: in his opinion, particles were not something that could in a Kantian manner be thought of as having substance. Schrödinger, who considered waves to be more important than particles, also joined this discussion. He thought of the accurately-specified masses and charges of particles as nothing more than gestalt-elements specified by wave equations. Individual particles were of no significance. They were not identifiable as individuals since the same particle could never be observed twice, nor could a specific electron, even in principle, be considered to be labelled without resulting in errors in calculation. On the other hand, it was easy to leave a permanent trace in wave structures which could be observed more than once.[740] At same time as the illusion of the objective reality of elementary particles in a peculiar way disappeared, it did not, however, disappear by being hidden behind some unclear misty veil of a new concept of reality: it was lost to the transparency of mathematical clarity.[741]

How should the ever-more-important mathematical structures and symbols then be understood? Max Born believed that symbols were not just a convenient way of shortening presentations, but an essential component of the method of penetrating to physical reality which lies behind phenomena. Through its increasingly mathematical methods and its abandonment of observable models, physics had gained the ability to handle an even larger collection of real phenomena. Mathematical constructions give humans the ability to achieve a better understanding of reality, since physics links observable phenomena to the hidden structures of pure thought. A mathematical formula is a symbol of some kind of reality behind everyday experience. Born had no hesitation in identifying these well-specified constructions as Kantian things ”as such”. They are images of the world behind phenomena, pure forms. Nevertheless, the structures are in no way empty or pallid abstractions separated from the world, as can easily be concluded from their

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738 March 1957, 117-122.

739 Heisenberg 1958, 15-19, 31. In spite of his stress on forms, Heisenberg did not want to abandon the modern materialism of the 19th century in an off-hand manner. It had provided much important information which was lacking in antiquity.

740 Schrödinger 1961, 53-56. The theory demands that all the states achieved by changing the positions of identical particles must be counted as one. The results thus agree with observations.

741 Heisenberg 1955, 12.

usability and their many concrete adaptations.[742]

Like Born, Heisenberg linked mathematical constructions to the world lying behind human experience. He did not however speak of the world of things ”as such”, he thought of quantum formalism as portraying some kind of world of possibilities. In quantum theory, Aristotle’s concept of potential had been given new form. Laws of nature were no longer absolutely deterministic, they rather specified the possibility that events might take place, the probabilities that something could happen. Possibility or tendency existed as some kind of intermediate layer behind the world as it appears to us.[743]

Also Einstein, even though he was sceptical about quantum theory, trusted mathematics. His well-known statement is that the most incomprehensible thing about the world is its comprehensibility. To him, mathematics was a universal language which could be directly used to describe nature. Natural researchers only had to find the correct isomorphic model for reality. By rejecting portrayals employing complementarity, he clearly believed that a correct ontological description of the microscopic world could be given by using unambiguous language, visualisable images and analogues. Seemingly inconsistent concepts such as ”particle” and ”wave” could perhaps be understood by specifying a new concept such as ”field”, from which they could be inferred.

Bohr stressed that we do not understand reality solely on the basis of a mathematical model. Even though he respected mathematics and believed that the symbolic language of quantum theory addressed microscopic reality better than the classical language suitable for the macroscopic world, he saw that mathematical symbols cannot be used to refer to the contents of experience in the absence of classical concepts.[744] We are forced to interpret both the theories we develop and the results we obtain by using classical language. Since physical theories have penetrated far beyond our normal observational world, they cannot as such, without clear interpretation, increase our understanding of reality. All knowledge of the microscopic world is based on mathematical models and indirect descriptions in which we apply concepts that are familiar at the macroscopic level to the microscopic world. In trying to understand and portray the microscopic world, we should employ both language that has been adapted and adjusted to the macroscopic world and complementary descriptions in which the conceptual limit essentially

[742] Born 1968, 179-186.
[743] Heisenberg 1958, 10.

merges with the limits of what we can observe.

By regarding mathematics as an accurate and precise language which humans had developed on the basis of natural language, Bohr moved what was prominent in natural science closer to people. He emphasised that the theory of relativity gave new content to concepts such as ”space” or ”time”.[745] When investigating the features of four-dimensional space-time, we could perhaps understand them, even though the words we are using are usually used when referring to the content they are assumed to possess in a classical context. Quantum mechanics obviously demands a new and even-deeper interpretation of concepts if we want them to ”correspond” to reality. The basis of classical description failed when as a result of the discovery of quantum of action, it become obvious that nature has placed limits on our possibilities of speaking about independent phenomena.[746] When the familiar space-time description cannot be employed when observing phenomena in the microscopic world, the meaning of such fundamental concepts as ”particle”, ”property” or ”being” becomes obscure. Bohr believed that we will be forced to abandon even more of the classical visualisable description of nature, especially in the region where quantum theory and relativity theory meet.

In addition to the fact that we cannot speak of independent phenomena at any degree of accuracy, we cannot fully isolate ourselves at an ontological level from the world we are investigating. Complementarity generalises our earlier frame of reference by noting that the quantum of action means that humans are an inseparable component of the world, and that our concepts are tools we use in describing our experiences in different interactive situations. Since, in modern natural science, elementary particles cannot be examined as the ultimate building blocks of matter independently of a experimental context, Heisenberg concluded that also in natural science, we are from the very beginning in the midst of a confrontation between man and nature. Natural science is, as it were, ”between” nature and man, and mathematical and classical concepts become devices in an endless chain of encounters between man and nature. The customary division of the world into subject and object, into internal and external worlds, body and soul, no longer offers adequate tools for the understanding of reality and the formation of knowledge.[747]

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[744] Bohr clearly did not believe that theoretical and classical language could be translated into one another in an unequivocal manner. If he had, complementary descriptions would have been unnecessary.

[745] Physics was able to produce new information concerning the foundations and limits of the descriptive concepts we employ even though the concepts were required to describe our experiences in an objective and inter-subjective manner.

[746] Bohr 1939, 25 and 1967, 91.

[747] March 1957, 95, 116. Heisenberg 1955, 12-13,18.

Bohr's way of thinking, touching both language and mathematics, can be considered a step in the direction of Empiricism. Ever since the days of Descartes, while mathematics has been generally understood as the sovereign tool of reason, Bohr puts its possibilities in proportion. Language is a device within which our experiences of the character of the world are stored, and which changes when our earlier assumptions about the nature of the world turn out to be inadequate. Even though we continue to visualize space in three-dimensional terms, relativity theory tells us that this type of observation does not address the nature of reality correctly, and that even though we still have to use classical language and logic, we know that these tools are not capable of describing the world with the depth of quantum mechanics. Bohr emphasised that the use of a descriptive concept in a specific situation depends on the ruling relevant physical conditions. Concepts only work in specific contexts, and if we see that the assumed conditions do not prevail, a change in the concept being employed will result.[748]

No-one will certainly wish to dispute that mathematics holds a position of fundamental significance in modern physics. In spite of the powerful development of mathematical theories, our conception of the reasons for the usefulness of mathematics has not actually progressed since ancient times. The ontological and epistemological problems of mathematics are foreground topics in the philosophy of mathematics. It is by no means clear what mathematics is about. What is the nature of the objects that it studies? What kind of being or kinds of existence are shared by mathematical entities? Are the concepts and methods of mathematics discovered or invented? And what kind of knowledge does mathematics provide? In physics, the nature of mathematics has not been clearly questioned. Is it, as Bohr maintained, primarily a tool for humans to use in description, or is it something ontologically more concrete, something with which the human intellect can directly reveal the structure of reality? [749]

New light on the foundations of mathematics has resulted from the theorems of Kurt Gödel and Alain Turing, probably the two most important achievements in twentieth-century mathematics.[750] Gödel's incompleteness theorem and Turing's theorem proved that there will always be unsolved problems in mathematics and logic. There are mathematical questions that admit no mechanical solution. This does not imply that certain problems cannot be solved at all.

[748] Hooker 1972, 134, 167 & 192.
[749] Reichel 1997, 3.

It simply states that creative work cannot be replaced by some mechanical, in the sense of algorithmic, technique, procedure or system that is described beforehand.[751] The classical image of mathematics has also changed as a result of the advent of computers. These machines are now commonly used in the study of non-linear and chaotic processes There are propositions and computer proofs that can no longer be surveyed by a single human being because they are too complex and their content has too many ramifications. The personal relationship between man and mathematics appears to be at stake: computer experiments are moving from the context of discovery to the context of justification. Imre Lakatos has called present-day mathematics a ”quasi-empirical” science.[752]

It has been said that even though few will admit it, most mathematicians and scientists view their theorems and laws in Platonic terms.[753] For example, the well-known physicist Richard Feynman considered, in accordance with Pythagorean traditions, that physical laws which observed mathematical principles represented rhythms and forms in nature which cannot be observed by the human eye.[754] He noted that all the laws of physics appear to follow great general principles; examples of which are principles of conservation, certain qualities of symmetry, the general form of quantum mechanical principles and the fact that all laws are mathematical.[755]

Is reality reversible or irreversible?

The relationship between change and eternity was already a subject of debate among the pre-Socratics. They attempted to reduce the observed movement, change and multiplicity in the world to some unchanging basis. Modern natural science has espoused the antique Atomists' concept of unchanging particles and has developed mathematical theories which are assumed to be founded on nature's eternal unchanging conformity to laws. Classical mechanics, the theory of relativity and quantum mechanics are, by their nature, reversible theories which handle time as a

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[750] Gödels incompleteness theorem states that in any consistent and sufficiently powerful axiomatic system, propositions can be formulated which are true but undecidable. The simplest formulation of the Turing theorem is perhaps the following: there is no algorithm to decide whether the generic Turing machine will halt or not halt on a generic input. Cacade 1997, 32.
[751] Cacace 1997, 27, 32, Suarez 1997, 45.
[752] Reichel 1997, 7-8, 11.
[753] Stenger 1995, 7.
[754] There is also rhythm and pattern between the phenomena of nature which is not apparent to the eye, but only to analysis: it is these rhythms and patterns which we call Physical Laws. Feynman 1992, 13.

parameter. Natural laws always remain unchanged, so the future and the past are treated as equivalent. In principle, processes described by theory are reversible, which means that they take place in the same way when the flow of time is reversed.[756] It is difficult to incorporate any kind of qualitative change such as evolution into a world where future and past are equivalent, even though, for example, R.G.Collingwood viewed historical understanding of the processes of reality to be a central feature of the revolution that is currently taking place.

The first irreversible process encountered by physics was connected with thermal transfer: heat moves from warmer to cooler locations until the difference in temperature between the two is reduced to zero, so the process is not reversible. Non-recoverable, irreversible processes are continuously being observed in chemistry, and investigations of highly unstable systems have revealed that they can develop in unpredictable and random ways. In specific circumstances, the degree of organisation of a system can increase as a result of interaction with its surroundings.[757] Evolution in living systems is a fact, which cannot be completely portrayed by using reversible theories.

Einstein believed, as did Giordano Bruno and the majority of all natural scientists, that the world is fundamentally eternal and unchanging. Surprisingly, however, time-dependent solutions were discovered in the cosmological formulae of the general theory of relativity soon after it was discovered. Even though Einstein fiercely resisted the introduction of irreversibility into physics, he became, against his will, the father of the idea of a developing universe.[758] In quantum mechanics, Schrödinger’s equation represented traditional reversible and deterministic thinking. Hamilton’s operator defined the development of systems in time in an analogue manner as the Hamilton function in classical mechanics. In measurement situations, however, it is generally necessary to rely on statistical investigations, since the wave function has to be presented as a superposition of eigenfunctions. By their very nature, the manipulation and measurement of systems are irreversible processes. The world is changed as a consequence of the actions taken by an observer. This results in a paradox: the Schrödinger equation cannot be tested without the irreversible measurement which the equation is unable to describe.[759]

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[755] Feynman 1992, 13, 59, 84. A thing is symmetrical if there is something you can do to it so that afterwards it looks the same as it did before. Conservation laws are connected to fundamental (spatial) symmetries such as translation, rotation and reflection in space. Most fundamental in modern physics are the internal symmetries e.g. SU(3)xSI(2)xU(1).

[756] Prigogine ja Stengers 1984, 11, 62.

[757] Prigogine ja Stengers 1984, 12.

[758] Prigogine and Stengers 1984, 15, 215, 294.

[759] Prigogine and Stengers 1984, 61, 226-229.

Bohr stressed the irreversibility of measurement and the individual character of each measurement situation. Full symmetry would demand that the observer and the observed (the subject and the object) be interchangeable, with no distinction being drawn between microscopic and macroscopic variables.[760] As detailed in Section 4.3.6. of this thesis, which dealt with measurement, the coupling of experimental equipment and the microscopic world could not, according to Bohr, be portrayed as causal. The attempt to hold onto an objective description from which the asymmetry caused by the act of measurement could be removed is quite clearly impossible. If the idea of free experimentation is accepted, we cannot examine the whole world externally as an deterministic clockwork mechanism in which only events resulting from the initial conditions are possible.

If it is assumed that an all-embracing model or theory which imprisons both human activity and human will could somehow be constructed, that we could describe the future course of development of the whole of the world as if we were outside it, such a model could hardly be presumed to be reversible in nature.[761] We should obviously need to know beforehand, while writing the theory, what kind of world will develop as a result of the actions we take. Even though development can to some extent be predictable and in broad terms we are perhaps forced to make specific choices if we wish to preserve the conditions we need to continue our existence, any attempt to adhere to reversible objective laws and to remove the asymmetry caused by measurement from our theory is clearly impossible. The world is changed as a consequence of the actions we take.

In spite of the changes observed in the world, belief in the fundamental unchanging character of reality has been a central point of departure in the portrayal of nature since Eleatic times. We have been able to improve our understanding of reality and the movements and change observed in the world with the help of some basic invariances. As Eino Kaila pointed out in his analysis, Galilei surpassed Aristotle in his understanding of the significance of dynamic invariance: in addition to individual substances or properties, specific major relationships can remain unchanged as change takes place.[762] When developing theories, it is typical to find new conformity to laws, according to which different phenomena can be returned to the same straightforward causes. In the description of nature by classical physics, an attempt is essentially

[760] Pais 1988, 243-245.
[761] For example in the many-world theory the branching of reality increases with time.

made to return all events to some influential material causes in space-time. The concept of force and cause could almost be identified, but the structure of quantum mechanics can no longer be directly adapted to a reality presumed to be particle-mechanistic. Quantum theory's state function can be thought of as referring to something that is outside space-time.

In modern physics, the important laws of conservation are governed by simple symmetrical principles. Specific quantities remain unchanged as space is translated, revolved or reflected. The laws of conservation control and restrict natural events, but as Herman Weyl said in his *Symmetry*: "The truth as we see it today is this: The laws of nature do not determine uniquely the one world that actually exists". These symmetrical principles may lead to many asymmetrical outcomes: as soon as a system has symmetry, a good chance arises that the symmetry may break. Symmetry breakage gives rise to the growth of complexity in the universe by generating outcomes that are more complicated than the laws themselves.[763]

If the growth in the complexity of the different phenomena observed in nature and qualitative development are to be reduced to spontaneously occurring symmetry breakages in specific fundamental symmetries, it appears that reality may be thought of as having two levels. Eternal symmetries, i.e. the invariant level of specific global characteristics or forms of nature, and the time-varying reality observed by humans which results from breakages in it. This form and matter combining, bi-level differentiation is reminiscent of the solutions at which Plato and Aristotle arrived when attempting to position humans and real change in the more or less “static” reality portrayed by the pre-Socratic natural scientists.

With the help of modern physics, it should be possible to obtain a much clearer picture of the changing world of observations in which humans operate and its connection with the unchanging fundamental properties of nature. Bohr’s viewpoint concerning the active role of human beings is also compatible with the emerging understanding concerning symmetries and complex systems. When a symmetry breaks, very tiny asymmetries presumably play a crucial role in selecting the actual outcome from the range of potential results allowed by natural law. I believe there is no point in denying that human beings are also very much able to generate some of these symmetry breakages. The element of freedom is compatible with the idea of a lawful cosmos. At the scale of the whole universe the influence of our choices may be minor, but the quality of our local neighbourhood depends decisively on our own actions, and these are, quite naturally, affected

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[762] Kaila 1939.

both by our beliefs and by our theories.[764]

5. Conclusions

The attempt to create a unified portrayal of reality in which all the phenomena we encounter in the world can be understood and explained via natural terms has been the prime motivator for natural philosophy. Since the beginning of modern era science has provided us empirically tested reliable knowledge concerning the fundamental laws and regularities in reality. There is no reason to believe that anything happens in the world is not as permitted by natural laws. The comprehensive theories of physics are the best tools we have and they should be taken as a fundamental starting point for the understanding of whole reality. Even though ontological conclusions cannot automatically be made on the basis of physics and the scientific method of approach to understanding the internal reality of humans is still less than adequate, philosophical analysis and description concerning real phenomena should be based on empirical foundation.[765]

A method of approach based on natural science does not mean an inevitable commitment to the mechanistic-deterministic conception of reality or a particle-mechanistic way of thinking. The prolonged debate concerning the interpretation of quantum mechanics has made it clear that the mechanistic-deterministic concept of reality associated with classical physics is not tenable. Later interpreters have not been able to salvage the dualistic and deterministic portrayal of reality with their auxiliary hypotheses, on the contrary, the need for a change in the conception of reality that was included in the Copenhagen interpretation has proved to be justified. New internal dependencies detected between observables, which manifest both in the new types of commutational rules in conjugated variables and empirically-observable non-local connections are facts whose reality can no longer be disputed after the many new experimental results testing Bell's inequality and large quantum systems, even though these phenomena cannot be understood within the framework of mechanical methods of investigation employed previously.

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[763] Stewart and Gikubitsky 1993, 15-17, 54.

[764] This aims to provide an ontological approach: how the whole of reality can be understod on the basis of modern knowledge.

[765] Some philosophers believe that the scientific approach is not relevant when examining human subjectivity. For example, in a response to my earlier article, Sami Pihlström argued that questions concerning human agency, freedom and ethics are far more important than scientific descriptions and explanations of the world. In his opinion, such questions cannot be defended or refuted by scientific means but should be investigated at a transcendental level in accordance with the ideas of Kant. See Pihlström 2002, 107-109.

This relationality connected with the whole system, which can also be seen as being manifested in so-called wave-particle dualism, questions the familiar concept of local objects and properties that are completely independent of one another.

The unexpected characteristics of quantum mechanics can be traced back to the new description of state. In contrast to classical mechanics, this is not based on the position and velocity of particles in space-time, but on a complex wave function. The biggest problem in the quantum debate has been interpretation of this abstract entity which gives probabilities for all the actual outcomes we observe but can never be observed as such. Regardless of whether the wave function is interpreted as just a mathematical tool suitable for prediction, or thought of as referring to some kind of transcendental quantum level, it is responsible for the non-local and statistical constitution of quantum physics. With the new description of state, some kind of indivisibility, internal spontaneity and chance appear to be part of reality. The presumption in classical physics that all happenings observable in nature can be addressed by examining them as nothing more than mechanical interactions between separate fundamental components of matter moving in space-time is not justifiable in the light of the new phenomena revealed by quantum mechanics. As Niels Bohr saw, particle-mechanistic space-time portrayal is only suitable for the description of macroscopic objects that are independent of the observer. All happenings cannot be reduced to their component parts without residuals, quite the contrary, understanding the development of the phenomena of reality requires that we also take account of the whole context of the situation that we are investigating.

Niels Bohr's framework of complementarity removes most of the apparent paradoxes of quantum mechanics without resorting to the addition of auxiliary hypotheses. By fixing attention on the epistemological conditions of ontological description, Bohr's complementarity challenges both Cartesian dualism and all types of ontological dogmatism.[766] Since, in quantum mechanics, not even the division between subject and object is an absolute one but rather a question of appropriateness depending on the context being investigated, the Copenhagen Group saw that human activity and influence could not be shut out when portraying nature. By allowing indeterministic and irreversible processes, quantum mechanics is able to offer a more satisfactory approach to understanding the relationship between human beings and nature. The role and

[766] Bohr's way of thinking also offers the possibility of avoiding the notorious measurement problem. In contrast to decoherence models, Bohr's approach utilises the possibility offered by the indeterminism of quantum mechanics and the irreversibility of the processes connected with measurement to rethink the relationship between human beings and the world. Even if we cannot have a comprehensive God's eye view of reality, our conception of reality can evolve with further experience.

existence of humans can be viewed from new perspectives in this kind of framework and it is also easier to locate our mental activities within the actual physical world.

Modern physics has demonstrated that the structure of reality is much more complex than we imagined. The understanding and explanation of new empirically-observed phenomena requires a new concept of reality, something that is clearly understood by different developers of ontological interpretations. Failure of the absolute and objective assumptions of classical paradigm does not signify that it is impossible to develop our knowledge concerning the fundamental ontological character of reality, its structure and the possibilities allowed. Quantum mechanics is a comprehensive theoretical framework, an empirically-based tool which could signify a historical step forward in our understanding of the nature of reality. The scientific description of reality may, as a consequence, free itself from the limitations of a classical world-view in the same way as Newtonian mechanics freed modern science from the restrictions of the mediaeval conception of reality.

A consequence of the new state description of quantum physics based on wave functions is that only part of the forms or possibilities at the quantum level are realised in the observable world. The shaping of the material world appears to be under the influence of a factor that cannot be reduced to a particles or mechanical interactions between them. This is something that recalls the ideas of Plato and Aristotle. In contrast to the antique Atomists, they emphasised that all happening and change in the material sense-world cannot be ultimately reduced to local causes acting between separate particles which persist in space. In accordance with the new description of state and the renewal of world-view, natural research could bring in thinking tools of a type which make possible the better-than-before investigation of questions concerning people and society - as happened at the time when antique thinking bloomed.

Within the quantum frame, it is not necessary that our inner reality be reduced to processes in the visible world which allow the employment of physics' universal conformity to laws to model human mental processes in a better way than is possible according to classical physics. We can learn to understand better both the position of humans in the wholeness of nature and the shaping of our internal reality. In contrast to the mechanistic and deterministic framework of classical physics, a quantum framework may also view our purposes, intentions, and actions as formative forces in nature in addition to material causes. Even though it is not sufficient to explain it, quantum mechanics' statistical conformity to laws allows that the world contains, or is influenced by, autonomous subjects of the type whose existence great philosophers from Spinoza to Kant and to Husserl have striven to defend. Progressing beyond the mechanistic-deterministic way of thinking offers a real possibility of transcending the conflict between humanistic and scientific ways of thinking that has troubled the whole of the modern age.

In the following sections, the kind of conception of reality implied by quantum mechanics is examined in more detail. As has already been said, a new framework can provide a better concept of the nature of reality and offer tools for the improved modelling and understanding of our internal reality and its degrees of freedom. The most important thing, and this is where a change in our concept of reality demands the redefinition of where we stand, concerns the position of humans, the nature of their freedom and their responsibility. Compared to Newtonian mechanics, quantum theory has given us much power to deal with reality and will give us a great deal more. We will become ever more able to influence the world and exploit its processes. As we are, however, not just external observers but deeply influenced by and dependent on the contextual processes of nature, it is important to see that we cannot consider ourselves to be totally-omnipotent agents able to rule and manipulate the realm of matter as we see fit. We are not just nature’s ”machine operators” but responsible agents whose actions, notions and goals have real consequences for both our own formation and our future circumstances.

5.1. Quantum mechanics requires a renewal of the mechanistic-deterministic conception of reality

Humans do not have certain knowledge of the fundamental nature of reality or of its substance. Our abilities to deal with nature are based on the experience we have gained. We can shape both our environment and ourselves within the limits permitted by our knowledge. The mechanistic-deterministic way of thinking and idea of the world adopted at the turn of the modern era has had a wide-ranging influence on our culture. Even though the views held by particular individuals or some great philosophers have diverged significantly from the assumed mechanistic-deterministic conception of reality, as an inter-subjectively-espoused ”certainty”, this way of thinking has had a profound influence of the direction of both scientific activities and cultural development for a long time. In many situations, the mechanistic-deterministic way of thinking has been justified and useful, even though no single model or paradigm concerning reality can be expected to offer tools for the clear description and explanation of all the phenomena we encounter. As with every comprehensive paradigm, the ”confinement” that results from the classical paradigm of science has been difficult to overcome as long as the way of thinking that supports it has offered a framework for the onward march of research.

By believing that the world is an complicated clockwork mechanism, humans have manipulated the world with the help of simplified reductionistic models which are formed by dividing reality into separated and individual constituents for research. In recent decades, many of the difficulties connected with scientific-technical development such as environmental problems and people’s growing feelings of emptiness and lack of purpose have attracted increasing criticism. Some have blamed science for these problems, even though they would be better interpreted as products of the limitations of the mechanistic-deterministic concept of reality, anomalies which are unintentional results. The unexpected consequence of these manifestations can be taken as an indication of the inadequacy of the ruling conception of reality. When an operation designed in accordance with a specific set of beliefs and models results in consequences that the model does not predict, it may be that we become conscious of the deficiencies or limitations of our portrayals and theories. Through increased knowledge and by acknowledging the basis for our problems, models can be renewed and we can attempt to create ever-better and more-comprehensive theories of the processes that comprise reality. Only by creating portrayals, models and explanations can we little by little become aware of limitations in them and obtain a better conception of our position and our possibilities in the world.[767]

The more-than-century-old debate concerning the interpretation of quantum mechanics has repeatedly precipitated questioning of the foundations for our conception and description of reality. Why are the new features of quantum theory so difficult to understand? Can reality be fundamentally divided into distinct objects which are independent of the observing subject? What do the statistical nature and complexity of natural laws signify?[768] Since these fundamental questions concerning the nature of knowledge and reality, questions long believed to have been satisfactorily answered, have once again become a subject of discussion, it is reasonable to claim that we are living in the middle of a crisis concerning the conception of reality. On the basis of

[767] As discussed in Section 3.5. our conception of reality has historically evolved through relatively abrupt changes involving major metaphysical reconsideration. Even if our descriptions - which presumably reflect out experience, our structure and our language as well as ourenvironment - change with new evidence, at their best they are not at all subjective. At the same time, these descriptions and theories and the world-views based on them are tentative and can be viewed, in an anthropological sense, as myths or narratives. We are not able to see how we are imprisoned by these models until an adequate amount of new experience allows us to overcome former beliefs.
[768] The positivist attitude in philosophy that concentrates on language rather than ontology has also prolonged interpretation discussions.

new facts revealed by quantum theory it can be concluded that at least some of the presuppositions concerning reality which were adopted at the turn of the modern era and which were considered justified on the basis of classical physics should be rejected if we wish to shape a new conception of the world which is compatible with the material being subjected to research.[769]

When forming fundamental presuppositions concerning reality it is not possible to avoid metaphysics, but it is not necessary, as has been discovered in philosophy of science when examining the basis for Positivism, for metaphysics to be meaningless or to remain beyond rational criticism. Natural science has achieved great victories by avoiding speculative metaphysics and placing its trust in the experimental method. When developing his interpretation, Bohr moved forward by carefully revealing and evaluating, in the light of new information, the background assumptions in classical physics that were taken as almost self-evident, such as the deterministic space-time description or the usefulness of Dualism. He saw that because of wave-particle dualism or the quantum of action, it was difficult to think of reality as consisting of indivisible, unchangeable and independent building blocks as presumed by the Atomists. In addition to the EPR paradox that was tested by Bell's inequality experiment, the uncertainty relationship, superposition and entanglement all bore witness to the holistic character of the microscopic world. In addition to the fact that we cannot predict with certainty how a system we are observing will develop, systems cannot be divided into separate components in the simple and unambiguous way that classical physics adopted from the Atomists of antiquity.[770]

The primacy of particles and even the presumption of empty space disappear as a result of quantum mechanics and quantum field theory. The fundamental components of matter differ quite clearly from the classical billiard balls moving and mechanically interacting in empty space. Even if all particles of the same class do possess specific internal properties such as mass or charge, these particles cannot be differentiated from each other or identified contrary to classical assumptions.[771] They cannot, even in principle, be directly observed. When a particle manifests somewhere, a dynamic attribute such as location is manifested simultaneously. Dynamic attributes are dependent on the whole research context. While, in classical physics, the

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769 In addition to the mechanistic-deterministic conception of reality, quantum mechanics also excludes many other models of the world that are, in principle, possible.

770 The collapse of the particle view or determinism does not mean that the idea of lawfulness should be abandoned.

state of a system consists of the location and velocity of its parts, specific properties of a quantum system are manifested when the corresponding operators operate on an abstract quantum state: in a specific measurement situation, specific properties will be elicited at specific probabilities.

In the light of quantum mechanics, the world cannot be fundamentally divided into permanent components. It rather appears that the basic reality addressed via the wave function or fields is at the same time one and many. Only at the macroscopic level is it possible to say that objects approximate to permanent structural components. The gravitational and electromagnetic interactions which keep the structural elements of macroscopic particles together are relatively weak. In the microscopic world, the ultimate indivisibility of a system is revealed when particles influence each other through the most powerful forms of interaction, the strong and weak nuclear forces. These forces are generally portrayed as the exchange of other particles. In string theory, particles are thought of as one-dimensional vibrating strings. These kinds of portrayal demonstrate that in modern physics, part and whole are interwoven in a fundamental, but difficult to describe, manner.

When speaking about objects and their relationships and attributes, we are at the core of metaphysics or ontology. This is something that is not commonly acknowledged in discussions concerning the interpretation of quantum mechanics. In later interpretations, classical physics' assumption of isolated material objects was taken as an obvious common-sense starting point. Within the world-view formed in modern times, this starting point is understandable, the accepted rules and assumptions are not considered to require explication under the dominance of "normal science".[772] As a satisfactory solution to the problem of interpreting quantum mechanics within the classical frame of reference has not been reached in spite of the long-drawn-out discussion, it is time to carry out a critical examination of the starting points. Because of modern physics, and above all because of quantum mechanics, our fundamental assumptions concerning reality should be a subject for reassessment. The basic metaphysical presumptions adopted at the turn of the modern age were half-truths only suitable for a macroscopic world. Fundamental reality cannot be described as a deterministic conformability to laws, nor is it possible for all its regular happenings, even at the material level, to be explained by mechanically-interacting particles moving in space-time.

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[771] Not even spatial distance guarantees individual identity since in quantum mechanics, two objects which have once interacted must be described by a single undivided state. Murdoch 1987, 189-190.

[772] Kuhn 1994, 100,120. Within a commonly-accepted paradigm, theories, methods and standards are intermingled.

5.1.1. Natural philosophy and the development of knowledge concerning reality

A concept of reality can be understood as a theoretical construction which humans shape on the basis of their knowledge at a given time. Science has demonstrated to be a unique tool for research and justification and the facts it provides are, with good reason, considered to be more believable than any great ruler or authority based on revelation. The precise methods of natural science and its empirically-based theories can be viewed as tools in the wider process of understanding reality.

The hypothetical-deductive development of science is based on the interaction between observation, reason and creative imagination. Scientific development moves forward with the aid of provisional hypotheses and paradigms, but can, in principle, go beyond all artificial ontological or transcendental limitations or categories. The basic assumptions of old paradigms can appear non-credible in the light of new knowledge. The example of quantum mechanics demonstrates that the self-correcting nature of science can also extend to ultimate basic presumptions concerning reality. Scientific results can both show the incorrectness of long-held ontological and epistemological assumptions, and at the same time offer new material for the creation of a more-comprehensive models of reality. Since knowledge concerning the nature of reality can, as a consequence of the results produced by science, change and increase through the creation and refutation of ever better frames of reference and paradigms, fundamental metaphysical propositions do not lie completely outside the scope of rational criticism. In such cases, consequences resulting from the use of models offer indirect ways of also testing the model itself, and even testing the basic metaphysical assumptions on which it has been constructed.

The universal theories of physics are a strong foundation for a credible conception of reality. Even though the world is not a clockwork mechanism, we know that its change and development take place within a specific framework of unavoidable conformity to laws. The new framework of reference that incorporates quantum mechanics does not require that we abandon the idea that nature conforms to laws, it rather means investigation of the character of this conformity and an expansion of the area in which it is applicable.[773] Via a more-comprehensive model and theory, we will be better able to both understand our environment and direct our activities. It appears to be increasingly apparent that in contrast to Kant's assumption, the scientific method can be employed in approaching both mental phenomena and ”things as such”. Science as an institution is not, however, a starting point for knowledge concerning reality. Also, within science, only individual insight can result in the creation of something new. If the new proposition can withstand critical research and evaluation by others, it may, step by step, influence our world-view and our conception of reality.

In addition to physics, the creation of a credible interpretation or frame of reference in which the new features revealed by quantum mechanics become more understandable also requires philosophy, something that the Copenhagen Group clearly understood. Even though, by developing its paradigms, exact natural science can demonstrate that earlier ontological and epistemological presuppositions are no longer credible, it cannot shape a new conception of reality using nothing more than its own resources. This kind of shaping and evaluating of metaphysical statements can be considered to be the task of natural philosophy.[774] The specific domain of natural philosophy is the conception of reality or world-view which can be seen as forming a directing background to almost all our activities. Using it, we attempt to understand the phenomena we encounter. Natural philosophy can be said to be the search for a synthetic, all-embracing frame of reference in which the so-called ”schism” between natural science and the humanities can be properly bridged.

Every time the fundamental beliefs which underlie our concept of reality have been the subject of reassessment, natural philosophy has been at the centre of our thinking, both in antique and modern times. The pivotal natural philosophers at the beginning of modern era were also the founders of natural science. The mechanistic-deterministic paradigm constructed on the basis of their thinking offered a durable and functional methodology that would turn out to be suitable for hundreds of years of physical research. Ways of thinking and the results thus obtained are powerful shapers of our world-view. It is still commonly believed that real phenomena must be both observable and measurable. Complicated phenomena should be explainable by breaking

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[773] When investigating physical conformity to laws, humans have gained a view of fundamental natural symmetries, and via quantum mechanics they are also able to address the structure of possibilities. From the human point of view, these eternal and fundamental everywhere-manifesting and development-controlling factors are comparatively successful in providing a general and all-embracing view of reality.

[774] Natural philosophy that evaluates metaphysical presuppositions cannot be reduced to natural science even though the achievements of science are a central starting point for reflection in natural philosophy.

them down into their separate original constituents and discovering the laws that influence these basic parts. This kind of world-view did not allow any non-material entities, and mind was often considered to be a separate substance. The mechanical and deterministic framework rejected any internal principle of change and attributed all motion to external causes which did not allow space for autonomous human beings or their free choices.

If natural laws are considered to be universal, there is no room in the mechanistic-deterministic world for autonomous human beings making free choices. The opposition of the humanities and natural science has been a hallmark of modern times. In the quantum framework, since the whole position of ontology is illuminated in a new way, this long-standing schism so characteristic of our culture can be alleviated. Physicalism does not require that everything, both the human mind and movements in society, should be understood in such a narrow, visualisable and controllable way as is suggested by the mechanistic-deterministic frame of reference. In the light of the Copenhagen interpretation and quantum theory, for example, the attempt to reduce individual human beings to nothing more than a biochemical machine is absurd. Taken as a single limited description, this model can, however, provide irreplaceably-valuable knowledge. Reality can be perceived in many different ways. If we do not imagine that only portrayals which can take place within a mechanistic-deterministic frame of reference[775] are possible, complementary models can be used to complement and merge differing, apparently-inconsistent points of view.

When searching for a new research programme or paradigm, the central criteria concerning its justification is that it should either solve or remove anomalies in earlier ways of thinking. In my opinion, the central problem in the mechanistic-deterministic conception of reality in the modern era has been its inability to throw clear light on the relationship between human beings and nature. This is reflected in the opposing positions allocated to the humanities and natural science, and it has also been influential in both environmental problems and in the birth of the *tekno sapiens* illusion. Since the observing and environment-shaping human being is usually thought of as being determined by the laws of an external world, or alternatively seen as essentially unaffected by its conformity to laws, humans have not taken a realistic approach to their own influence on the system they are investigating.

[775] If we accept Bohr's complementary way of seeing and stop seeking perfect correlation between a single objective description and reality, there would remain plenty of space in which we could locate our own activity and descriptions of our inner realities.

5.1.2. Re-evaluation of the position of the human being

Descartes stated that the thinking mind was not part of the dimension of nature's mechanical processes.[776] In philosophy, Descartes' dualism gave birth to the mind-body problem, a solution to which has been sought on the basis of ontological Dualism, Materialism and Idealism. In a way, both Materialism and Idealism are tied to the dualistic approach: everything must ultimately be reduced to either matter or mind, one or the other of Descartes' fundamental domains. Strict Dualism leads to Interactionism, while Materialists and Idealists can conclude that there is some degree of Parallelism in material and spiritual phenomena. In spite of centuries of pondering, however, none of these philosophical approaches have succeeded in offering a solution to the problem of the relationship between mind and matter that is satisfactory to everyone.[777]

In scientific circles, Materialism has been popular since the Enlightenment, even though the great philosophers of the modern era did not accept it. They also criticized Dualism. When trying to offer an overall picture of the world, Spinoza and Leibniz ran into serious difficulties because of the commonly-accepted classical paradigm of science.[778] Kant came to the conclusion that natural science was not able to deal with subjective questions concerning ethics and metaphysics. The scientific approach to mind and the psychophysical problem, however, was clarified to some degree when cognitive science provided the computer metaphor in the middle of the twentieth century. Mind was viewed as software and matter was viewed as the hardware of a computer. In Functionalism, it is not necessary for mind to be reduced to matter even if this approach is often connected with Materialism. Functionalism can also be seen as being compatible with Dualism. Mind-states do not need to be identified with brain-states even if they are somehow realised in them.[779] For example, Patricia Churchland has argued that what counts for mentality is not the material of the entity but its internal structure.[780]

Regardless of whether Functionalism is connected to Materialism or Dualism, it still remains a prisoner of the classical paradigm in just the same way as any of the great systems built by philosophers in the modern era. Only the statistical conformity to laws of the quantum frame of

[776] At the end of his *Treatise on Light,* Descartes explicitly says that "God or the rational souls present in the World will never disturb the ordinary course of nature in any way". Descartes 1999, 112.
[777] The problem of psychophysical interactionalism or parallelism could not be satisfactorily solved by an idealism or materialism which was not able to overstep the traditional mechanical view concerning physical reality.
[778] Spinoza accepted Pantheism but had to reject free will because of deterministic physics. Leibniz proposed Parallelism but was ultimately led to Idealism in order to guarantee subjective antonomy.
[779] Revonsuo 2001, 58, 77. Cognitive science has commonly believed that intentional states could be explained without mentioning consciousness in any way.
[780] Churchland 1988.

reference allows humans located within nature to have a real ability to choose, even though this is not sufficient as an explanation concerning the exact nature of ”true choices”. In Bohr’s complementarity frame of reference, the oppositional stance of natural science and the humanities disappears of its own accord. When humans are viewed as an active and responsible part of, or partner in, nature, rather than as the external operator of a machine, their knowledge, values and intentions are no longer only their own internal affair, they are of vital importance to the development of the whole system. As will be presented in more detail in Section 5.3. of this thesis, conscious humans in the quantum frame of reference do not need to remain external observers, they can be principally seen as active formers of reality who actualise some of the potential possibilities offered by nature on the basis of their own understanding and will.

In his complementarity, Bohr replaced the passive observer of classical physics with an active participant who is deeply interconnected with reality. Quantum theory allows some freedom and responsibility for humans because the past does not determine a unique future. Instead of dividing mind from matter, mind or consciousness can be understood as part of the world in which it works and about which it creates descriptions. Allocating humans a place in reality offers the possibility of constructing a causal theory of action which could not succeed in a world presumed to consist of deterministic matter. As usually understood, Determinism implies that at any time the future is already fixed and unique, with no possibility of alternative development. If humans wished to be seen as part of nature in this frame of reference, their behaviour also had to be determined by external events beyond their control.

In what follows, an attempt is made to use the material already presented to outline a dynamic ontological-epistemological frame of reference in which the paradoxes of quantum mechanics can become understandable. While the starting points are taken as Niels Bohr’s concepts of the impossibility of absolute objective description and our presence in the reality we are investigating, the interpretation is developed further. Bohr avoided the adoption of an ontological attitude, but in what follows, the inaccessibility of final truth is not viewed as a hindrance in attempting to construct a new and more-functional ontological framework for perceiving reality. When epistemological elements are considered in addition to ontological assumptions, knowledge concerning the limitations of our portrayal can also be addressed as a factor which urges development forward. While the question of the correctness of a world-view cannot be finally resolved, our portrayal can become more comprehensive in the way that it is better able to take account of the different development possibilities within different inter-dependent systems while at the same time considering our influence on evolution.

5.2. A New Onto-Epistemological framework

In the modern era, philosophy has had to operate within the mechanistic and deterministic conception of reality. It has been impossible to question the Newtonian conception of matter even if a philosopher wanted pay attention to the mind. By questioning the familiar thought that physics or any ontological description could ever provide an objective God's eye-view to all reality, Bohr took a long step forward: humans do not need to be external to the reality they are observing and reality does not need to be limited to just those phenomena describable by particles obeying deterministic laws in space-time.

The Copenhagen interpretation makes a genuine effort to renew the world-view of physics from its own starting-points. Even if it remains inadequately-structured and inherently inconsistent, it encapsulates the most fundamental questions concerning interpretation. In addition to the statistical predictions, the vagueness of the concept of an object was obvious to the Copenhagen Group.[781] When we combine the epistemological lesson stressed by Bohr with an ontological reassessment, we have strong cornerstones for a new realist way of thinking. This realism does not need to mean visualisability or the adoption of a mechanistic and deterministic concept of reality. If the particle-mechanistic model of reality really was abandoned, many of the paradoxical features of quantum mechanics would automatically disappear. For example non-locality or the EPR-paradox are not a problem if, as Heisenberg suggested, mathematical symmetries are understood as being more fundamental factors than material substance: material systems are then able to appear within the limits permitted by formalism, even if these phenomena cannot be understood within a particle-mechanistic frame of reference.

In recent philosophy of science, the difficulty of reconciling humans with nature has appeared in the antagonism between Realism and Pragmatism. Realism has traditionally adopted the presuppositions of classical physics concerning the external objective observer, while Pragmatists have concentrated on humans, their actions and practice. In the quantum framework,

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[781] For example, Heisenberg wrote that electromagnetic theory, which highlighted fields instead of matter, already represented a step towards abstract presentation which abandoned the atomic philosophy of antiquity. Heisenberg thought that elementary particles were abstractions derived from observations. They did not actually exist like trees and stones. Heisenberg 1955, 11. Heisenberg 1958, 13.

such strict divisions are unnecessary. When the describing human being is clearly located in reality, ontological and epistemological aspects become intertwined. The aim of describing reality and the capability of doing it become part of human nature. Inter-subjectively-verified (complementary) descriptions give us real knowledge concerning reality, even though they are not final truths and cannot represent the whole of reality in an exhaustive manner. Description and practice, rationalism and empiricism cannot be unequivocally divided and this is why the tension between them could not be settled in a satisfactory manner within the mechanistic-deterministic frame of reference. In the quantum framework, denial of the dichotomy between matter and spirit does not need to mean traditional Materialism or Idealism. Our mental states may be both real and causally-relevant, but they do not need to be reduced to material processes in an external world.

5.2.1. The abstract reality of state functions

Many of the unexpected characteristics of quantum mechanics can be traced back to the new description of state based on the complex wave-function. The wave-function is the most important term in quantum theory and the biggest problem in discussions of the theory has been interpretation of this complex entity, something which can never be directly observed. Some scientists think the wave-function is no more than a mathematical tool or instrument which is suitable for predicting the actual outcomes we observe. Others argue that the wave-function refers to some kind of transcendental quantum level. In any case, the wave-function is responsible for both the non-local and the statistical constitution of quantum physics. With this new description of state, some kind of indivisibility, internal spontaneity and change appear to be an unavoidable component of reality.

It is no longer possible to interpret the mathematical theories of modern physics as describing material particles moving in space-time, which in turn means that the particle-mechanistic idea suggested by the ancient Atomists has failed. Modern physics has demonstrated that the long-held ontological view concerning the foundation of reality is false. Unfortunately, the falsification of previous hypotheses as such does not suffice for the offering of a new ontological model which suits the new theories. The mathematical symbols and abstract physical theories suitable for predicting some observable outcomes do not carry with them a direct and clear interpretation of the character of reality that lies behind these theoretical representations. It is also highly arguable whether there is any form of “transcendental” reality beyond immediate observation.

Even if, since Galilei, it has often been said that *the Book of Nature* is written in mathematical language, many physicists nowadays understand mathematics as an abstract tool or instrument. Bohr also, in line with the Positivism of his time, understood mathematics as more an instrument, a tool for systematising observations and for use in forecasting. He evaluated the correctness of earlier metaphysical presuppositions using the new theory and experimental results as a foundation, but perhaps fearful of making errors, did not wish to postulate any new metaphysical ideas. In this, he was essentially left bound to the complementary fragments of the earlier comprehensive model, and it was not possible to link the fragments together at the level of empirical observations in any way. Nevertheless, Bohr on the other hand saw that even though it is not possible for us to avoid complementary descriptions when we are describing phenomena we have observed with classical concepts, mathematics appears to be a better way of addressing reality: its precise and explicit language are well suited to empirical experimental results, as if directly penetrating behind the world of observations. In fact, it was the mathematical formalism of quantum mechanics which demonstrated that the area of applicability of classical concepts was limited. Quantum theory addresses the fundamental entanglement which exists in the phenomena being investigated and reveals the inadequacy of the particle-mechanics space-time description.[783] Even though to Bohr, mathematics was a language, he did not attempt to describe the reality it portrays in another, more observation-oriented language. Bohr’s complementary portrayals are restricted to the world of phenomena and, in essence, offered different viewpoints on the processes taking place there.

According to the Realistic approach to mathematical theory, it is believed that something in nature corresponds to the abstract mathematical representation. This provides a strong argument that the fundamental entity of quantum mechanics, the state-function, is also an abstract representation which corresponds something in reality even if it transcends direct observation. The fundamental nature of the state-function gives us reason to suspect that the reality addressed by quantum theory is not limited solely to objects manifested in classical time and space. If we believe that this mathematical entity is addressing some structure which lies behind the observable world, there is nothing to stop us from attempting to also provide a metaphysical

[783] Even if the Schrödinger equation includes a description of space-time, non-classical configuration space holds a

description of this situation in natural language. This does not mean being satisfied with one of the non-credible auxiliary hypotheses with which later interpreters have attempted to rescue the basic presumptions of classical physics, but a comprehensive and exhaustive interpretation, a world-view on the basis of which the new features of quantum theory become understandable. In this way, mathematical language would not be used as an instrument but more as a stage in understanding.[784] A portrayal of such a type translated into natural language will certainly be unavoidably tentative and metaphorical. The guiding principle when postulating metaphysical claims that are outside the dimension of direct empirical verification can only be that such claims should be credible and compatible with experimental facts. Successful conjecture, i.e. new hypotheses concerning reality, can at their best reveal new concretely-observable connections and relationships, as Kant understood.

In searching for invariances, physics has not taken a clear stance concerning the fundamental relationship between mathematical structure and reality. What is the nature of mathematical objects and universal concepts? Are mathematical laws linked to ontology or epistemology? Is mathematics the universal language in which *The Book of Nature* is written and which humans can understand by using their intelligence, or is it nothing more than a human creation which suits our analysis of experience? It is certainly true that in physics, natural language, suitable as it is for the portrayal of an intuitive understanding of our everyday environment, does not work as well as abstract mathematics. Physical laws are mathematical and the proportion of mathematics in physical theories is ever-growing. For example, the attempt to understand particle physics has consisted almost completely of mathematics, group theory and the geometry of abstract spaces.[785]

From a historical point of view, powerful growth in mathematics has either preceded or been linked to each leap forward to a better understanding of reality and its more-comprehensive portrayal. Mathematics was developed strongly in antique times, and bloomed again at the time of the Renaissance.[786] In the 1800s, intense development occurred once again when, among other things, imaginary numbers added a new dimension to the sequence of numbers. In some basic way, mathematics appears to display the structure of the world it is addressing. The mathematical theories of physics help in predicting new phenomena and point to hidden connections between

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key position in quantum mechanics. Only in one case it can be thought that the state-function exists in space-time.

[784] The endeavour to use visualisible ordinary concepts does not represent an attempt to reduce scientific language to common language.

[785] Omnes 1999, 272.

[786] In 1687, only a handful of mathematicians were really able to understand Newton's *Principia*. Toulmin, 230.

them.[787] Even so, mathematics is, to a certain extent, a human creation, a language formed with the help of logical thought. Mathematical constructions suited to the portrayal of reality must be verified according to empirical observations. In mathematics, what is significant is not the character of its entities, but rather their relationships, their form, and the geometry which connects them together.

Enquiry into the nature of mathematics is closely connected to the dispute between Nominalists and Realists, unsolved since the Middle Ages, about the nature of the link between human concepts and reality. When something is successfully proved in mathematics, the proof is final and does not change in the way that other scientific hypotheses change. Taken to the limit, is the mathematical understanding of nature based on some kind of sharing or participation between the human intellect and nature so that the discovered mathematical model *per se* corresponds to a natural structure, or is it a question of nothing more than the interpretation of observations, so that, for example, the theory of everything is only a human creation, a model stretched to the ultimate possible extent, in which all the then-current knowledge of nature's fundamental symmetries and entities is crystallised? If mathematical and physical reality are considered to be identical, are we perhaps making the same type of mistake as was made in the Middle Ages when logic and reality were often considered identical? The mathematical tradition of describing reality is however fundamentally locked to the thinking that some kind of reality corresponds to the abstract description it provides. This is a strong argument that the wave-function, the fundamental entity in quantum mechanics, touches something that truly exists in reality even though it does not refer to anything we can directly observe in the familiar material world.[788] Many physicists have provisionally divided reality into two levels: 1) the complex quantum level where superpositions etc. are at work, and 2) the classical level, in which only some of the possibilities allowed by the quantum level may become actual.[789]

This kind of approach recalls the ideas discussed in antiquity. It has points of contact with the ideas of Heraclitus' *logos* and the ideas of Plato and Aristotle who, in contrast to the Atomists, emphasised that all happening and change in the material world cannot ultimately be reduced to local causes acting between isolated particles persisting in space. Plato and Aristotle stressed

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[787] Omnes 1999, 51-58, 84-85, Singh 1998, xii, 92-95.

[788] The form and solution of the wave-function depends on the characteristics of the object under study as well as on the context, i.e. on the boundary conditions that prevail in different circumstances. In principle, the quantum state gives probabilities for all possible occurrences in the three-dimensional material world.

[789] Penrose 1994, 308. Also Primas and Atmanspacher, see Lampinen 2002. This coarse division does not mean that these physicists would not believe that there are macroscopic quantum phenomena, or that in principle, the macroscopic level could not be described by quantum mechanics.

form, as does quantum mechanics.[790] In addition to the localised-particle aspect, a holistic-wave aspect also belongs to reality and profoundly affects the formation of physical events. Using Plato's and Aristotle's terminology, wave configurations can easily be identified as certain kinds of form or internal pattern which control and are manifested in the formation of matter. Plato's and Aristotle's rejection of Atomism has become a subject of renewed interest: nothing in the visible sense-world appears to be without matter, but at the same time, matter seems to be more that just matter. Matter and form are closely connected, integrated.

The great thinkers of Antiquity would undoubtedly have asked whether the state-functions belong to the eternal world of ideas or whether they are some kind of universals which guide the unfolding of different kind of things, namely the actualisation of hidden potential structures. Even though quantum states cannot be observed directly, are they something that exists or are they some kind of potential non-being, out of which may, according to Aristotle, something may emerge? The formalism of quantum mechanics is generally thought of as describing the probabilities of happenings manifesting in the physical world. If conceptual Realism is accepted and quantum theory is considered to be an abstract description, the quantum level has to be accepted as some kind of reality. Its wave configurations, which cannot be directly observed or measured, can be interpreted as representing factors controlling the formation of matter, potential forms which could be actualised. The complex entities of modern physics are somewhat reminiscent of the "perfect" ideas of Plato – as they can only be imperfectly manifested in the visible sense-world, even the best measurements only project onto the world some part of the information contained in the quantum states. It is also quite clear that we are not able to truly enter the ”quantum world” to any greater degree than Plato thought human beings could enter the eternal world of Ideas.

At the same time as quantum mechanics argues with Reductionist particle mechanics, it appears to illuminate the relationship between the changing world of the senses and eternal and unchanging reality in a new way, regardless of whether this particular invariable is considered to be either a real participant in reality or just an abstraction resulting from a theoretical description

[790] When trying to understand the formation of the things and phenomena in the material world, both Plato and Aristotle thought that nothing in the visible world is just matter but also not without matter. Matter and form were united and form did not mean just the visible form of different things even if it became observable in them. By using this kind of terminology, the quantum state could be called a kind of form which transcends and defines the dynamic and qualitative forming of matter. David Bohm also stressed the concept of form. For him, the form of the wave-function was its second spatial derivative which in-formed matter, the energy of particles.

which is searching for invariances. Plato is often said to have totally separated the eternal world of ideas from the changing sense-world, but in spite of the heuristic separation between classical and quantum levels, theory shows that the quantum world is not an isolated one. There is a clear connection between the macroscopic world and the quantum level since every occurrence at the visible (material) level changes the structure of future possibilities. Aristotle rejected Plato's strict boundary between the two worlds and put the "play of possibilities" down to a non-being which was not directly detectable but which had the potential to be something.[793] With his idea of potentiality, Aristotle clearly remained in this world, as does quantum theory. We have one reality which includes various kinds of tendencies or dispositions which may become real and detectable.

Even though the quantum state appears to be a relatively simple structure which develops in accordance with deterministic laws, in the real observable world it can manifest many different aspects in different interactive situations. In this way, the modern physics that has been refined the mechanistic-deterministic way of thinking is also capable of responding to the criticism that Aristotle aimed at the antique Atomists and pre-Socratic natural philosophers: since their presumption of a world of "dead" matter did not offer tools for their understanding of it, they had been led astray from the path that concerned birth, destruction and change. Through quantum mechanics' abstract mathematics and its concept of state, physics is now able to address in a theoretical manner the statistical dynamics of the shaping of individual events manifested in the world of the senses. Quantum mechanics appears to be a universal theory which is actually able to take account of not only the changes that take place, but also the context in which they occur.

If humans can, via mathematical description, also address something that is external to space-time, structures that can possibly be manifested in the observable world are not limited by physics to the so-called "world of matter". The mathematical descriptions of physics are also not limited to an eternal and unchanging world that lies beyond phenomena, in which only events which result from certain initial conditions are thought to be possible. The existence of statistically-predictable phenomena make it necessary to add some temporality and uncertainty to an objective world ruled by absolute conformity to laws. Quantum mechanics also offers tools for dealing with the evolving physical world that surrounds us, a world in which change is both

[793] In the opinion of the scientific realist, the non-observable can exist. As Parmenides concluded, non-being cannot be.

possible and unavoidable. While the traditional external observer formerly portrayed the observable physical world with the assistance of invariant and deterministic natural laws, in the light shed by quantum mechanics, only the quantum level is deterministic.[795] This, however, is neither invariable or independent of the observable world's statistically-predictable events, since the consequence of interactions that occur in the observable world is that the theoretical distribution of possibilities will be redefined.

Although humans are physical beings bound to a world of changing matter, they strive to obtain knowledge of the whole of reality in their portrayals. The position of humans makes it necessary to describe different levels in differing ways, and in this kind of several-level context, Bohr's and Einstein's divergent views on the nature of description can, to some extent, be reconciled. Einstein could be correct in his belief that mathematical description truly addresses something of the fundamental structure of reality: that it extends to the reality which lies behind the observable world and in this way facilitates some sort of understanding of that world. Mathematical theory is capable of addressing both the fundamental and unchanging symmetries of nature and the conformity to laws and possibilities which correspond to observable reality. As Plato did in his time, Einstein focused on the eternal and the invariant, while Bohr, in line with the empirical tradition, held tightly to the observable macroscopic world, in which only some of the possibilities imparted by the quantum level are realised. As three-dimensional projections of multi-dimensional and actually fundamentally-indivisible reality which are restricted by commutation relationships, these possibilities can only be presented in a complementary manner.

Bohr's view of the limitations on our models is credible: in describing our experiences we are bound by the conditioning of our language, our structures and our history to tentative models and methods of approach which have been developed with the passage of time. It is not, however, essential to limit models to nothing more than that which is suitable for a world of changing observable phenomena. All models do not have to portray perceivable events in classical everyday language, since humans can also make ontological assumptions and form models of reality on a mathematical basis. In spite of this, it is difficult to challenge Bohr's thinking that the familiar method of description employed by natural science, i.e. the viewpoint of an objective external observer, does not work when portraying the formation of those phenomena in which human activity in the shaping of reality must be taken into account. Humans are bound to the

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[795] Development at the quantum level is deterministic if measurement does not intrude on the system. Symmetries are considered to be eternal and unchanging.

models they create, and contrary to the assumption made in classical physics, cannot be detached observers of all events which take place in the world of matter.

5.2.2. Embodied representation

Classical physics recognised only the world of matter and influential causes, there was no place for random events in the world it portrayed. From the viewpoint of quantum physics, the perceivable physical world is not however unchanging or deterministic, and measurement does not only reveal things as they are, incidents that have taken place, but can also create new states of affairs. In its search for absolute invariance, classical physics' method of explanation requires that the world is in principle completely open and available to an isolated observer who can provide a comprehensive and fully-objective portrayal of the events that take place within it. The problem of measurement implies that humans cannot be excluded from the world they are investigating. We define and construct experimental situations, and as a consequence of this activity in reality the desired attributes actualise within the limits of the allowed possibilities.[797] All seemingly absolute and objective natural facts are not, or cannot remain, wholly independent of the way in which we act and carry out experiments. Even though we need not doubt that all events in reality conform to laws, nature's causal lawfulness cannot be identified with predictability.

By choosing a specific item of measuring equipment, the experimenter essentially presents nature with a certain type of unique question. The shaping of reality is neither completely independent of how we act nor does it remain unaffected by our presence. Although the state-function gives the probabilities that different possibilities will be realised in an ever-changing perceivable world, the birth of a specific interaction phenomenon requires manipulation of the world, either the asking of specific questions or execution of specific experiments, and as a result of these the perceived physical reality may also change. The shaping of reality by observers cannot be completely predicted in advance or comprehensively described from an external viewpoint, even by employing statistical laws, although this way of thinking is one which has become generally familiar. Knowledge is not just a mirror in which reality is reflected, it is a

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[797] Even if human beings create different kind of circumstances where various attributes may appear, observation does not directly influence the formation of reality. The objective structures of observable reality can still however change as a result of human action. Humans influence both the formation of reality and the distribution of consequent possibilities.

factor through which we are able to bring about change in ourselves and in the external world. [798] The form of the questions we pose determines to a significant extent the kind of answers we receive. Even if it is always humans who form the question, nature must be allowed to answer for itself. We can only predict probabilities. In our investigation of one property, by measuring it, we at the same time alter the possible distribution of other values.

Measurement, human choice and the actions we take have a clearly irreversible character. This also means that everything cannot be ascertained at one and the same time, and that initial conditions cannot be returned to at a later point in time, since the world has changed as a consequence of our activity. No single individual measurement situation or description visualised on the basis of it can address the abundance of reality. Bohr did not believe in the possibility of a ”God’s eye view” or ”view from nowhere”. Belonging to a specific temporal context implies that even though our descriptions and explanations can be developed, a tiny but unavoidable ”blind spot” will remain whose significance cannot be ignored. Our portrayals cannot, from an absolute point of view, correspond to reality, nor can we recognise in advance the character or formation of objects that are manifested in the perceivable world. Even though we target reality in our descriptions, the models and theories thus formed are just a part of human knowledge, not part of indispensable ontological reality. The world and portrayals of it should therefore be separated from one another. Even though humans are, from an ontological point of view, part of the processes which constitute reality, in descriptions and interpretations of our observations and experiences we have to "step outside" this immediately-experienced reality.

Only as outsiders can we stop to investigate and evaluate our perceptions and our experiences, only by conducting our examination from an external position can we create inter-subjectively-understandable images or maps from them. The models of reality that we create can be comprehensive mathematical theories or individualised descriptions of phenomena that we encounter. We can look at reality from different perspectives and viewpoints, we can choose to be in close or far-away locations.[799] Models can be superimposed or limited, they can appear contradictory but anyway complement each other by offering different viewpoints for the portrayal of specific real situations. Which particular model is good depends to a great extent on where it is to be employed. Models do not reduce to some simple ingredients, even though the

[798] The choices we make influence not only the shaping of the nature that surrounds us, they also affects our own internal structure and our future circumstances.

[799] Even though humans always observe and shape the world in unique individual situations, they can, on the basis of their experiences, attempt to achieve descriptions which are universal and generally-valid. Since the act of description separates us from reality, we can attempt to remove ourselves as far as is possible.

all-embracing and universal general ones actually allow us to address fundamental elements of the ontological structure of reality, within the framework of which all other events should be credibly identified.

This viewpoint signifies a challenge to ontological Dualism. In our activity and our perception we participate in the shaping of reality. From an epistemological point of view, it is however necessary to make a distinction between the subject making the portrayal and the object of the portrayal. In describing and rationalising our experiences, it is as if humans have been appointed as external observers of the process of reality: they imprison their experiences within the models they create. Models created by humans do not correspond with reality in an unproblematic way, and this demands an reassessment of the concepts of both theoretical description and the character of explanation. The method of explanation and concept of knowledge employed by classical physics must be re-evaluated, since even the best models that address reality remains abstractions which can be subject to change as a result of future developments.

More-accurate and comprehensive models which better address the ways in which nature operates offer humans the possibility of an ever-improving understanding of both themselves and their environment. Since our own being and our activity are also part of the wholeness of nature, we can, on the basis of natural methods of operation and associated knowledge, also attempt to create models which describe both ourselves and those natural process in which we participate. Bohr focused attention on the fact that part of us can be an external examiner of situations whose formation actually depends of us. It was a habit of his to give students who visited the Copenhagen Institute and were fluent in Danish a copy of a book by the philosopher Paul Möller, in which the human self is depicted as examining itself in such a way that part of the ego always steps out of the preceding situation. In the end, the philosopher feels that he is looking at an infinite series of egos, as if he were standing on the edge of a bottomless abyss.

In the ontological-epistemological model presented here, the position of humans in the physical world changes from that of an external observer to that of an evolutionary influencer who, as a psycho-physical unity, has an immediate presence in the reality being examined. The subject making of portrayals and the part of consciousness which may step out of them also belong to reality. Although so-called 'mind' and 'matter' operate seamlessly in the same system, we do not know the final character of this system. The different views concerning ontological entities are founded on our own descriptions. For this reason, it is my opinion that this outlining of an ontological-epistemological model does not imply Materialism any more than it implies Idealism. It would be better to call it ”Realism based on metaphors”. A more-accurate portrayal of the relationship between the aspects of reality that are termed mind and matter requires us to have more accurate knowledge than is currently available about, in particular, the development of mental structures. As will be proposed in more detail in the following sections dealing with humanity, quantum mechanics can offer new tools for the handling of mental states and the psycho-physical problem.

Development of our physical world-view appears, in the light of what has been said here, to be moving in a direction anticipated by process philosophers at the beginning of the 1900s when they proposed that a process-ontology is a more suitable way of depicting reality than the traditional ontology of things. For example, A. N. Whitehead rejected Materialism, Idealism and Dualism by criticising the presuppositions of classical physics.[800] He viewed change or process as a fundamental factor in nature. In his opinion, physical nature or life cannot be understood without their being fused together in all the beings that exist.[801] In the light of what has already been said here, the wave-function of quantum mechanics demonstrates the limitations of the traditional space-time portrayal. From an ontological point of view, reality is better thought of as a hierarchically-structured holistic unity, in which the possibilities of events being manifested at different levels are limited by physical laws and symmetries. In a developing system, limitations on nature’s conformity to laws do however have many degrees of freedom, which humans can also exploit for good or less-good purposes.

5.3. The Human Being as an Evolutionary Agent

The Greeks felt uneasy when they encountered reasons to doubt the togetherness of the body and the soul. At the turn of the modern era, all of the subjective mental content linked to the soul was however clearly separated from natural processes. Classical physics focused on revealing the natural laws in the material world, but the basic problem of how is it possible for mind to have a genuine causal effect in the physical domain is still one of the basic problems in modern philosophy of the mind and in cognitive science.

[800] Bohr also considered that quantum mechanics exceeded the earlier dualistic starting point and did not imply materialism any more than idealism. The phenomena we describe using the concepts of mind and matter belong to the same reality. We need both concepts, but reality does not need to be reducible to either one of them.
[801] Whitehead 1934, *Nature and life*.

In general, attempts to avoid the psycho-physical problem thrown up by Cartesian dualism when approaching mental and cognitive phenomena in a scientific way presume the ontological primacy of the material world. The positioning of human mental activity within a mechanistic-deterministic frame of reference brings with it major problems of principle to which no successful solutions have been found in spite of developments in artificial intelligence. When the world of matter is assumed to be a closed system, the way in which human free will or the contents of the mind can have a causal effect on the inevitable laws and processes of material world escapes explanation. The question of whether this matter requires some special explanation has divided philosophers. Compatibilists have traditionally assumed that conscious phenomena are compatible with Determinism, while in the opinion of the Incompatibilists, freedom is simply not compatible with Determinism. If the laws of nature are universal, there can be no free agents because every action is determined by events that have already taken place.

Combatibilists concentrate on human experience and the concept of freedom. Freedom is, in essence, just a matter of not being constrained or hindered in particular ways when one acts or chooses. It is simply a matter of having genuine options and opportunities for action, and of being able to choose between them according to what one wants and thinks is best. It can be believed that phenomena of consciousness can be contemplated in a manner completely independent of physical theory when there is no difference in principle whether the laws of nature are deterministic or statistical.[802] Even though the Compatibilist concept of freedom can be supported, Incompatibilists have viewed Compatibilist theories as not even touching the real problem of free will. There can be no free agents in an overall deterministic framework. As every action is determined in advance within a mechanistic-deterministic frame of reference, humans are not given either real freedom or the possibility of influencing the world’s closed deterministic processes. Within the scientific method of approach, the internal freedom and creativity that most of us feel to be natural have had to be explained as being either more or less apparent. In fundamental terms, the conflict between the Compatibilists and the Incompatibilists can be viewed as a product of the mechanistic conception of nature adopted at the turn of the modern era, a conflict which disappears in the quantum frame of reference. Bohr emphasised the fact that humans are not just onlookers, they are also actors in the theatre of reality. Closer examination of

[802] Strawson (encyclopedia) 743-746. In a Kantian framework, for example, subjects live not just in a physical, scientifically-describable world, but also in a normative universe of discourse which gives rise to freedom and responsibility. Pihlström 2002, 109-110. This kind of metaphysical argumentation is not in strong opposition to the view I defend in the following sections. The quantum framework makes it possible to overstep traditional boundaries.

the measurement situation revealed our dialogue with the world, one manifestation of a type of activity that does not exist in the world of classical physics.[803] In the quantum frame of reference, the world that is examined by natural science has room for a responsible human being making genuine choices.[804]

An actor need not, however, inevitably be an autonomous subject capable of freely choosing and defining its own directions. If all our subjective phenomena, the whole of human activity and the knowledge, skills, values and goals it contains gain a place in the dynamic fabric of reality, from nature's point of view we obviously might be able to select the wished-for processes from the particular set of internal and external possibilities offered by our environment. The internal dynamic of our human capabilities and choices could bring some new organisation to the world, but no-one yet knows how great our influence on the universe and its total energy balance is now, or could be in the future. For example, Freeman Dyson takes the optimistic view that life plays a significantly-more-important part in the drama than we think it does: it can shape the whole universe according to its own wishes and desires.[805]

5.3.1. Transcending the division between subject and object

Even though the way of thinking in which humans are embedded in a fundamental way in the world in which they operate receives powerful support from both evolutionary theory as well as quantum mechanics, the question of transcending the division between subject and object remains a difficult one. According to Cartesian dualism, the subjective content of the human mind is usually viewed as being almost the opposite of a natural objective process. On the other hand, when searching for a unified basis for explanation, human activity has customarily attempted to achieve understanding on the basis of natural science. Philosophers of the Enlightenment solved the psycho-physical problem directly by placing humanity in its entirety as subordinate to material and deterministic natural processes. Doctrines such as Behaviourism,

[803] The influence of measurement situations on formation of the world is naturally infinitesimal in comparison to other human interaction. It does however show in a concrete way that humans cannot be disconnected from the development of nature. Our choices and our actions result in irreversible changes in nature.

[804] In a quantum framework, the effect of mental states on matter can be explained in accordance with the physical laws of conservation. For example, John C. Eccles has proposed a detailed hypothesis for the mind-brain problem that does not infringe the conservation laws of physics. See Eccles 1994. Any probabilistic theory offers the same possibility. C. Peirce, who studied statistical laws, held the opinion that these permitted human autonomy.

[805] F. Dyson 1971, 50-59.

Socio-biology or Evolutionary psychology can be seen as continuations of this materialistic trend. Humans are viewed as complicated automata in a world which has no place for real freedom.

Even though some of our brain activity can be modelled using computers, the analogy which portrays humans as passive machines is only considered a suitable one by a minority. We conceive ourselves as active agents, something that classical physics' conception of the world does not recognize. The great system-building philosophers of the modern age such as Leibnitz, Spinoza and Kant saw that conscious, willing and knowing humans could not be reduced to matter, even though they cannot be fully separated from it. In humanist circles, it has always been emphasised that the theories of classical physics are unable to directly model even the biology of living beings, let alone explanation of the nature or development of mental states or social constructions. The mechanistic-deterministic frame of reference can be viewed as basically deficient in its understanding of these phenomena. This does not however mean that humans and the activities they engage in cannot be approached by using scientific tools within a more-extensive framework.

In western philosophy, doctrines in which humans are allocated the position of being a fundamental part of reality have, in the last century, been presented by Marxists and Pragmatists. Quantum mechanics has not had a great influence on the formation of these doctrines, even though, for example, when giving the Gifford Lecture in 1929, John Dewey offered the opinion that Werner Heisenberg had liberated us from the limits that clockwork-like reality established in the 1600s when the Cartesian division between nature and humanity, matter and mind, was established.[806] Also Karl Popper, who in addition to physical and organic worlds attempted to outline the development of a world of social and cultural entities. Popper's thinking illuminates the fact that paying attention to the influence of humans does not require the abandonment of either Realism or the idea of nature's objective lawfulness. The indeterministic conformity to laws in quantum mechanics allows allows humans a place as part of reality.[807]

From both a detailed and more natural-scientific point of view, the portrayal of humanity as located within reality has been attempted by Michale Polanyi and Ragnar Granit. In his *Personal Knowledge*, Michael Polanyi rejected the ideal of scientific detachment. He considers that while this false ideal may perhaps be harmless in the exact sciences, it exercises a destructive influence

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[806] Toulmin 278-280. Dewey also criticised modern philosophy's search for certainty.

in biology, psychology and sociology. Polanyi regarded knowing as an active comprehension of the things known, an action that requires skill. The personal participation of the knower in all acts of understanding does not make our understanding subjective. Comprehension is neither an arbitary act nor a passive experience, but a responsible act claiming universal validity. Such knowing is indeed objective in the sense of establishing contact with a hidden reality.[808]

Polanyi attempted to understand the position of the mind in physical reality with the help of a hierarchical model. His proposal is that reality is in some way layered, with the emergence of certain more-complicated higher-level structures whose properties cannot be reduced to properties of lower-level components. Polanyi believed that it is as meaningless to represent life in terms of physics and chemistry as it would be to interpret a grandfather clock or a Shakespeare sonnet, and that it is likewise meaningless to represent mind in terms of being a machine or as a neural model. Lower levels, however, do not lack a bearing on the higher levels: they define the conditions for their success and account for their failures, but cannot account for their successes because they cannot even define them.[809]

In the manner of Polanyi, the Nobel-Prize-winning physiologist Ragnar Granit, born in Finland, highlighted the birth of hierarchies in the evolutionary process. Hierarchical organisation implies that at each level, new functional relationships are created which use lower organisational levels.[810] The principles governing the isolated particulars of a lower level leave indeterminate conditions to be controlled by a higher principle. For example, the tongue cannot run our speech but voice production leaves the combination of sounds into words, which is controlled by vocabulary, largely open. Next, a vocabulary leaves the combination of words to form sentences, which is controlled by grammar, largely open, and so on. In consequence, the operations of a higher level cannot be accounted for by the laws governing its particulars at the next lower level. You cannot derive words from phonetics; you cannot derive grammar from vocabulary; the correct use of grammar does not account for good style; and good style does not supply the content for a piece of prose.[811]

Granit uses this analogy to show how conscious man makes use of neurophysiological mechanisms without being governed by them. In an analogous way, a computer makes use of the

[807] See for example Popper 1972, the chapter “Clocks and Clouds”, and Popper and Eccles 1977.
[808] Polanyi 1958, vii,viii.
[809] Polanyi 1958, 382.
[810] Granit 1977, 85.
[811] Granit 1977, 72-73. Granit quotes Polanyi’s article in Science 160 (1968) 1308-1312.

laws governing electrical circuits, the so-called ‘hardware’, but the *purpose embodied* (authors' italics) in its design cannot be reduced to hardware terms without losing its relevance.[812] Granit believes that from the evolutionary standpoint of modern biology, consciousness is an emergent novelty. Life creates novelty from one level to the next, and a warp of creative purposiveness is woven into the fabric of biological hierarchies with consciousness located in its top level.[813] Polanyi also focused attention on the fact that as far as we know, the tiny fragments of the universe embodied in man are the only centres of responsibility in the visible world. So far, the appearence of the human mind has been the ultimate stage in the awakening of the world.[814]

Like Polanyi and Granit, Bohr also saw that an organism has the kind of wholeness that a system constructed out of a host of atomic bricks - the kind thought of by classical physics- could never have. He also saw that the difference between living and dead matter was not so simple. For example, a ship is not a completely dead object. It behaves towards men much as a web behaves towards a spider or a nest behaves towards a bird. Its formative force emanates from man, and the process of repair is in some way analogous to the process of healing. What constitutes an important difference is that in man, this formative force also involves consciousness. Bohr believed that any science which deals with living organisms must cover the phenomenon of consciousness because consciousness is also part of reality.[815]

Many other researchers have also seen some sort of Emergent materialism as offering the most credible possibility for describing the phenomena of life and consciousness within the scientific world-view. While Reductionist materialism attempts to reduce consciousness to matter, in Emergent materialism it can be seen as arising out of a material process, but as a qualitatively-different factor. In a strict interpretation, Emergence does not necessarily fit within the Reductionist way of thinking typical of the mechanistic-deterministic frame of reference. The birth of the contents of consciousness and its causal influence on closed processes in the world of matter require that contingent changes take place in the world which cannot be exhaustively explained by Emergent materialism any more than they can by Functionalism operating within a deterministic framework. When mind is considered to be a property or a function of the ontologically-primary physical substance or a higher-level result of the functioning of ontologically-primary physical parts located at a lower level, such a view is bound to leave the

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812 Granit 1977, 73.
813 Granit 1977, 72-73.
814 Polanyi 1958, 405.
815 Bohr in a discussion recorded by Heisenberg in 1971, 109-110, 114.

mind epiphenomenal, as causally inefficacious.[816]

Since the mechanistic-deterministic context does not offer even Emergent materialism clear opportunities, and without dwelling on the fact that psychic or spiritual factors could perhaps have some more fundamental and somehow independent role in the world, many humanistically-oriented thinkers have, with good reason, concluded that the psycho-physical problem or mental phenomena cannot be explained within a physical context. Since the equations of classical physics are inadequate for dealing with psychic phenomena, it is believed that addressing a portrayal of the development of people's inner world will never be possible via the methods of physics. The humanist and natural-science methods of approach are often seen as irrevocably incompatible. Granit, for example, believed that many of his explanations do not, and never will, end up as the differential equations that the physicist uses when interpreting the world.[817]

It is however essential to note that even though the formulae of classical physics are not adequate to provide an accurate portrayal of human activity or the relationship between matter and mind, the quantum physics frame of reference offers better possibilities. Via its more-sophisticated equations, quantum theory questions the whole of the earlier particle-mechanistic conception of reality. Modern physics has provided us with fundamental tools for reconsidering the utmost ontological and epistemological presuppositions which often still categorise our thinking. When, instead of treating particles as its "objects", quantum mechanics deals with new kinds of regularities such as wave configurations which contain the statistical distribution of all the happenings which can be manifested in space-time, such a context also offers new space for the explanation of consciousness phenomena.[818] Within a scientific frame new solutions can also be sought outside familiar ontological categories and ways of thinking.

5.3.2. Quantum mechanics and the modelling of our internal states

On the basis of a Naturalist method of approach, it is natural to assume that nothing happens in the world if such a happening is not permitted by the laws of nature.[819] Presumably, since our

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[816] Pylkkänen, 1992, 43.

[817] Actually Granit's ideas have many similarities to those of David Bohm.

[818] A major metaphysical problem in understanding psycho-physical causation has been the fact that natural laws only appear to connect events to events, not agents to events. See for example Jubien 1997,114-126. As the state-function is not an event, metaphysicians should study carefully the possibilities that it offers.

[819] The principle does not mean that we already know all the natural laws or that we are able to explain everything using them as a basis. Neither can we know whether natural laws could themselves develop.

subjective states and properties belong to the same existing reality as the so-called world of matter, the laws controlling regularities in these phenomena should also be a subject that is approachable using the methods employed in natural science. A unified scientific description of reality does not however have to signify being tied to classical physics' mechanistic-deterministic concept of reality or to a particle-mechanics way of thinking.

As the long-drawn-out and unresolved dispute between the Compatibilists and Incompatibilists indicates, it is difficult if not impossible to reconcile any type of freedom and ”immaterial” mind-states with mechanistic-deterministic reality. The birth of states and the contents of mind, and their feedback connected with phenomena in the material world do not appear to be either returnable or connectable in any clearly-identifiable manner to particles and the deterministic laws which relate to them. The methods employed in classical physics which are suitable for investigation of the macroscopic world do not, in my opinion, offer tools adequate for the task of examining the content of the human mind and understanding its development. We do not know whether humans possess something which cannot, in principle, be incorporated into computers or artificial intelligence systems: the relationship between our mental states and brain activity remains obscure. In cognitive science, attempts have been made to portray the mind as the software (i.e. programme) of a ”brain computer”. Even though Functionalism is usually linked to Materialism, there is no need to identify mental states with physico-chemical brain states, the former can simply be thought of as in some way implementing the latter. For example, according to Patricia Churchland, when investigating mentality, it is not important from which material a being has been constructed, the only important thing is the structure of its internal activities.[820]

Throughout modern times, philosophers have usually attempted to hold on human autonomy and responsibility, even though a physical explanation of the causal influence of our internal states on the processes of the material world has not proved possible. Modern-day philosophy of the mind and philosophy of cognitive science are mostly committed to Physicalism, and reject any mental substance. At the same time, they are usually reluctant to completely deny the existence and causal efficacy of mentality. No clear answer to the question of whether mental states and events are also physical entities has however been found.[821] The 'Mind-Body Problem' is an item which appears regularly on lists of major philosophical issues in introductory books. Even if the mind has lost its position as a particular kind of persistent object, it has kept its place as a central concept in contemporary debates on the philosophy of mind. In the new ontology of the

[820] Churchland 1988.

mind, categories such as mental events, states and processes have replaced modifications of the soul.[822]

Traditionally, physicists investigating the dimensional world of inorganic matter have not really participated in investigations of the phenomena of consciousness, but the advent of quantum mechanics has changed the situation. Many physicists have begun to become involved in questions concerning consciousness. In basic philosophical or cognitive-science texts dealing with phenomena of the mind or consciousness, references to quantum theory are few and far between. Even in those works that defend Materialism, it is unusual for there to be even a few words concerning the nature of matter.[823] The dominant research tradition appears to take the concept of reality legitimised by classical physics as a given: manifestations of consciousness are investigated at the macroscopic level within a mechanistic-deterministic framework.[824]

Part of the problem of understanding the way in which the brain operates is certainly connected with macroscopic phenomena, but in principle, the possibilities offered by the quantum frame of reference can also be considered to be a better starting point than those of classical physics when we are attempting to address our internal dynamics. Since the classical physics method of approach is not even adequate for explaining the behaviour of atomic particles, we can make the defensible assumption that profiling difficult-to-address phenomena of the mind also requires a more-developed physics. The existence of the state-function and fields mean that modern physics is no longer restricted by Atomistic ways of thinking adopted at the beginning of the modern era. All physical events observed in nature do not need to be reduced to observable and directly measurable quantities and material entities. The shaping of reality can also be influenced by structures or causes that are not directly manifested in space-time.

Currently, the principal trends in neuro- and cognitive science being debated by philosophers appear to be Reductive materialism, in which the mind is identified with specific brain states, or Eliminative materialism, in which the concept of the mind as viewed by common psychology is completely eliminated. If the existence of independent mental phenomena is accepted, one can choose Parallelism, side-by-side spiritual and neural activity, or Interactionism, in which some

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[821] Pylkkänen, 1992, 43.
[822] Steward 1997, 1-2.
[823] Squires 1990, 3-4.
[824] This choice is sometimes defended by saying that the human brain and nerves are macroscopic objects or that quantum indeterminism would cause further complications in understanding psychophysical causation. These arguments are not valid outside a mechanistic-deterministic framework.

degree of interactivity between spiritual and neural functions is assumed. Parallel function can mean that everything has a spiritual component, that spiritual functions are by-products of material functions, or that spiritual functions are identical to some neurological functions. None of these views can however be made credible with the help of artificial intelligence or its applications. Within Interactionism, the following proposals have been made: 1) that spiritual functions cannot be fully described using neural networks, 2) that spiritual functions cannot be fully described in a formal manner, and 3) that biological intelligence should be viewed as a product of evolution, a ”system” which has a seamless connection to the organism it serves.[825]

In a physical context, it is usual to think of phenomena of the mind as externally determined. In recent years, the rapid development of cognitive neuroscience and brain research by measuring brain activity and employing imaging systems has opened up new possibilities for the modelling of internal reality. Magnetic-resonance images have provided an indication that the contents of mind or consciousness cannot be directly reduced to the physiology of the brain. Human attentiveness and our state of alertness has a powerful influence on brain activity and we are clearly able to change our brain states via conscious mental exercise. Even though Materialists can maintain that ”mental exercise” is just a brain process which in itself is nothing remarkable, scientific-technical development may, little by little, demonstrate that the mechanistic concept of human being is not a credible one. The universe that lies within us does not have to be any simpler than the external cosmos, and does not have to be determined by laws that exist in that cosmos. Fundamental understanding of conformity to laws within the mind would appear to require the adoption of a multi-disciplinary approach. It is my belief that experimentation in the fields of brain research, neurobiology, psychology and modern physics will all be required. Fruitful interaction between these different methods of approach is unlikely without a profound renewal of the underlying ontology.

Suitably-interpreted quantum theory can be viewed as offering a foundation for the investigation of both mental and material phenomena. Bohr’s complementarity signifies a challenge to the strict dualism of subject and object. Reality appears as a single complex whole which we can divide and portray from different viewpoints. In the non-localised reality at quantum level, different tendencies and dispositions can be something actual and real, even though they cannot

[825] Jalonen 1990, 125-126. For example, behaviourism rejected any talk of autonomous mental states as unscientific. Cognitive science has been more tolerant and in its multidiciplinary circles mental states and phenomena are usually considered to be causal factors explaining behaviour even though they are fundamentally believed to be identifiable with certain brain states or brain phenomena.

be directly understood by reducing them to material particles moving in time and space. This offers new possibilities for the modelling of our internal states and an improved understanding of our psychic structure. In contrast to the mechanistic-deterministic reality of classical physics, mental states and influences can, in the quantum frame of reference, be real, even though they are not directly-manifested and measurable objects in space-time to which certain quantitative properties can always be assigned.

If some kind of invisible states also belong to reality, the primary obstacle to our physical understanding of mental states disappears. The same universal laws could be used to model the formation of both the material world and subjective reality. The abstract wave-function might not only control the formation of matter but also the formation of mental states.[826] Through the concept of quantum states, dispositional but causally-relevant mental characteristics could be handled in a scientific manner without there being any need to attempt to reduce them to physical processes in the material world. It is not necessary to identify mental states with brain states on a one-to-one basis even if they can be closely connected. Consciousness phenomena that are not directly manifested in space-time can be approached mathematically in the quantum frame of reference through the state-function, but there is no requirement for our inner reality to be reduced to material processes in the external world.

The composition and contents of the human mind clearly constitute in processes of the material world and are the result of individual development. Both the links between the synapses of nerve cells which are related to learning and the whole of the brain's structure develop throughout the course of our lives. The plastic shaping of the brain is linked to development of the content of our minds. It can be hypothesised that specific probabilities can be allocated to the production of particular structures in the human mind as a result of specific experiences, and that these structures can, under specific conditions and interactions, result in specific consequences with particular probabilities in a manner that is analogous to the physical research already conducted with quantum systems.[827] Even though, quite naturally, the contents of the mind are even-less-readily yielded and much-less-predictable entities than objects that belong to the observable

[826] Professor Kullervo Rainio has presented an exhaustive model to deal with cognitive processes within a quantum framework. See Rainio 1998 or 2000. Presumably the thoughts of Wolfgang Pauli and David Bohm about psycho-physical reality are based on the same idea.

[827] Compared to classical determinism, the quantum state-description appears to be able to deal with phenomena that are more complex. For example, in connection with health problems, mechanical determinism is not able, in addition to direct physical factors, to deal with the combined effect of a multitude of other relevant causes such as nutrition, environment and the social relationships which may influence an individual case. These could cause states which might correlate and in certain conditions produce certain effects with predictable probabilities.

world of matter, different mental contents such as knowledge, feelings and models of behaviour can be shaped according to specific possibilities permissible at the ”quantum level” which are then realised in differing ways in each individual according to their particular composition, according to the surrounding environment, according to developments which have already taken place, and following choices which have already been made.

It is clear that mental states cannot ever be wholly observed or completely known any more than this is possible with the other quantum states investigated by physics. Regardless of their specific “transcendentalism”, quantum states do however have a concrete influence on the shaping of the material world. Also, possibilities contained within the structural composition of the mind can, in different circumstances and through differing interactions, be realised in the observable world in differing ways. Different mental states can clearly have a varying degree of observable influence on the world of matter: part of the internal structure of our minds need not necessary exert any external influence. Some quantum states may present in certain position in space, some are perhaps only found in some people’s minds. In the state-function representation, mental states do not have to be just brain events even though the two may be closely and lawfully connected. In this kind of frame of reference, the functionalist approach of cognitive science could be truly combined with the biological levels of description employed in neuroscience.[828]

State functions are inseparably connected with phenomena that occur in the world of matter, but they cannot be completely reduced to material processes or to directly-measurable objective qualities. In principle, their relationship to the ”mental world” can be of a similar kind. In the quantum frame of reference, physical and psychic entities do not have to be returnable to each other, both are rather just different presentations of quantum states. Handling the contents of the mind with state-functions does not require any type of artificial truncation. All the elements and influences that we believe exist in someone’s mind can be included in a quantum state that describes a given situation. Within such a framework, differing mental states, memories or feelings can be spoken of as being comparatively independent and might also be connectable to certain observable physiological influences, but, for example, the problem of where such states should be permanently localised does not have to be a problem any greater than that of where other attributes not manifested in certain situations should be located.

[828] The mechanical and causal biological explanations and functional explanations of cognitive science are based on partly-incompatible presuppositions or background assumptions: functionalism denies the relevancy of biological levels of description. Revonsuo 2001, 81.

The concept of a quantum state which controls the shaping of material phenomena can provide a simple explanation of certain holistic and non-local features connected with particular brain activities and phenomena of consciousness. Within the classical mechanistic-deterministic frame of reference, it is difficult to explain the basis for different states of consciousness such as dreaming and waking which are typically linked to the presence of different electrical oscillations in the brain cortex, or what it is that synchronises and combines, for example, visual information into an integrated whole by activating 40 different brain areas – the binding problem.[829] It is estimated that the human brain has 10^{11} nerve cells or neurons, each of which has links with hundreds or perhaps thousands of other nerve cells. Even though all the genes constituting our genetic inheritance were used to control and monitor the birth and maintenance of the connections between nerve cells, only a vanishingly-small amount of information is available concerning the birth of this extraordinarily-precise process of biological evolution.[830]

As humans, we know that we can if we wish, and also without wishing it, be involved in many different situations and feelings. Deeper interaction between people and understanding one another requires, in addition to the exchange of information, empathy and the skill to place oneself in another's situation or ”soul-view”. If every individual human is assumed to occupy their own unique state-space, its nature and the factors it contains can be thought of as directing our activities and the questions we ask in different interactive situations. We can, for example, presume that we obtain the projection of other people's state-space-functions via those basic vectors on which we ourselves operate.[831] Since everyone of us is bound to our own ”apparatus”, we cannot assume that we obtain a clear picture of the overall abundance of what is a complex system, at least when the other system is more complex than our own. For example, through learning, humans can make choices and even, if they so wish, change some part of the contents of the mind, but part of their cognitive composition is unconscious and can subconsciously affect the actions that an individual takes. One example of this is the reactions we learn during childhood, reactions from which it can be difficult to free ourselves at a later date even though

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[829] The stability and unity of a person's identity is also difficult to explain. Why do we usually feel ourselves to be a whole which is ”ready” as such, even if, for example, learning may cause a multitude of new states within us.

[830] Kaila 1998, 11. It has been suggested that the formation of brain is guided by epigenetic information which is born in interaction between an individual and his/her physical and social environment and constructed above genetic functions. The birth of this kind of information structure is however difficult to explain within a mechanical-deterministic framework.

[831] In quantum mechanics, operators coordinatise the quantum system. Other phenomena which are inexplicable within a mechanistic-deterministic framework could also be better understood by using quantum concepts. For example, the expansion of consciousness to include new insights could perhaps be viewed in terms equivalent to quantum tunneling: in certain ircumstances, the mind might be able to use borrowed energy to intrude into an otherwise forbidden area. Correlation phenomena might explain Heisenberg's observation that the most-fruitful developments in the history of human thought occur when two ways of thinking which are similar enough for proper

the manner in which they are manifested is inconvenient or unpleasant.

In addition to the modelling of our internal states, new physics could, via its concept of quantum state, also open up better-than-before opportunities for understanding different cultural and collective structures and social activities. On a mechanistic-deterministic foundation, it is impossible to explain why humans can create, and in their actions comply with, different immaterial structures which have both a cultural and societal influence. Why does a specific group collectively adopt a specific social constructions? How can a film, a sports competition or a concert tug at our feelings? Why, in specific situations, do what are considered to be irrational forms or constructions such as myths and utopias come to the fore time and again and affect the course of history. Why do individuals, even to the point of fanaticism, adopt some political or religious ideology just as if they have melted into it and become caught up in its control.[832] Different invisible ”states” or mental structures appear to define human behaviour in much the same way as wave-functions define the impact of electrons on a photographic plate. The situation of a specific culture or group dynamic appears to give birth to specific behaviour roles into which some of the group's members enter. Human groups can, within specific limits and in specific situations, be portrayed as formless material which can assume different forms or shapes.[833]

The unequivocal modelling of these complex ”immaterial” structures which are manifested in the mind and their possible influence on the formation of processes in the observable world naturally requires much detailed investigation. Possibilities linked to the contents of the mind and the wide variety of their influence can appear almost infinite when compared to phenomena that can actually be observed in the world, but the formal modelling of the basic normalities does not need to transcend those difficulties which are met on an everyday basis by quantum cosmologists or constructors of unified theories. For example, in the same way as the statistical resources available to sociology and the social sciences, cognitive psychology and different therapeutic experiences offer ready material for defining the measurable influence that our internal states have on reality.

interaction encounter each other.

[832] See Tamminen 2004.

[833] The situation is in some way comparable to the concept of matter held by Plato or Aristotle. They did not regard atoms or elements to be the most fundamental elements as the formation of material phenomena was dependent on forms which did not show up directly. Jung's concept of archetypes as ordering structures or Bohm's active information also bear similarities to this idea.

Describing reality as a complex quantum system obviously permits an attempt to forecast the development and formation of our whole ”psycho-physical” reality by incorporating the possible consequences of the contents of the human mind into the wave function that describes the system. The accomplishment of any specific quantum level possibility in either the material world or in somebody’s mind changes both reality itself and, at the same time, the distribution of the system’s future development possibilities. In such a frame of reference, the linkage between psychic and physical sides become clearer. The solving of psycho-physical problems does not demand the adoption of a position on whether humans or reality are, in the final ontological analysis, formed of matter or spirit. The world has degrees of freedom whose recognition makes their employment possible.

5.3.3. The psycho-physical problem and free will revisited

Some kind of interaction or unification between (so-called) mind and matter can basically be taken as a prerequisite for all our activities,[834] even though a more-accurate understanding of this connection has not really advanced within the mechanistic-deterministic framework of classical physics. We do not know how the neural processes in our brains and the contents of our conscious experience are connected. In philosophy, the discussion concerning human free will and its influences has culminated in the opposing views of the Compatibilists and the Incompatibilists about whether free will and the deterministic operation of nature can be reconciled. Combatibilists simply take practical freedom and responsibility as consistent with Determinism, whereas for scientifically-orientated thinkers it is usually evident that Determinism prevents freedom.[835] From a narrow Materialist and natural-science viewpoint, unification of free will to natural order will not succeed within a mechanistic-deterministic frame of reference. Since alternative possibilities of action require contingency, the determinism of classical physics poses insurmountable problems for free will.

If natural laws are considered to be universal, no external factor can affect the closed processes of the material world. In the quantum frame of reference, ”external factors” are however a natural system component. The abstract notion of the wave-function refers to a complex quantum

[834] Descartes was also careful not to stretch the transcendency of soul to complete dualism. Mind and matter had to interact in some way. In cosmological terms, the relationship was guaranteed by God. In individuals, the pineal gland (for which no other function in anatomy was known) served as mediator. Collingwood 1960, 7.

state that does not show up in the visible material world even though it provides the probabilities of all possible occurrences. In the quantum frame of reference, our mental states may be something real even if they are not directly reducible to material particles moving in space-time. The psycho-physical question of the relationship between mind and matter can thus be assessed in a wider context than was previously possible. The concept of quantum state might help in elucidating the subtle inter-relationship between *res extensa* and *res cogitans*. Quite clearly, what we really want to understand in this discussion is the question of how such non-physical things as purposes, deliberations, plans, decisions, theories, intentions and values can have a part in bringing about physical changes in the physical world. Popper calls this Compton's problem and believes it to be more important than the classical mind-body problem of Descartes, even if the whole problem has rarely been considered by philosophers.[836] The "hard problem" of how physical processes in the brain give rise to subjective experience is not the most important one, we should be asking in what manner we can describe these different aspects of reality within a unified frame of reference.

Popper believed that *pace* Hume and Laplace and Schlick, it is clearly untrue that all the tremendous physical changes brought about by our actions can be explained in purely physical terms, either by a deterministic physical theory or by a stochastic theory as if they were due to pure chance. He understood that an acceptable solution to either Descartes' or Compton's problem must explain freedom, and must also explain why freedom is not just chance. Otherwise, a world which includes human creativity and human freedom can only be an illusion. Mere physical indeterminism is insufficient, we must try to understand how men can be 'influenced' or 'controlled' by things as abstract as aims, purposes rules or agreements.[837] In his solution, Popper offers a new theory of evolution and a new model of organism. He tries to solve the problems of Descartes and Compton by offering a new kind of view of the world - one in which the physical world is an open system. The evolutionary theory that Popper proposed yields an immediate solution to the classical Cartesian body-mind problem, and without saying what the mind is, offers an almost trivial solution to Descartes' problem. It does so by saying something about evolution, and thereby about the functions of mind and consciousness. Popper

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[835] As physical indeterminism asserts that there are at least some exceptions to precise determination, many physicists such as Compton have welcomed the new theory in enthusiastic terms. It is no longer justifiable to use physical law as evidence against human freedom. Popper 1972, 217-220

[836] Popper 1972, 230-231.

[837] Popper 1972, 229-230. Pure chance is no more satisfactory than determinism. Determinists such as Schlick have put it this way: "...freedom of action, responsibility, and mental sanity cannot reach beyond the realm of causality: they stop where chance begins ... a higher degree of randomness simply means a higher degree of irresponsibility. One has to understand that the only alternative to determinism is not just sheer chance." Popper 1972, 226-228.

sees the evolution of life as a process of elimination through trial and error, a process which allows us to understand the emergence of biological novelty and the growth of human knowledge and human freedom in a rational, though far from complete, manner.[838]

Popper's solution to Compton's problem yields the view that control of ourselves and our actions by our theories is a plastic arrangement which combines freedom and control. Conscious states may function as monitoring systems, as systems which eliminate errors. Rational human behaviour becomes something intermediate in character between perfect chance and perfect determinism. As we can discuss our theories in a critical manner, we are not forced to submit ourselves to their control, and can reject them freely if we think that they fall short of our regulatory standards. Control is therefore a long way from being one-sided. Not only do our theories control us, we can also control our theories, and even our standards. This leads to the conclusion that our mental states control some of our physical movements, and that there is some interaction, some feedback between mental activity and an organism's other functions.[839] Although Popper's qualitative description is credible, it does not offer a proper explanation of the situation. What is the nature of our mental states or how such control can be physically understood?

In Popper's solution, there is an interaction between mind and matter, the mental and physical states, which means that the physical world cannot be closed. As we have seen, the quantum framework also allows the Popperian type of solution to Descartes' and Compton's problems when combined with the idea of a closed physical system. If we take the state-function description seriously enough, the world can be seen as a developing or changing monistic system to which humans belong and which they shape by their actions. If the abstract wave-function controls not only the formation of matter but also the formation of mental states, we have proper tools to deal with both these aspects in the same overall framework. "The predetermined course of events" could then be interrupted if only we are able to note and affect our own mental states and act accordingly. It is not necessary for mental states to have a direct causal influence on matter, only on the reformation of the mental states themselves. If we believe that our consciousness or will can exert an influence on a reshaping of our mental contents, relative free will and the idea of lawful reality can be reconciled within the quantum framework. The problem

[838] Popper 1972, 232, 254-255. The mind-body problem disappears in Popper's model, but since he does not trust physics sufficiently to elaborate quantum states for mental processes, he is not able to further elucidate the relationship between mental and physical.
[839] Popper 1972, 240-241, 250-252.

that remains is the nature of this conscious part of the mind. It might be viewed as some kind of universal process which can, by the making of decisions, actively cultivate the formation of the universe, i.e. its future possibilities.

Physicists usually prefer the idea of a closed physical world and this means that they do not accept Dualism. For example, inspired by quantum mechanics, Wolfgang Pauli and David Bohm decided to speak about psycho-physical reality, in which the human mind, our internal subjective states and conscious phenomena also belonged to reality. In this way, non-physical things such as purposes, deliberations, plans, decisions, theories, intentions and values can play a natural part in bringing about physical changes in the physical world. There is no need to explain their existence through mechanical interactions between particles or strive to make them emergent in some way. These statements based on the results of physical experiments contain interesting points of contact with many of the central ideas presented during the history of philosophy.[840] At the same time, they provide fundamental material for the shaping of metaphysical assumptions concerning reality.[841] Using the knowledge base of modern-day natural science it can be claimed that Cartesian dualism has been demonstrated to be non-credible: that the so-called ‘material’ and ‘spiritual’ processes are linked almost inseparably to each other in many ways. Reductionist materialism can also be rejected, since even phenomena of the material world cannot be reduced to particles moving in conformity to laws in space-time.

In the history of philosophy, both Spinoza and Leibniz clearly rejected Cartesian dualism. They believed that humans belonged to the world in the actions of both their bodies and their souls. In contrast to Kant, they can be viewed as also seeking a physical or scientific hold on humans. In general terms, these great system builders presented ideas about psycho-physical reality that are similar to those of Bohm or Pauli. Although the method of approach taken by Spinoza and Leibniz can be considered more beautiful and more all-embracing, the modern physicists have better justification for their views. The quantum frame of reference offers real possibilities for further development of Spinoza’s Pantheism and Leibniz’s Parallelism. At the dawn of the modern era, philosophers could not dispute the reality of the material world assumed by classical

[840] Thoughts by physicists have often been treated as representing idealism, pan-psychicism or materialism, but these kind of traditional classifications are more or less problematic since the concept of matter has changed radically as a result of modern physics. Their argumentation aims at solving Compton’s problem rather than Descartes’. Trying to reduce everything to matter or mind is not as important as trying to discover a monistic or organistic framework which would transcend Cartesianism.

[841] Seen from inside of current research traditions, the general and overall views of physicists may appear either amateurish or too-speculative. They are not necessarily either completely-coherent or consistent, and their basic hypotheses concerning physiological and physical phenomena may benefit from criticism.

physics, they had to work within the mechanistic-deterministic paradigm or research programme.

Spinoza's universum was an ordered whole, not a lifeless world of innumerable separate things. It was at one and the same time both nature and God, a thinking being of infinite dimension. Spinoza viewed human behaviour and emotions as members of nature's unchanging organisation which could be investigated using the same ”geometric methods” as those used to examine lines, surfaces and solids.[842] Spinoza was not however able to incorporate free will in his *double-aspect* system, since the thinking aspect of reality remained tied to events in the material world that were assumed to be deterministic. Leibniz also believed that reality included both a dimensional physical aspect and a mental thinking component. In his Parallelism, matter and mind are connected to one another almost seamlessly. Perceptions were alterations in the soul itself. Emphasising spiritual monads, Leibniz was in the end forced put his faith in Idealism, as classical physics' assumption of the mechanistic-deterministic character of the world would have placed too-severe limitations on understanding the influence exerted by features of the spirit and the soul.[843]

Even though both Parallelism and Pantheism, neither of which could be accommodated within a materialistic and mechanistic-deterministic framework, nowadays appear to be more-credible attempts to reconcile the realms of matter and mind, both Leibniz and Spinoza were searching for answers to Descartes' problem rather than an answer to Compton's problem. Their method of approach was primarily ontological while any solution to Compton's problem requires a clear physical description. The formation of internal human dynamics cannot be illuminated to any significant extent by employing philosophical analysis alone. The degree of speculation employed by system builders can be criticised from the viewpoint of both natural science and Positivism. Even though the psycho-physical problem naturally disappears if reality is postulated as being in some way psycho-physical, the form of the problem becomes the more-precise portrayal of this postulated metaphysical reality. Empirical science does not offer direct tools that we can use to select the correct ontological model from an infinite number of possibilities. Durable assumptions can only be found through a step by step process of detailed research and the testing of different hypotheses – i.e. by trial and error.

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[842] Spinoza believed that although humans could develop within the material world, they did not have either free will or absolute power concerning their actions.

[843] The relationship of the conscious monad to physical structures would have been easier to explain if Leibniz had had Zohar's or Stapp's knowledge concerning wave-descriptions. As more complicated structures have a more complex wave configuration, they could connect to more delicate fields and would thus be able to ”see” their environment in a clearer way.

The fundamental starting point when questioning the nature of reality does not concern interaction between matter and mind, or their parallel existence, as much as it concerns the possibility of obtaining knowledge about its structure. Questions which illuminate the nature of reality are not soluble on the basis of ontology, more important is a comprehensive physical portrayal or theory which we can then strive to interpret. Bohr rejected the traditional ontologising and objectivising methods of approach, and stressed that quantum theory is an extreme theory of reality created by humans. It is beyond the thinking that touches both mind and matter and it can assist in defining both of them. To Bohr, talk about mind and matter was nothing more than ways of dividing and identifying the multiplicity of reality in a way we can understand. Even though the ontological description of reality has traditionally employed concepts of matter and spirit, these concepts do not necessarily target the depths plumbed by the mathematical formalism of quantum mechanics in a particularly informative way. In the light of Formalism, reality appears much more as if it should be portrayed as one single whole, quantum reality, part of which we can perceive as the external world of matter, part perceived via introspection as our inner reality.

The strict division of the world into objective and subjective parts carried out by Descartes is linked to the schematic view of primary and secondary qualities adopted at the turn of the modern era. Galilei embraced this thinking of the antique Atomists, as did Locke and many other philosophers. All the primary qualities were assumed to be within the objects themselves, while the secondary qualities were born in the human sense organs. In modern-day research, this separation forms a generally-accepted starting point. It leads to the thought of how objectively-existing brain states give birth to subjective phenomena. When modelling the world through the state-functions of quantum mechanics it is however possible to think that the most primary causes or qualities are never directly manifested in the ever-changing sense-world and, on the other hand, that the structure of people’s internal world cannot necessarily be reduced to secondary phenomena born in our senses as a result of influences from the external world.

The question of the precise relationship between mental and material phenomena, or rather of how humans can, through their internal states, control their actions and affect the formation of the material world is perhaps thrown into clearer relief when it is liberated from the Cartesian context, i.e. the concept of reality formed at the beginning of the modern era. Throughout antiquity and the whole of the Middle Ages, it was presumed that humans possessed both a visible material form and a soul. Plato, for example, saw the soul as being made up of several layers. It was not immaterial, it was made, according to specific proportions, of very fine material that was invisible. The existence of this material animated the whole cosmos and in some way it shared the destiny of the visible world.[844]

At the beginning of the modern era, the tradition of natural science rejected all discussion of the soul. Talk about an object's essence or its internal change could not be reconciled with a mechanistic-deterministic conception of reality, and in today's world, very few people believe in the existence of the soul as any real or substantial entity. Surprisingly, however, the quantum frame of reference offers possibilities for a new kind of attempt at describing the delicate relationship between the visible material world and its invisible part that was sought by Plato and Aristotle. The mathematically-accessible abstract quantum state can be interpreted as an immaterial form or structure which shapes events in the visible world while itself changing and evolving its processes.

The idea that some sort of invisible, mathematically-addressable internal side is linked to all physical structures should certainly not be taken as signifying a return to the type of language used in bygone days and to the obscure metaphors then employed. Through its unique structure, quantum theory can lead to a clearer-than-before understanding of the character and connection between what are termed the physical and psychic aspects of reality. The forming of both of these can take place according to similar kinds of laws or partly within the same framework of conformity to laws. According to quantum theory, each atom and object has a specific energy structure and specific probabilities associated with the manifestation of these different states. Each physical form or structure exhibits specific quantum states in specific conditions, in the way shown by the analogue of standing waves formed in an oscillating spring. Perhaps the different energetic and excited states formed in different parts of our brains or our bodies could be connected in some way with the different fundamental states or levels of consciousness that humans are capable of experiencing.[845]

[844] Aristotle also thought that all being had two sides. Form and matter were manifested in human beings as soul and body. They could not exist independently. The concept of soul was also of great significance to Spinoza, Leibniz and Kant.

[845] For example, Damasio believes that consciousness as a capacity to experience must be explicable as a function of the brain. If quantum states are real and somehow become visible in brain and mental phenomena, development of the complexity and sensitivity of the mind as aresult of experience, learning etc. might lead to better contact with the delicate structures of reality. Ethical development could thus lead to the kind of harmonious connection with reality assumed by, for example, Heraclitus and Spinoza.

It is not difficult to reconcile free will with the reality portrayed by quantum theory, in which the statistical laws allow variations in the shaping of individual events, provided that humans are believed to have the ability to consciously shape the contents of their own minds. The presumption that free will is impossible is based in the incorrect metaphysical belief that the world is deterministic in nature. In the quantum frame of reference, the world is not limited to just material systems, reality also includes invisible quantum states. Humans realising these states do not need to remain determined by an external factors if they can, by changing the contents of their minds, also change activities that affect the material world. No direct psycho-physical causation or mechanism for explaining the connection between mind and matter is required. In fact, if the assumption of substance-dualism or the division of subjective and objective qualities is incorrect, the psycho-physical problem does not even exist.

If the shaping of our mental states and the material world are both founded on the specific possibilities allowed by quantum reality, their compatibility is not a problem. We are able to follow the plans we make since electrons and atoms behave in accordance with their own conformity to laws. While the contents of our minds develop according to the system's conformity to laws, this process has many degrees of freedom. Development does not need to be determined in advance any more than it needs to be completely random. In specific situations, humans can intervene in the flow of reality. By making conscious choices, we can, if we so wish, influence the evolution of certain parts of this complex psycho-physical system.

5.3.4. Observers and Actors - the role of consciousness

Within the deterministic frame of reference based on classical physics, humans were left without any kind of creative role. Just as it was thoroughly natural for mediaeval thinkers to view nature as subservient to man's knowledge, purpose and destiny, in the modern era it became natural to view nature as existing and operating in her self-contained independence, and insofar as man's ultimate relation to nature is clear at all, to consider our knowledge and purpose as somehow produced by her, and our destiny therefore wholly dependent on her.[846] In a quantum frame of reference, demands of the approaches promoted by both the humanities and by natural science can be made compatible. Humans with all their mental states and qualities can be part of existing

[846] Burt 1980, 24.

reality.[847]

Quantum mechanics makes possible the thought that humans play a greater and more active role in the drama of existence than has formerly been accepted. Within the indeterministic frame of reference of quantum physics, humans can be viewed as having true evolutionary influence. By actively reflecting and shaping their environment, humans work inside nature: we create new models and tools using the possibilities permitted by nature, actualising potential opportunities contained within the system on the basis of our own understanding and will. This kind of actor capable of making choices can be understood as an responsible and autonomous subject whose existence philosophers such as Spinoza, Leibniz, Kant, Husserl and Heidegger have striven to defend.

Even if it is now possible to defend human autonomy at the same time as humans with all their subjective states, knowledge and beliefs, values and intentions are ontologically immersed within nature, it should also be understood that a comprehensive portrayal or theory that incorporates this kind of activity cannot be provided. Even though, via the concept of state, the quantum frame of reference offers improved possibilities of modelling conformity to laws in the development of our internal state, it is essential to note that even in the best models or descriptions of the world, something external remains. Portrayal is not able to address the portrayer, the *conscious* factor, who by modelling strives to achieve an ever better understanding of themselves and the environment. In the final analysis, the maker of models has to be separated from the models which are created.

On the basis of quantum mechanics, Roger Penrose and David Hodgson have pointed out that the computational, mechanical model is not adequate to explain human consciousness.[849] Like computers, we are capable of arriving at logical conclusions in a formal manner according to specific algorithms, but formal reasoning only represents part of the overall capacity of our imagination. Our minds also employ rational ways of proceeding that cannot be reduced to logical or formal methods of reaching conclusions. Machines always operate on the basis of a

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[847] In a complementary quantum framework, the dualism between science and humanism as well as between mind and matter can be reconciled without either losing their special characteristics. All descriptions aspire to different aspects of a single complex whole.

[849] If consciousness emerges from the complexity of the neuron system and brain, it is difficult to explain why all parts of the brain are not conscious. According to Hodgson, mere processing of information does not imply consciousness. In many cases, the brain can function like a machine and the task of consciousness could be the capability to observe, evaluate and interrupt mental functions and reactions that have become automatic. Hodgson 1991,157-168.

specific program, but the human mind is able, when necessary, to move outside all closed algorithms and invent new creative solutions to problems. These non-mechanistic operations are simply not describable within a closed mathematical form.[850]

Even though physical description has managed until now by employing algorithmic and computational models, this does not of itself prove that non-computational description could also be required. Penrose has presented plenty of examples of non-computable physical processes and also commented on the non-algorithmic nature of mathematical insight.[851] It is not necessarily so that understanding can be reduced to computational rules, and thus counter to the ideas of Reductionist materialism, the workings of the human mind or the operation of consciousness cannot be considered as being analogous to the operation of a computer. They cannot be comprehensively understood within a mechanistic-deterministic frame of reference, since the modelling of which they are capable can actually demand the existence of properties that today's computers do not in fact possess. In particular, simulations of conscious thinking that employ nothing but computation have not succeeded in any believable manner.[852]

Hodgson highlighted the reaching of conclusions based on probabilities, informal plausible reasoning, such as those based on induction or the use of analogy. Such rational thinking which is dependent on consciousness cannot be completely reduced to mechanistic steps, it must be a flexible process able to draw on innumerable sources. For example, the shaping of scientific theories, philosophy, and legal processes all require this type of structured and rational thinking, of which logical conclusions represent only a small part. Rather than the reaching of formal conclusions which can only produce mechanical explanations based on and contained within the initial conditions, this shaping is a flexible process of arriving at conclusions which produces new knowledge. Reaching conclusions on the basis of probabilities is a process which is difficult, if not impossible, to formalise. Attempts have been made to formalise the process of induction, but both Putnam and Newton-Smith, for example, take the view that this basic

[850] All computers function in a computational manner according to certain algorithms. In some easily-definable top-down functions such as numeric calculation, the machine exceeds the abilities of an average human but in "learning" bottom-up processes such as articifial neural nets, computers are only able to reach the levels achieved by humans in some restricted problems, and have difficulty in doing so. Penrose 1994, 19.

[851] Penrose 1990, 538-541. Penrose 1994. The views of Roger Penrose have aroused great interest but have also been criticised. When interviewed by Horgan, David Bohm also expressed the hope that future scientists would be less dependent on mathematics for the modelling of reality and would draw on new sources of metaphor and analogy."We have a strong assumption that mathematics is the only way to deal with reality. Because it worked so well for a while, we have assumed that it has to be that way." Horgan 1998, 88.

methodological maxim of science cannot be formalised.[853]

The credibility of conclusions based on probabilities and analogies does not depend solely on logic, it also depends on non-formal *judgement*s. Naturally, such conclusions do not lead to unambiguous results, all the knowledge so gained is provisional and subject to error.[854] Clearly, only this way of arriving at conclusions can create new models concerning reality and discover significance in the slowly-constituting processes of reality. Since they lack both the ability to make judgements based on understanding and the skills required to make qualitative holistic comparisons and assessments, computers are simply not capable of shaping such metaphysical hypotheses. Although humans also exhibit different levels of these skills, having real understanding is something that is quite different to possessing the ability to memorise and calculate. Consciousness brings us additional information. We know how perception, thinking and experience feel. This type of information can be encoded into a computer, but coded information is not the same thing as the contents of the consciousness of a conscious being.[855]

Also, mathematical understanding is something quite different to the act of calculation. In mathematics there are problems that cannot be proved or to which no algorithmic solution exists, such as the question of whether given figures cover a plane, but the human mind can achieve a solution. Gödel's incompleteness theorem demonstrates that there are indeed true algebraic statements which cannot be proved correct in a consistent formal calculus. This made the end a Formalist programme in logic. Logicians have debated whether the process of arriving at a conclusion is more semantic than syntactic. Semantic theories can be said to be based on mental models, while syntactic theories are based on the rules of deduction. Semantic tenability concerning a meaning cannot be reduced to a syntactic proof.[856] Neither can it be reduced to the movement of material particles.

Estimations of significance and judgements are essential when shaping a conception of reality and a world-view. Only by assigning significance are we able to connect empirical observations

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[852] The belief that computers would be conscious or that mere computation might invoke feelings or intentions in machines, is without basis until we have an explanation of consciousness. We hardly will be able to produce conscious machines until we know what consciousness is and there is a test capable of proving whether a thing is conscious or not. Squires, 1990, 26-30.
[853] Hodgson 1991,124.
[854] Hodgson 1991, 136-7.
[855] Hodgson 1991, 101-107. The question of whether a message is only a function of itself, or whether it also depends on the state of mind and the expectations of the receiver, has been discussed within information theory.
[856] Jonson-Laird 1993, 5-6, 15, 21.

and abstract rational theories to some wider frame of reference.[857] When highlighting the significance of the mental side of humans it is sometimes said that meanings obey specific laws of mentality. In organising either a subjective world-view or a system of scientific concepts, meanings are related to each other through their own significance.[858] Whatever entities the meanings or mental laws are supposed to be, they escape scientific investigation and necessarily remain unfounded. This kind of blunder can be avoided by replacing the theory of human knowledge, largely Subjectivist since Descartes, Hobbes and Locke, by an objective theory of essentially-conjectural knowledge as Karl R. Popper proposed in his *Objective Knowledge*. [859] I consider it reasonable to believe that human beings acting in a real worls aim to systematise their inner and outer experiences by creating inter-subjectively-valid theories and models which improve their possibilities. The fact however remains that even if we are able to proceed in our objective modelling, the thinking and creative part of reality clearly cannot, in any scenario, be completely described by any model – not even when consciousness is though to be an ontological part of a single monistic reality.[860]

As we gain more knowledge of the processes of reality via improved models and learn to use these models in a proper way, another causal factor, the conscious mind, appears to exist in reality in addition to the laws that work at a material level. This conscious mind is capable of using and developing the systems in which it operates. In this sense, Hegel was correct in maintaining that the existence of living beings means that the world operates on a new organisational principle. World history, or evolution, moves forward as we become conscious of the possibilities that the world contains. Our ability to create portrayals, models and concepts means that we are able to bring new structures and qualitative differences into the world in a way that dead material, without our knowledge and ability, cannot.

In the framework of classical physics, the world was presumed to be ”ready”: it would work as

[857] Meaning is necessarily connected with the interpretation and description of reality. In contrast to pure mathematics, a physical theory always has to be interpreted. Understanding and explaining are relative. They both involve relating observations of the phenomena concerned to what is already known and understood. We need a metaphor, and explanation depends on a shared conceptual framework. Devlin 1997, 285- 287.

[858] Rauhala 2003, 65. Rauhala does not believe that physiological descriptions of the brain are able to deal with experiences or meanings. Even if these were physiologically conditioned, nets of meanings cannot be understood or mastered using the logic of physics.

[859] Popper 1972, preface. The Cartesian starting point in epistemology is usually rejected by philosophers of science who take a naturalist or externalist approach.

[860] Philosophers have often made this distinction. Plato thought that part of the soul belonged to the sense-world and part to eternal reality. Aristotle also believed that active reason reached a human being from the outside, and Antonio Damasio, for example, makes a distinction between mental flow and a self who is aware of this flow. *Scientific American*, Volume 12 1/2002.

well in all its aspects without the presence of humans. Classical physics positions the whole of organic nature as nothing more than a powerless and secondary side-product of some natural evolutionary process which results from physical laws. As there was no space for our creativity, meanings or intentions within the mechanistic-deterministic frame of reference, our dynamic interaction with the rest of nature - our “inborn” activity - was left unexplained and in part unobserved. When, at the turn of the modern era, Francis Bacon encouraged people to exploit the possibilities that knowledge concerning the natural world could bring, he did not warn of the negative consequences of manipulating nature. Scientific-technical developments have shown Bacon’s anticipation concerning the benefits was legitimate but environmental problems have also made it quite clear that we cannot control and exploit our surroundings in any way we wish.

The development of technology has meant that the creative role of humans has grown significantly and will continue to grow. As our knowledge of reality has grown in depth, we have become increasingly able to influence even those regions of nature previously thought to be objectively bestowed or beyond our reach. By increasing the level of our knowledge, we can, to an ever-increasing extent, influence those sectors which were previously assumed to be unchanging and independent of humans. Genetics and nanotechnology are starting to produce new ”objective” external realities for future generations. The extent of expectations concerning new technology are major, but we are not able, using a mechanistic-deterministic foundation, to predict how our psychic, social or political structures will be changed as a result of its introduction. In the worst case, an unsatisfactory view of human possibilities and our relationship with nature could result in the disappearance of our species.

It is evident that we cannot completely remove ourselves from nature’s contextual processes or destroy those boundary conditions within whose resources we conduct our lives. Classical physics offered humans the possibility of controlling many of nature’s processes, but the anomalies that have resulted from scientific-technical development such as environmental problems or feelings of lack of purpose are clear evidence that a mechanistic-deterministic world-view does not address all the components of reality. In this new situation, Bacon’s idea of controlling nature should be clarified. According to his well-known statement, we can only control nature if we obey it. In order to control a deterministic material world humans had to bow down in front of nature’s irresistible processes, instead that they could, for example, be seen as cooperating with natural forces. Humans who are also active participants and whose accumulated experience makes them capable of creating ever-better models of reality can, by using the models thus created, assume an ever-increasing role in shaping the world's processes.[861]

When humans become conscious of some process or law in nature and use this knowledge to their advantage they can, in a specific sense, free themselves from the ”power” of natural processes. Without this kind of understanding, the progress of phenomena in reality is, from the human viewpoint, totally determined by external factors. Our fundamental models and beliefs concerning reality are immensely influential. They guide our actions and are able to have an effect on our environment. The contents of our minds may in a way ”materialise” in the external world even though they naturally carry greater significance for our invisible internal reality. As a major part of reality is not located at the perceivable material level, it is as if we are forced from inside, based on our gradually increasing knowledge and understanding, to learn step by step to control the overall development of this complex whole which contains so many possibilities. While, within the modern era, the world was considered to be a machine, robotics and automation have developed at dizzying speed, but questions of the meaning or purpose of life are usually shuffled aside. If we were to believe that inside, humans belong to the wholeness of nature, it might signify a new type of responsibility. We would not then perhaps wish to control and exploit the wholeness of nature from the outside as if it were nothing more than a machine.

As the influence exerted by humans grows and the volume of our activity increases, it is ever more important to remember that the models of reality we create do not, as such, directly correspond to reality. Maps and the landscape they portray are different things. Reality is not exhausted by the models we create, in our relationship with it we are forced to operate in the zone of uncertainty. Reality may be a great deal richer than we presume. It is certainly not a lifeless clockwork mechanism, independent of our actions, it reacts to human activity. In selecting our courses of action and making value judgements concerning our models and the consequences and effect of our activity, pure logic is not sufficient, we must employ the wisdom and ethical powers that we possess. The formation of reality and our future circumstances depends on the values that we adopt and exercise.

Profound creativity and understanding are possibilities open to humans, even though the unique incidents which occur in specific circumstances and contexts are unlikely to ever be predicted and modelled from an external viewpoint. Our human abilities, our conscious understanding, our will and our feelings are elements of reality which should not be forgotten. They are the

[861] We can naturally only actualise possibilities that are allowed by natural laws.

foundation, the highest level in Granit's representation, resources which represent the basis for the opportunities we are given to make use of the multiple possibilities offered to us. The amount of freedom, responsibility and creativity of individual member of the human race may depend on the states that each individual on one hand allows, and on the other hand is able to realise in his or her mind. Since the application of knowledge requires case-specific reflection, our ethical aspects cannot be neglected. For humanity, the possession of freedom and responsibility opens new dimensions.[862]

We should remember that it is not necessary for us to blindly accept the models or conditions we are given. Instead of considering technological and economic progress an end in itself, we could focus our attention on understanding human nature and culture. Even though we are living a process whose final character we cannot know, we are able to observe and evaluate the consequences of our theories and beliefs. We are able to solve the problems we encounter and develop better methods of portrayal, define new targets and objectives. All models, theories and world-views are best understood as provisional creations benefiting from experience, tools which can be developed in the light of new experience. We should be careful not to let mechanical conception of reality to reduce ourselves to mere machinery. We are not pre-programmed machines, we can adapt and adjust using our own wisdom and understanding as and when necessary. As well as presenting us with a life-long challenge, it is our privilege as human beings that we are able to judge and choose what we should do in each unique situation.

The objective portrayal of reality which focuses on the external world often ignores humans and their internal reality. The method of approach employed by natural science has rejected the long experimental tradition of humanity, which speaks of the possibility of achieving higher mental states through mental exercises and meditation. We have no reason to doubt the existence of our internal states or our ability to realise such immaterial relations which Plato highlighted in his concepts of beauty, goodness and truth. The quantum frame of reference gives us a possibility to portray and understand them better, so that they could be better manifested in the reality that surrounds us. The most interesting and rewarding questions in human history may well lie ahead of us, if we can only learn to improve our sensibilities and our understanding in a conscious way, widen our horizons, and seek moral maturity.

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[862] Our freedom is naturally relative. Even if we are able to create new models and tools and to some extent guide the direction of future events, we have to build on the foundation provided by former models and concepts.

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