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Philosophic Problems of Nuclea

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existence of living organisms. From the standpoint of modern physics, according to Bohr, we should expect the laws characteristic of these organisms to be separated from the purely physical laws in a rational and accurately comprehensible manner, just as, say, quantum theory is separated from classical mechanics. A similar solution will, on a smaller scale, apply to the investigations into the properties of the atomic nucleus, which occupies the centre of interest in contemporary physics. The edifice of exact science can hardly be looked upon as a consistent and coherent unit in the naïve way we had hoped. Simply following the prescribed route from any given point will not lead us to all other rooms of this building; for it consists of specific parts, and though each of these is connected to the others by many passageways and each may encompass some others or be encompassed by others, nevertheless each is a unit complete in itself. The advance from the parts already completed to those newly discovered, or to be newly erected, demands each time an intellectual jump, which cannot be achieved through the simple development of already existing knowledge.

Thus contemporary science, to-day much more than at any previous time, has been forced by nature herself to pose again the old question of the possibility of comprehending reality by mental processes, and to answer it in a slightly different way. Previously the example of science could lead to philosophic systems which assumed a certain truth—like the 'cogito, ergo sum' of Descartes—as the starting point from which all questions of 'Weltanschauung' could be attacked. But now nature, through the medium of modern physics has reminded us very clearly that we should never hope for such a firm basis for the comprehension of the whole field of 'things perceptible'. Rather when faced with essentially new intellectual challenges should we continually follow the example of Columbus, who possessed the courage to leave the known world in the almost insane hope of finding land again beyond the sea.

This realization can preserve us from the mistake, not always avoided in the past, of attempting to force new fields of experience into an outmoded, unsuitable structure of concepts.

'explained' by their reduction to manifold geometric configurations. It can be said, in a sense, by reversing the above statement, that, while Democritus's atomic theory offers an explanation of the qualities mentioned, it still leaves unexplained, i.e. unreduced, the geometrical properties of the world. We must thus distinguish between 'analytical' and 'immediate and direct' concepts. The desire, fulfilled in atomic theory, to depict perceptible qualities of things, like colour and hardness, by means of reduction to geometrical configurations (in the widest sense), enforces the sacrifice of ascertaining the true nature of these qualities by means of science. Thus it can be easily understood why the poets for example always looked upon the atomic concept with horror.

Hand in hand with the development of the concept 'matter' went the attempt to give a more precise meaning to the word 'space' while the naïve conception of the world understood it to consist of many individual things separated by space, the Greek concept of 'empty space' gave rise, at first, to great difficulties in the theory of perception. Parmenides, who had placed the concept of 'being' at the apex of his philosopy, gave it from the very beginning a material character. Existence and taking up space are to him identical. Since there exists only 'being' and as 'non-being' cannot exist, hence empty space (i.e. 'non-being') cannot exist. Parmenides's teaching had, in the last resort, to explain the whole perceptible world as 'imagination'. From it we can feel quite clearly how inconvenient, at first, the concept of empty space must have been to the philosopher. For that reason, a sharp separation of space and its geometrical properties from the concept of matter was not achieved for a considerable time. In Plato's *Timaeus*, for instance, the physical properties of elements are related to geometry, i.e. the properties of space. The individual elements of matter are built up of fundamental components of stereometry and these in turn of simple triangles. Aristotle moved much further than his predecessors, from a deductive science based on abstract principles, to one descriptive and recording. Yet even he brings forward the following proof of the impossibility of empty space. Bodies fall more slowly in water than in air due, apparently, to the different resistance

offered by water and air. Thus, the less dense the surrounding medium, the faster is the fall of all bodies, so that in empty space bodies would fall with infinite speed, which is absurd. Hence there is *no* empty space. Space is as yet always taken to be 'filled with matter' and philosophers dared not assign any properties to absolute 'emptiness'. Democritus's materialism boldly surmounts this obstacle too: to him, matter consists of atoms separated by empty space, and geometry is a property of empty space. Other qualities too, like 'above' and 'below' are assigned to space. The acceptance of the naïve division into matter and space, without criticism, is fundamental for the progress achieved by materialism. The well known explanation of the states of matter for example, is based on this very independence of the structure of space and matter. It needs to be stressed that in this instance, too, the successes of Democritus's teachings had been achieved at the expense of an understanding of the nature of the relations of space and matter. You know that real progress in this question of 'space and matter' has only been very recently achieved in the general theory of relativity. During the whole development of science from Democritus to Newton and Maxwell, the discussion of this problem had been of no importance. Space was 'explained' by analysing its geometrical properties and by transposing the geometrical experiences of daily life, without any further thought, to the world of atoms and stars. We had done without a deeper understanding of the relation: space-matter.

In these two discussions of the concepts of matter and space we already meet the quite general problem of the real meaning of the term 'understanding' of nature. Did Democritus's atomic theory lead to an understanding of the qualities of matter or had it done without such an understanding? In what sense did the theory 'explain' the geometrical behaviour of bodies? Could the researches of Pythagoras's pupils on the oscillations of strings and their harmonies, could Democritus's suppositions be classed as 'Science'? Questions such as these had already very early been the subject of Greek philosophic thought.

You will recollect the famous analogy in Plato's *State*, in has constantly augmented our 'insight into nature' ('διάνοια'). However, a contemplation of this development raises the impression that the two kinds of perception ἐπιστήμη and διάνοια, though in a sense interdependent, nevertheless stand to one another in a mutually exclusive relationship. The more new fields are opened up by physics, chemistry and astronomy, the more we are in the habit of replacing the words 'interpretation of nature' (*Naturerklärung*) by the more modest expression 'description of nature' (*Naturbeschreibung*). It becomes more and more clear that we are dealing, in this progress, not with immediate and direct knowledge but with analytical understanding. Every great discovery—and this can be seen especially in modern physics—moderates the pretensions of scientists to an understanding of the universe in the original sense. We believe that this process is deeply founded in its own nature or in the nature of human thought itself. Naturally, every attempt to show the compulsory nature of this development by means of an epistemological analysis (*erkenntnistheoretische Analyse*) of the word 'understanding', is bound to leave a feeling of insufficiency. However, this is not the place to argue the value or the necessity of this development; it seems to me to be more correct to demonstrate by means of the history of physics, including its most recent developments, how straight and consistent has been the path of science in the course of the centuries. This may convey to you the feeling of the peculiar, quite impersonal compulsion which seems to find expression in this development.

The starting point of Galileo's physics is abstract and lies exactly on the line which Plato had already mapped for science. While Aristotle had still described the real movements of bodies in nature and hence had, for example, postulated that light bodies generally fall more slowly than heavy ones, Galileo was concerned with an altogether different question: how *would* bodies fall if there were no air resistance? How will bodies fall in empty space? He succeeded in formulating mathematically the laws of this theoretical movement, though it can be only approximately realized by experiment. In place of a direct conliving and immediate understanding, which had been the basis of scientific progress since Newton, was also the real reason for Goethe's bitter struggle against Newton's physical optics and his teachings on colour. It would be superficial to neglect this struggle as unimportant, there is a good reason for one of the most eminent of men using all his power to combat the achievements of Newton's optics. One can only charge Goethe with a lack of consistency. He should not only have combated Newton's views but he should have said that the whole of Newton's physics, optics, mechanics and gravitational theory was the work of the devil. It is, on the other hand, a clear sign of the strength and inner consistency of abstract science, that, in spite of all these objections, it steadily progresses in the same direction. Indeed the fact cannot be neglected that this strength is partly due to the possibility of controlling technical development with the aid of abstract science.

The rounding off of mechanics by Newton, of electricity and optics by Maxwell, and the great developments in chemistry at the beginning of the last century, directed our attention again to the problem of 'matter'. They stimulated a new desire to solve the problem whose solution the Greeks had initiated with the newly gained tools of modern science. Democritus's atomic theory was revived. Gassendi had endangered his life as early as the seventeenth century through his public teaching of atomic conceptions. His successors 'explained' the different states of matter by the supposition that the atoms are in a strict order in the solid, that they move at random but are tightly packed in the liquid and that they flit about like a swarm of midges with considerable interatomic distances, in the gaseous state. Thus the qualities density, shape and mobility were reduced to geometric configurations of the atoms. To these qualities there was added in the last century that of temperature. Heat, which had hitherto been regarded by many as a distinct substance, consisting of Democritus's atoms of fire, was now conceived as the mechanical energy of physical atoms. The movement of atoms in a hot body is faster than that in a cold one, or a strong movement of atoms causes the sensation 'warm'. As you know, all phenomena it re-establishes the balance between the various properties of matter which had been lost in the old atomic theories, the geometrical properties are no longer favoured above others. As Bohr has stressed, it is no longer correct to say that the qualities of bodies have been reduced to the geometry of atoms. On the contrary, the knowledge of the colour of a body is only made possible at the expense of the knowledge of the atomic and electronic movements within this body. Conversely, a knowledge of the electronic movement enforces the sacrifice of the knowledge of colour, energy, and temperature. Both these can only be reduced to the mathematics of the atom. In modern atomic theory, no property of bodies affecting the senses is accepted without its being analysed, nor is it automatically transferred to the smallest particles of matter. Rather is every property analysed for the purpose of διάνοια. Hence it follows as a natural corollary that atoms can have none of these properties in the usual sense.

The discussion of Newton's mechanics and optics will have already given you the feeling that the strength of this abstract development of science lies, in the first place, in its capacity to encompass large fields of experience in a simple manner and continuously to simplify and unify the picture of nature drawn by science. Atomic physics has, as is shown more clearly than ever by the progress of recent years, led to the most brilliant successes. We cannot, without admiration, pass by the fact that the infinitely diverse phenomena of nature, on earth and on the stars, can be classified by so simple a scheme of laws. On the other hand we must not forget that a high price had to be paid for this unification of the scientific concept of the universe. Progress in science has been bought at the expense of the possibility of making the phenomena of nature immediately and directly comprehensible to our way of thought.

Thus I return to the question posed at the outset: can science claim to lead to an understanding of nature? I have attempted to show how physics and chemistry—driven, we hardly know by what force—have continuously developed in the direction of a mathematical analysis of nature under the guiding principle of equal to the product of mass and acceleration, will be shown to be true. This represents the validity of Newton's mechanics. How far this claim to validity is justified can best be seen from the fact that Archimedes' laws of the simple lever still form to-day the theoretical basis of all load-raising machines and there can be no doubt that they will do so for all time. In spite of this there has arisen in modern physics the necessity for a revision of classical mechanics. To understand this, one must examine more closely the nature of this revision. When one considers the basis of modern physics, one finds that it really does not infringe on the validity of classical physics. Rather has the necessity, and indeed the possibility, of a revision been raised by the limits encountered in the application of the system of concepts of classical physics. It is not the validity but only the applicability of the classical laws which is restricted by modern physics. The experiences which provide the basis of relativity theory have shown for example that the simple time-concept of Newton's mechanics ceases to be of use when we are dealing with bodies moving with a speed that approaches the velocity of light. It is impossible to conceive of a watch which would measure the quantity t in Newton's equations. It is for that reason that Newton's mechanics cannot be applied in this case. Again, to use an example from nuclear physics illustrating the positive side of the statement. As far as the track of an electron in a Wilson cloud chamber can be investigated, the laws of classical mechanics can be applied to it. Classical mechanics does predict the correct track of the electron. But if, without observation of its track, the electron is reflected at a diffraction grating, the basis for an unambiguous application of the space-velocity concept has disappeared and classical laws cannot be applied to such a process.

This situation shows clearly that the possibility of a revision of the exact laws of classical physics arises as a result of the lack of precision of the concepts used in the system. Thus, while the quantities x, t and M used in Newton's mechanics are linked without ambiguity by a system of equations whose solutions contain no degree of freedom apart from the initial conditions,

nevertheless, the words 'space, time, mass' which are attributed to these quantities are tainted with all the lack of precision to which we have to acquiesce in everyday life. It is true that it is one of the basic experiences conditioning our science that to a certain extent communication with other people can be achieved with the aid of these words. But this again is only possible through an exact analysis of the validity of these concepts. And this in turn could only be carried out if there existed a simpler system of concepts which we could, so to speak, trust implicitly. Thus the validity of classical physics is limited by the lack of precision of the concepts contained in its axioms.

After what has just been said, it can be seen that science obviously runs the danger of being forced into a revision of its basis as soon as it leaves the field of common experience. The current concepts will lose their value for the orderly presentation of new experiences. It seems that one might escape this danger, from the outset, in science, by applying all concepts only within the limitations on which they are founded on experience; i.e. modern science should be preceded by a purification of language eliminating all ambiguous terms and concepts. But such a programme could never be carried through. The most common terms would need revision and there is no knowing how much of our language would remain. Also there is no criterion allowing an *a priori* assessment, as to whether the application of a term is objectionable or not. Before the experiences of quantum theory the results of Wilson's cloud chamber experiments could unhesitatingly be expressed in these words: 'We see in the cloud chamber that the electron has described this or that path.' Indeed we could accept this as a simple description of experimental facts. It was only later that we came to know, from other experiments, the problematic nature of the term 'path of the electron'. Therefore the only possible progress for science seemed to lie in the unhesitating use, in the first place, of existing terms for the description of experience, and the revision of these terms from time to time as demanded by new experiences. To demand a previous clarification would be equivalent to an anticipation by logical analysis of the whole of the future development of science. It is obvious, then, that the lack of precision contained in the systems of concepts of classical physics is a necessity. Hence we must also become reconciled to the idea that even the mathematically exact sections of physics represent, so to speak, only tentative efforts to find our way among a wealth of phenomena. This will obviously apply to modern as well as to classical physics. For, if certain ambiguities of the time concept have been remedied by relativity theory and certain ambiguities of the concept of matter by quantum theory, yet there can be no doubt that the future development of science will force further revisions and that the concepts used at present will also prove to be limited in their application but in a sense as yet unknown.

Here we can suitably ask the question: how can we speak of exact science at all? As an answer we can again quote an example of the range of validity of classical mechanics. So far as the concepts space, velocity, mass, etc., can be applied unhesitatingly—and that certainly applies to all experiences of everyday life—Newton's principles certainly apply. These laws therefore represent an idealization, achieved by taking into account only those parts of experience which can be 'ordered' by the concepts space, time, etc. Seen from this point of view, the forming of concepts in classical mechanics appears only a consistent extension of language. Here too, every single term represents an unconscious attempt to introduce order and communication into certain experiences by stressing common trends and by introducing a suitable notation. And just as further development of language is only possible on the basis of already existing words and terms, so in physics the concepts of classical physics form the necessary prerequisites for the investigation of atomic phenomena. Looking at classical physics as a whole then, its essential idealization consists in its ordering of experience on the assumption of objective events in time and space. Classical physics represents, in a sense, the clearest expression of the concept of matter (*Dingbegriff*), in that it attempts to make the description of the world as independent as possible of our subjective experiences. Because of this, the concepts of classical

physics will always remain the basis for any exact and objective science. Because we demand of the results of science that they can be objectively proved (i.e. by measurements, registered on suitable apparatus), we are forced to express these results in the language of classical physics. Thus, for example, for an understanding of relativity theory it is essential to stress that the validity of Euclidian geometry is presupposed in the very instruments—used for the measurement of the deviation of sunlight—which are to show the variations from this same Euclidian geometry. It can also be shown, as Dingler, for example, has stressed, that the very methods used in the manufacture of these instruments enforce the validity of Euclid's geometry for these instruments (within the range of their accuracy). In a similar manner, we must be able to speak without hesitation of objective events in time and space in any discussion of experiments in atomic physics. Instructive examples of this are the experiments where the presence of neutrons is shown by the artificial radioactivity caused by them. The physical processes underlying these experiments can, without doubt, only be understood by using the abstract concepts of quantum theory. Yet the experiments are suitable for measurement because their results can be expressed in classical terms without paying attention to the abstract character of the 'quantum-theoretical' connection. Thus: 'By means of artificial radio-activity we can state that a neutron (i.e. a certain particle [*bestimmtes Ding*]) was found at that definite place at that time.'

Thus, while the *laws* of classical physics, seen from the point of view of modern physics, appear only limiting cases of more general and abstract connections, the *concepts* associated with these laws remain an indispensable part of the language of science, without which it would not be possible even to speak of scientific results.

Before the discovery of relativity theory this fact formed probably the main reason for the belief that classical concepts would have to be the constituent parts of every physical theory for all time. And even to-day, criticism of relativity and quantum theory (erroneous criticism, I believe), is based on this score.

Thus, it is said: it is impossible to make time relative since the discussion of every measurement presupposes absolute time. Or, in the case of quantum theory, that the use of statistical laws must always remain unsatisfactory in a description of nature. Also, that the inability to predict an event can only be looked upon as a sign of a problem as yet unsolved. Hence the question needs to be asked: How does modern physics gain the freedom to pass beyond the limits of classical concepts?

It was the increased range of technical experience which first forced us to leave the limits of classical concepts. These concepts no longer fitted nature as we had come to know it. We observed the track of an electron moving as a particle in a Wilson chamber and, on another occasion, we found it reflected on a diffraction grating like a wave. The language of classical physics was no longer capable of expressing these two observations as effects of a single entity. We had, first of all, to define more closely those places where classical concepts became ambiguous in their application.

It is the definition of the precise point at which a development beyond classical concepts has become logically possible, which represents the core of any modern theory. Thus the core of the special theory of relativity is the statement that the simultaneity of two events at different places is a problematical concept. Similarly, in quantum theory, it is of the greatest importance that to speak simultaneously of a definite position and a definite impulse of a particle is meaningless. The same statements have occasionally also been put in this way: The question of a 'real simultaneity' of two events is a 'false' problem as is the question of the exact position and exact impulse of a particle. These are questions to which there is no answer because they are put in a false way. Indeed this formulation contains the logical quintessence of the situation confronting us. It expresses in the clearest manner that the concepts, which we are forced to use in expressing our experiences, are too ambiguous to account fully for the facts of nature. What is decisive, however, is not the statement, that there *are* 'false' problems, but a reason *why* they exist.

The special theory of relativity states that there is, up to the

present, no means of transmitting signals with a velocity greater than that of light. Hence it is impossible to give a clear definition of an absolute time-scale. This, however, is a negative statement. Only the supposition that it is *in principle* impossible to transmit signals with a speed faster than light, and arising from this the postulate of the constancy of the velocity of light, makes possible a logically satisfying ordering of experience. It is only this second positive step that justifies the statement that the question of an absolute time-scale is a 'false' question. The same applies to quantum theory. The restrictions of classical concepts as enunciated in the uncertainty relations acquire their creative value only by making them questions of principle. They then afford the freedom necessary for a harmonious and non-contradictory ordering of our experience. Only the system of mathematical axioms of wave and quantum mechanics entitles us to class the question of position and impulse values as a 'false' problem.

The appreciation of the logical situation in which an apparently correctly formulated question becomes devoid of meaning, has thus become the precondition for an understanding of modern physics. On the other hand, modern physics also shows that the relegation of a question to being a 'false' problem is only possible and can only become fruitful on this condition: it must create the freedom necessary for the establishment of the required abstract interconnections. In our approach to a description of nature we use concepts which lack precision in certain respects, though we naturally cannot appreciate that at the time. Yet finding these weaknesses will lead to new knowledge only if they can be used in a definite way for an appreciation of new kinds of interconnections. So long as this has not been done, we have no reliable criterion for asking whether a problem has or has not a meaning. We must rest content with treating all theses of physics—even those formulated mathematically—merely as word images, since we cannot know the range of accuracy of the terms and concepts used. We are merely endeavouring to make our experience of nature intelligible to ourselves and to others.

However, once these new connections have been established we can penetrate into a new world of concepts qualitatively different from the old. In this way relativity and quantum theory represent the first decisive step out of the field of apprehensible concepts into an abstract field, as yet untouched, and the character of the connections discovered in it leave no doubt that these steps can never be retraced. Of course, these new connections cannot claim to use concepts better defined than the classical ones and they may yet have to be revised in the future. Nevertheless, the concepts developed in these theories have proved themselves to such an extent in the ordering of the more delicate experiences, that we have reason to believe them as suitable for our new experiences as the old concepts were for the experiences of everyday life. Hence they will in their turn become the precondition for any further development of physics. After all, the discovery of a new system of concepts means nothing more than a new method of thought which can never be annulled as such.

For this reason the real situation in our science can in no way sustain the hope, occasionally expressed, that at some future date classical concepts may yet be used for the ordering of relativistic and atomic phenomena. It is more likely that there is a certain range of experience which can be interpreted by Schrödinger's wave mechanics but not by classical mechanics, and we must assume that even the less palatable features of the laws (Gesetzmässigkeiten) of quantum mechanics will remain integral parts of theoretical science. As an example, I should like to discuss the finality of the statistical character of quantum mechanics and whether any hope can be entertained of extending and completing quantum mechanics on a determinist basis. Indeed there could apparently be no objection to an assumption that, say, the radium atom possesses hitherto unknown properties which accurately define the time of emission and the direction of an α-particle. However, a more detailed analysis shows that such an assumption would force us to consider as wrong those very statements of quantum theory which allow an accurate mathematical prediction of experimental results. We

have, so far, had every reason to rely on those parts of quantum mechanics. I should like to deal with this in greater detail.

Any experiment in atomic physics starts with the following situation. With the aid of more or less complicated apparatus we put questions to nature directed towards establishing some objective process in space and time. We may, for example, want to know whether electrons are deflected at a certain place. In this situation it follows automatically that, in a mathematical treatment of the process, a dividing line has to be drawn between, on the one hand, the apparatus which we use as an aid in putting the question and thus, in a way, treat as part of ourselves, and, on the other hand, the physical systems we wish to investigate. The latter we represent mathematically as a wave function. This function, according to quantum theory, consists of a differential equation which determines any future state from the present state of the function. But we are satisfied with the laws formulated in terms of classical concepts for the making of our apparatus and feel entitled to use them for measuring purposes. The dividing line between the system to be observed and the measuring apparatus is immediately defined by the nature of the problem but it obviously signifies no discontinuity of the physical process. For this reason there must, within certain limits, exist complete freedom in choosing the 'position' of the dividing line. The behaviour of the measuring apparatus must not, of course, contradict the laws of quantum mechanics. Indeed quantum mechanics contains the laws of classical mechanics as a limiting case and the position of the dividing line can be freely chosen within certain limits. The laws of quantum mechanics assume their statistical character only at the dividing line, because the physical connections, on both sides of the dividing line, can be unambiguously formulated. The possibility of statistical inter-connections is created only by regarding the effect of the measuring apparatus on the system to be measured as a partial disturbance uncontrollable in principle. Thus the only place for a determinist supplement to quantum mechanics would be at the dividing line. Since, however, the new physical properties to be determined must be attributed to a definite

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Ideas of the Natural Philosophy of Ancient Times in Modern Physics[1]

Modern science has followed many trends of early Greek natural philosophy by reconsidering the problems with which that philosophy had grappled in a first attempt to understand the surrounding world. Hence it may be well worth considering which of those early ideas have retained their creative power in modern physics, and what shape they have acquired by absorbing the scientific experiences of the intervening two thousand years. There are, especially, two ideas of early Greek philosophy which to-day still determine the course of science, and which are therefore of special interest to us: the conviction that matter consists of minute indivisible units, the atoms, and the belief in the purposely directive power of mathematical structures.

The thesis of the existence of atoms was the natural consequence of the development of the concept of matter, the classification of which was the first endeavour of ancient natural philosophy. The conviction that, in the transience of phenomena, there must be something permanent which is subjected to change, led to the teaching of the existence of some 'fundamental matter'. For Thales, this fundamental substance was simply water, on which all life appeared to depend. His successors defined this concept more accurately and attributed to it the characteristics of entity (Einheitlichkeit) and indestructibility. Thus, to make intelligible the variety of phenomena, several

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[1] First published in *Die Antike* (Organ der Gesellschaft für Antike Kultur.) Vol. XIII.

ized, though the listener may not be conscious of this. This discovery represents one of the strongest impulses of human science, and its effects, in nature as well as in art, can constantly be seen, once the creative force of mathematical order has been appreciated. I would mention the kaleidoscope as a specially simple and obvious example. Here, something beautiful and orderly arises from a random picture, through simple mathematical symmetry. More valuable and important examples can be found in an analysis of any work of art or, in nature, in the study of crystals. If the essence of a musical harmony or a form of fine art can be discovered in its mathematical structure, then the rational order of surrounding nature must have its basis in the mathematical nucleus of the laws of nature. Such a conviction found its first expression in the Pythagorean teaching of spherical harmony, in the attribution of regular shapes to the elements. Thus in *Timaeus* Plato explains the atoms of earth, fire, air and water as cube, tetrahedron, octahedron and icosahedron respectively. But in the last resort the whole of mathematical natural science is based on such a conviction.

Modern science has thus accepted from antiquity the idea of a pattern capable of mathematical description, but it carries it out in a different manner, rigorous and, we believe, determined for all time. The realm of mathematical forms at the disposal of ancient science was still comparatively limited. They were primarily geometrical forms which were related to natural phenomena. Hence Greek science searched for static patterns and relationships. The subjects of its investigations were the unchangeable orbits of the stars, or the forms of the everlasting and indestructable atom. However, the laws that could be derived from those assumptions could not accommodate the experiences of later centuries based on the use of more delicate apparatus. Modern science has demonstrated that in the real world surrounding us, it is not the geometric forms but the dynamic laws governing movement (coming into being and passing away) which are permanent. Even Kepler thought he had found in the orbits of the stars the harmonies of Pythagoras's school. Science since Newton has attempted to see them in the mathematical heuristic principle in exploring the natural laws in any field opened up as a result of new experiments. In such a case the inner relations seem to be understood only when the determining laws have been formulated in a simple mathematical way.

This search for the mathematical structure of phenomena, as taken over from antiquity has, however, given rise to an accusation. It is said that it illuminates only certain and, at that, not the most essential aspects of nature and, rather than being of help in an immediate and general understanding of nature, it is actually a hindrance. This complaint can best be answered by drawing attention to the starting point of Pythagoras's teachings. It is the conscious understanding of the rational numerical relations underlying musical harmonies which make possible both the construction and use in performance of a musical instrument. It is, however, in the unconscious mental acceptance of these rational relations that we can grasp the real content of music. Similarly, the precondition for an active, practical intervention in the material world, is just this conscious knowledge of mathematically formulated natural laws. Behind this, however, there is a direct understanding of nature unconsciously accepting these mathematical structures and mentally recreating them. All human beings are capable of this understanding if they are willing to enter into a more intimate receptive relation with nature.

that the fundamentally different attitudes of the poet and the mathematician to the world have led to such different theories. This certainly expresses an important reason for the dispute, but it would be unjust to conclude that this other poetic side of the world need necessarily be alien to the scientist. We need only mention Kepler who, after all, helped to create the most important foundations of this mathematical science. Kepler always sensed in all his varied and intricate speculations on number the harmony of spheres. Listening to the enthusiasm with which he celebrated new discoveries about the harmony of planetary orbits it would be ungenerous not to credit him with definite poetic sensibility. Newton devoted a large part of his life to philosophical and religious investigations and it is probably correct to say that the world of poetry has been familiar to all really great scientists. The physicist, at any rate, also seeks to discover the harmonies of natural events. On the other hand, it would be an equal mistake to believe that the poet Goethe had more interest in arousing a vivid impression of the world than in acquiring a real understanding of it. Every genuinely great work of creative writing transmits real understanding of all aspects of life otherwise difficult to grasp. This is especially true of a work like the theory of colour which must transmit new understanding and is written with full claims to scientific accuracy.

Perhaps the difference between the two theories is most accurately defined by saying that they deal with two entirely different levels of reality. We must remember that every word of our language can refer to different aspects of reality. The real meaning of words often emerges only in their context or is determined by tradition and habit. Modern science soon made a division of reality into objective and subjective. While the latter is not necessarily common to different people, objective reality is forced on us from the outside world always in the same way and for that reason early science made it the subject of its investigations. In a way, science represents the attempt to describe the world to the extent that it is independent of our thought and action. Our senses rank only as more or less imperfect aids enabling us to acquire knowledge about the objective world. It first half of the last century attempts had been made to link electrical theory with mechanics through the concept of force. However, the discoveries of Faraday and Maxwell have shown that electric and magnetic phenomena can best be understood by basing them on the idea of the electric field. True, the field concept can be made plainer by comparison with the oscillations of elastic bodies but this is obviously a simile for showing mathematical interrelations, and has no connection with our immediate sense-impression of electricity. For even when we talked of an ether whose elastic oscillations had an electric effect, this ether was outside the range of our sense-impressions. At the same time, however, this science, in becoming more and more abstract, reveals a new power. It can recognize the interconnection between the most diverse phenomena and relate them back to a common root. It is the finest justification of our enquiry into the objective world that it has led to unexpectedly wide interconnections, and that, in spite of all the complexity of detail, it has, more and more, simplified our ideas of nature. Through Maxwell's discovery, light was recognized as an electromagnetic phenomenon. This led in turn to the recognition that electric and magnetic effects, light, invisible ultra violet and infra red rays and heat radiation are but different aspects of the same physical effect in spite of the fact that they belong to entirely different parts of our world of the senses. This development is carried to its logical conclusion in modern atomic physics. Atomic physics undertakes to explain all properties of matter accessible to our senses of our experiments, by tracing them back to properties of the atom. These latter can be laid down in simple mathematical laws. Thus the infinite variety of phenomena is reflected in the infinite number of deductions from a simple system of mathematical axioms. In fact modern atomic physics can explain, from the properties of atoms, the properties of solids, chemical regularities, the effects of heat and anything else arising from an observation of matter. It is true that up to the present this explanation has been carried out, with the precision ultimately required, only in relatively few cases, but in all these cases our theory has stood up to the most rigorous tests in be a blessing or a curse. Hence many warning voices have been raised during recent years counselling us to turn back. Already, they say, a great scattering of intellectual effort has resulted from our negation of the world of direct sense-impressions and the division of nature into different sectors. Further withdrawal from 'living' nature will, so to speak, drive us into a vacuum where life will no longer be possible. When we are not advised simply to throw over all science, pure and applied, we are exhorted to develop science in close connection with daily experience. We are told that it is not sufficient to understand the laws governing all processes of the objective world but that it is essential to visualize at any given moment all the consequences of these laws in our world of the senses. In his constant dealing with nature in his own experiments, the scientist should become so familiar with observed phenomena that laws would appear merely a useful summary of his experiences. Thus the danger of completely separating the two kinds of realities is to be avoided by making the world of experiments as direct and 'living' as surrounding nature. But it is obvious from the start that the interrelations of nature can only be understood by a man who is thoroughly familiar with the manifestations of nature in the field concerned. There has never been progress and discovery without detailed knowledge based on experimental results. But the dangers of modern science are not surmounted in this way. For our experiments are not nature itself, but a nature changed and transformed by our activity in the course of research. To effect a real change would undoubtedly entail a complete abandonment of the whole of modern technology and science, which is linked with it. Nobody is in a position to say whether such a break would mean happiness or disaster for mankind. But however we may feel about this, one thing is certain. Such a break is impossible. We have to reconcile ourselves to the fact that it is the destiny of our time to follow to the end of the road along which we have started.

At the beginning of our modern era navigation flourishing and the daring feats of the circumnavigators of the earth opened up the possibility of the conquest of distant lands and of the return with immense treasures to their homelands. There may have been some doubt as to whether the new wealth would weight the scales equally with happiness and distress. Perhaps there were warning voices then who advocated a return to the more peaceful and less pretentious conditions of life of a previous epoch. But at such times warning voices resound unheard. The attraction of foreign lands and treasures can only come to its natural conclusion when these countries have been explored and their treasures have been distributed. Only then shall we have the vision to see more closely defined tasks, though they may be more important, and it is thus that science and technology will continue to develop in our time. Just as frontiers could not prevent the attraction of foreign countries, so no external obstacles will be able to prevent the progress of technology. Only nature herself can call a halt to our endeavours by showing us that the field to be conquered is not infinite. It is perhaps the most important trend of modern physics that it shows us the limits of our active attitude to nature.

Atomic physics took as a starting point the apparently natural supposition that our knowledge of the atom will, with increasing accuracy of observation, perfect itself more and more. Though atoms represented the final indivisible 'brick' of matter, they nevertheless appeared to be miniature parts of ordinary matter. The atom then, at least in our imagination, was endowed with all the macroscopic properties of matter. Only in the course of time was it recognized that the smallest particles, for instance electrons, could not themselves possess the 'sense-properties' of matter if they were to explain these properties on a larger scale. Otherwise the question of the reason for those properties would not have been solved but only moved one step further away. For example, if we say that a stronger movement of the atoms within differentiates a hot from a cold body, then an individual atom can be neither hot nor cold. Thus the atom was progressively divested of all its 'sense-properties'. The only properties which appeared for a long time to be retained were geometrical ones—the atom took up space and position, and had a definite movement. The development of modern atomic physics, however, has removed even these properties by showing that the degree to which such geometrical concepts can be applied to the smallest particles depends directly on the experiment in which they are involved. True, with a comparatively moderate demand for accuracy, we can speak of the position and velocity of an electron: true also that, compared with our daily experience, this accuracy is quite considerable. But measured by an atomic scale it is insufficient, and a law characteristic for this miniature world prevents us from determining position and velocity with the desired accuracy. Experiments can be done enabling us to determine, say, the position of a particle with great accuracy, but in the course of this measurement the particle has to be exposed to strong external influences which are responsible for a considerable uncertainty as to its velocity. Nature thus escapes accurate determination, in terms of our commonsense ideas, by an unavoidable disturbance which is part of every observation. It was originally the aim of all science to describe nature as far as possible as it is, i.e. without our interference and our observation. We now realize that this is an unattainable goal. In atomic physics it is impossible to neglect the changes produced on the observed object by observation. We decide, by our selection of the type of observation employed, which aspects of nature are to be determined and which are to be blurred in the course of the observation. This is the property which separates the smallest particles of matter from the range of our commonsense concepts. The supposition that electrons, protons and neutrons, according to modern physics the basic particles of matter, are really the final, indivisible particles of matter, is only justified by this fact. It would no longer make sense to visualize a three dimensional structure of these particles.

From what has been said we can conclude, along two different lines of thought, that the range of science and technology as we know it, is finite. On the one hand, our arrival, in atomic physics, at the final indivisible particles of matter should, in the not too distant future, lead to a complete survey of all the forces of nature yet to be exploited and hence of all possible technical possibilities. On the other hand, the way in which atomic phenomena are divorced from those of our everyday experience serves as an important example that in science the way in which a question is put and the method of research employed already singles out a finite and limited field from the abundance of physical phenomena. Previously, it appeared to be the task of science to describe the motion of bodies in space and to understand their regularity. Now we recognize that the range of atomic phenomena cannot be tackled in this way. When we ask of nature position and motion within an atomic system we destroy, through the impact of essential experimental measures, certain interconnections characteristic for a world of atomic size.

It is tempting to generalize these ideas and to recall Goethe's criticism of Newtonian physics. Goethe said that what the physicist observes with his apparatus is no longer nature. He probably meant to imply that there are further and more 'living' aspects of nature which are not accessible to this particular method of science. We are, of course, ready to believe that science, where it turns from inanimate to living matter, will have to be more and more careful in its interference in the course of an experiment. As our desire for knowledge also reaches out to higher, spiritual aspects of life, so we shall have to be content with a passive, contemplative kind of investigation. From this point of view, the division of nature into a subjective and an objective sector would appear an over-simplification of reality. It would be more to the point to imagine a division into many overlapping sectors, divided by the type of question we ask of nature and by the amount of interference which we allow during observation. In attempting such a classification in simple terms we are reminded of the classification of 'related aspects' as it appeared in the appendixes to Goethe's theory of colour. Goethe stressed that all the effects which we observe by experience are connected and continuous, yet the separation of one from the other is unavoidable. He classified them from low to high; accidental, mechanical, physical, chemical, organic, psychic, ethical, religious and of genius ('genial'). Seen in the light of modern science we might perhaps change some of the first delineations. For *mechanical* we might substitute all those

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On the Unity of the Scientific Outlook on Nature[1]

We are witnessing a change in the external features of the world. The struggle for its reshaping is carried on with all our resources and absorbs all our powers. In such times, changes in the world of the mind, of which science is a part, automatically recede into the background. Yet the slow changes of human thought and desire have no less an impact on the external features of the world than great single events. A fundamental and lasting change, which has gradually matured in some fields of intellectual activity, can also be of importance on a world scale, in the shaping of our future. We may thus be justified, for once, in looking at our epoch from an unaccustomed angle. In the realm of science our times can be described as momentous. It appears that the various branches of science are beginning to fuse into one great entity and it is this unity I wish to discuss. The way in which this topic has been raised already implies the admission that up to now things have not been going too well.

I. Let us first turn to the initial stages of science at the beginning of the modern era. In the days when Galileo discovered the law of falling bodies and when Kepler studied the motions of the planets, there existed a single unified idea of nature, but it was not yet a scientific one. The picture of the world was still entirely determined by belief in a supernatural revelation as laid down in the Holy Scriptures. The scientist thought it was his

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[1] Lecture delivered on November 26th, 1941 at the University of Leipzig.

all its ramifications but as a whole—to re-live the Plan of Creation. To-day the scientist's pride is love of detail, the discovery and systematizing of the smallest revelations of nature within a narrowly circumscribed field. This is naturally accompanied by a higher esteem for the craftsman in a special subject, the 'virtuoso', at the expense of an appreciation of the value of interrelations on a larger scale. During this period one can hardly speak of a unified scientific view of nature, at least not as far as content is concerned. The world of the individual scientist is that narrow section of nature to which he devotes his life's work.

There is, it is true, a certain common scientific method and—as an expression of that method—a conception of the final aim of science, for which the model at least for exact science, was Newtonian mechanics. One had, from certain given data, to calculate the movement of nature, and many scientists were convinced that this task could be solved, at least in principle, in all fields of science. The most concise expression of this view of science at the time of rationalism was Laplace's fiction of the demon. He would be in possession of the complete data on the present state of the world and from this knowledge he could derive its whole future development.

The aim, then, was the creation of an edifice including all laws of nature which would make such a calculation possible, at least in principle. Whether all natural phenomena could, in the last resort, be traced back to the laws of mechanics or whether there might be yet other types of systems of concepts was left open.

The example of Newtonian methodology did, however, unify only the so-called 'exact' sciences. Quite different ideas were current among scientists concerned with animate nature. Vitalism, so prevalent in the second half of the eighteenth century, adhered to laws independent of physical and chemical interrelations. This was true in spite of the occasional references to electrical processes in connection with the 'elan vital', the force which distinguished animate from inanimate matter. It was in fact an *a priori* assumption that the laws of the processes of living matter were of a different character from the laws of

physics. Most important of all—there never was a question of a mathematical formulation of these laws or the prediction of animate processes. In chemistry, too, it was at first widely believed that substances formed by living organisms were of a fundamentally different structure from those which originated in inanimate nature and which the chemist can synthesize from the elements in a retort. The possibility of relations other than those of 'exact' science were especially stressed and generalized by romantic natural philosophy. Important scientists have attempted, in vain, to introduce the type of law postulated for animate processes into processes of inanimate nature, e.g. astronomy. The romantics defended themselves against all attempts at explaining natural processes in terms of 'mechanical manipulation'[1] ('Stossen und Schlagen'). But these endeavours of the romantics could not prevail against the methodical assurance and transparent clarity of 'exact' science.

During the second half of the nineteenth century one could perhaps speak of at least a methodological unity of science. Wöhler's discovery had introduced the synthesis of organic substances from inorganic matter and this convinced the chemists that chemical reactions in living organisms were governed by the same laws as those in inorganic matter. From then onwards chemistry followed methodically the example of Newtonian mechanics and the success of the 'atom-hypothesis' made its contribution in spreading the ideal of a science based on the mechanics of elementary particles. In biology, vitalist views had been attacked by Darwin's theory of evolution and increasing attention was paid to analysing cause and effect. Even in medicine great successes had been achieved by an attitude of mind which likened processes in organisms to processes in a complicated machine.

In a way there existed thus a unified scientific view. Nature consisted of matter subjected, in conformity with natural laws, to change in time and space by action and reaction. Such changes took place by movement in space, or perhaps the internal movement of individual parts or again by a change of

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[1] This is a reference to Oken as quoted on page 36. [F.C.H.]

material qualities (colour, temperature, tensile strength) which also depended on movement of the smallest particles, the atoms. We can regard such a view as an idealization of nature in which time and space are treated as independent categories into which events are projected as objective happenings. It is precisely this idealization on which Newton's mechanics is based and, as we have seen, mechanics was the methodological example for all science.

Although this view of nature had decisively advanced the development of science it was soon seen that it was incapable of creating a durable unity of its different branches. For the idealization just described hardly suited the concepts and problems of all the individual sciences. The system of chemical concepts had developed from an observation of material qualities and had become to a great extent independent of mechanical explanations. In biology scientists had to deal with processes of an altogether different kind which could be made intelligible by concepts such as growth, metabolism, heredity, etc. Finally no suitable place could be found in this view of nature for that great realm of reality comprising mental processes, and this was probably partly responsible for the much regretted division of mental activity into the sphere of science and the realms of art and religion. We can understand that this view of nature could never be fully convincing; nor could it prevent the disintegration of science into highly developed individual disciplines. It necessarily favoured a development in which the application of scientific thought to practical ends took the place of the 'universitas literarum'.

Though it cannot be said that this development has exhausted itself, there are some clear indications that the sciences are beginning to be drawn together more closely by new and different perspectives and there can be little doubt that the one-sided scientific view of the late nineteenth century is being replaced by new forms of thought.

II. The new process of the unification of science had its basis, however, not in the method but in the content of the individual bodies Planck had first discovered a strange discontinuity of the energy content of the atoms. It appeared as though a small radiating system could have only quite definite, discrete energy values. Later Rutherford developed from his experimental work the idea that an atom can be likened to a small planetary system in whose centre is a positively charged atomic nucleus, embodying practically the entire mass of the atom. Round this nucleus circle negative electrons. The stability of this planetary system could be explained by Bohr a few years later by means of Planck's quantum hypothesis, and finally, a quarter of a century after Planck's discovery, the exact mathematical form of the laws governing atomic structure were found.

Quantum theory did in fact satisfy all the demands which, within the limits of our present knowledge, could be made on atomic physics. The theory enabled us, at least in principle, to calculate—and to that extent 'explain'—the properties of macroscopic matter. In the case of a few very simple substances, such as hydrogen, we have succeeded in calculating with great accuracy the most important chemical properties, the colour in discharge tubes, phenomena at low temperatures and other related properties. These calculations have even brought to light some phenomena which had been overlooked by the careful work of the experimental physicist. In the case of many other substances, quantum theory can supply at least a qualitative explanation of their properties such as, for example, electrical conductivity of metals or the structure of crystals. Thus we are perhaps justified in believing that we have reached a level of research comparable to that of the knowledge of the mechanics of the heavens after Newton. We may say that we are capable of a quantitative 'calculation' of the properties of matter in all cases where mathematical complications do not prevent the execution of this task in practice.

A heavy price had, however, to be paid for the achievement of this ambition. It meant, in the simplest form, the loss of just that nineteenth century scientific conception of nature or, expressed more accurately, the loss of that conception of reality on which Newton's mechanics rested.

This was because quantum theory made the atom into something inaccessible to our senses or our imagination, unlike objects within our daily experience. An atom or, more correctly, the smallest unit of modern nuclear physics, an electron no longer displays 'in itself' ('*an sich*') even the simplest geometrical and mechanical properties but it shows them only to the extent to which they can be made accessible to observation by external interference. Different observed properties of an atom are complementary in the sense that the knowledge of one particular property can exclude the simultaneous knowledge of another property. This strange kind of reality of the atom or the electron carries with it various important consequences. The behaviour of an atom in many experiments can be described by means of mechanical concepts: we can, for example, speak of the track of certain particles. In such experiments the laws of classical mechanics always provide a correct account of the event concerned. Hence, we can say that the laws of classical mechanics apply to all those atomic processes in which they can be directly checked. There are also, an the other hand, experiments in which it is necessary to use non-mechanistic concepts for a description of the state of an atom, e.g. concepts which express the chemical properties of an atom. In such cases no use can be made of mechanistic descriptions and the question as to whether the laws of mechanics 'apply' is irrelevant. Mechanical and chemical properties are mutually exclusive. This is clearly expressed in the mathematical formulation of the quantum laws and makes possible the peculiar non-mechanical stability of atomic systems on which is based our knowledge of macroscopic matter (*Materie im Grossen.*).

These facts demonstrate the finality and assurance of classical theory which apparently cannot be shaken by any new experience, and which holds good wherever its concepts apply. On the other hand, nature makes provision for relations of quite a different kind by forcing us to create some external disturbance in the course of each observation and thus withdrawing from our grasp an apprehensible picture of the atom. An atom can no longer, without reservation, be 'objectively' described as an

object in space changing in time in a definable manner. Only the results of individual observations can be objectively described but they never present a complete and apprehensible picture. It follows that the conception of reality on which Newton's mechanics was based was too narrow and had to be replaced by something broader.

Previously, physics had attempted to treat processes accessible to our senses as secondary and derived and to explain them in terms of events on an atomic scale (*in kleinen*).

These events were considered to be the 'hidden' objective reality. However, we now recognize that events accessible to our senses (with or without the aid of scientific apparatus) can be considered to be 'objective'. That is to say, we can justifiably claim that an event observed by us has 'objectively' taken place. But atomic processes cannot always be represented as objective events in time and space. Only a reversal, if I may express it in this way, of the order of reality as we have customarily accepted it, has now made possible the linking of chemical and the mechanical systems of concepts without contradiction.

Atomic theory has thus joined physics and chemistry into one great and unified science. We may ask ourselves what has been the practical effect of this new unity on the individual parts of science and what influence has it already exercised on our scientific conception of nature?

We might have thought that the new situation would necessarily lead to an extraordinary upsurge of chemistry, since all fundamental problems of chemistry, e.g. the nature of chemical forces, had now been solved by atomic physics. On closer inspection it soon becomes apparent, however, that chemistry had long since left the realm of research into fundamental relations in favour of that of their practical application. The problem of the nature of chemical forces, once the central problem of chemistry, has been so completely relegated to the background that no chemist needs to take any notice of it when dealing with some small, though in practice perhaps important, question. A fundamental solution could be of little use in a particular question since real theoretical treatment based on atomic theory the sum of its individual parts' expresses this contradiction but it does not resolve it.

The problem we have just posed appears in an entirely new light if we make use of the methods of thought of quantum theory and if we, like Bohr, take the theoretical situation of atomic physics as an example of method. In quantum theory too there apparently existed, at first, a contradiction between classical physics on the one hand and chemical concepts on the other. The first completely determined the properties of a system from its initial conditions and applied wherever these could be checked, the second led to a system of concepts which had no immediate connection with classical physics. The contradiction was resolved by our knowledge that a situation which could be described in chemical terms excluded the accurate knowledge of the mechanically determining conditions. This exclusion arises automatically through the disturbance which, according to natural laws, is inevitably implied in every observation. We can imagine a similar situation in biology. The statement that 'a cell is alive' could include an accurate and complete knowledge of the conditions which determine its physical structure. The achievement of such a complete knowledge would probably necessitate such drastic interference (e.g. the use of X-rays) that the cell under observation would be destroyed. At least the methodological example of quantum theory can demonstrate that there is no necessary logical contradiction between the basic thesis that 'the physical-chemical laws apply without qualification in living nature' and the vitalist thesis that life has its 'own' laws.

This does not yet, of course, solve the problem, and research has for some decades explored the borderlines where a solution is likely to be found. The properties of an organism as a whole are of little help since their physical and chemical relations cannot be grasped in all their complexity. When they can be understood, their physical and chemical properties are obvious. The real problem of living organisms as a whole lies in the very reason for the origin of such complex formations and this question immediately leads us to those of growth, cell division,

the doubling of chromosomes and genes, i.e. the borderline between biology and the chemistry of large molecules.

In this field, the results of the new atomic physics can be used not only for their method but also for their content, and the special aspects of quantum theory which relate to the theory of perception gain in importance not only in method but also in content. Genetical investigations into the frequency of mutations, for instance, seem to indicate that under certain conditions an event on an atomic level, such as the release of a single chemical link in a chromosome of a cell nucleus, can cause changes in the whole future development of the organism. In such cases the statistical laws of quantum theory assume a direct practical importance for the behaviour of a living being

Studies on the borderline between the chemistry of albumens and the biology of the smallest elementary units will thus—apart from all considerations of principle—first of all have to exploit to the full the concepts of physics and chemistry, in order to establish just how far they can be used for a description of living processes. In doing this we are aware that the natural laws may themselves prove to be a barrier, and this would prevent us from neglecting those other aspects of life from which vitalism once drew its strength and which impress upon the observer's mind what has been called 'reverence before Life'. The change in the order of reality which has taken place within quantum theory has also brought the biological branches of research, whose subjects are those other characteristic aspects of the process of life, much nearer to the 'exact' sciences. It means that, apart from specific borderline research, certain common thought relations have been established between two previously entirely separated fields of science.

The developments of the last decades have thus drawn biology, physics and chemistry more closely together. A real fusion of the three subjects into a unity of content could, however, only be achieved by fundamental extensions of our knowledge of the processes of life. But there seems to be already a beginning of a methodological unity which is no longer supported by the desire finally forced us to revise the fundamentals of science and has convinced us that there can be no such firm foundation of *all* perception. After all, our idea of a world moving in time and space is only an idealization of reality dictated by our desire to see the world, as far as possible, objectively. Quantum theory uses a different idealization, less obvious and complying to nothing like the same extent with our desire to see things objectively but it enables us, in compensation, to understand completely the laws governing chemical changes. Chemical processes cannot be related to the physical behaviour of the smallest particles, within the framework of the conceptions of reality of classical physics, and we are thus prepared for other occasions when we again find that peculiar complementary relation between different aspects of reality.

Of course, we cannot assume such simple proportions as: biology relates to chemistry, as chemistry to physics. It would probably be more correct to say that a completely new level of perception and understanding has to be achieved in the transition from an aspect of reality already 'understood' to one still new. Such a step may be as difficult as was the advance from classical physics to atomic theory.

Yet, having said this, we probably understand now, better than before, that there exist apart from the phenomena of life, still other aspects of reality, i.e. consciousness and, finally, mental processes. We cannot expect that there should be a direct link between our understanding of the movement of bodies in time and space, and of the processes of the mind, since we have learnt from science that our mental approach to reality takes place, at first, on separate levels which link up, so to speak, only behind the phenomena in an abstract space. We are now more conscious that there is no definite initial point of view from which radiate routes into all fields of the perceptible, but that all perception must, so to speak, be suspended over an unfathomable depth. When we talk about reality, we never start at the beginning and we use concepts which become more accurately defined only by their application. Even the most concise systems of concepts satisfying all demands of logical and mathematical precision can only be tentative efforts of finding our way in limited fields of reality.

Thus we are no longer in the happy position of Kepler, who saw the interrelations of the world as a whole as the will of its creator, and who believed himself, with his knowledge of the harmonies of the spheres, to be on the threshold of understanding the Plan of Creation. But the hope for a great interconnected whole which we can penetrate further and further remains the driving force of research for us too.

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Fundamental Problems of Present-day Atomic Physics[1]

Practically all public discussion of atomic physics is in fact concerned with atomic technology, i.e. the application of the enormous energy of atoms to weapons of war or to machines. The real science however, of which this technology is but a branch development, is much less known to the general public. Occasionally there may be reports of the success of a British scientist in discovering a new elementary particle, or of new knowledge of the inner atomic forces gained in experiments with a new giant cyclotron in California, or again of Stalin Prizes awarded to two Russian scientists for their work in high altitude laboratories in the Caucasus. But the real aim, the common bond linking all the efforts of men of different nations and making them part of a pattern, this aim is hardly ever discussed. And yet this is precisely the object of atomic physics for the physicist. For him there is ever present in his work the centuries-old desire for a unified understanding of the world, and he judges every discovery, at least unconsciously, on its ability to bring him nearer to the goal of his ambition. That is why I should like to speak to you to-day about those fundamental ideas which combine various experiments and theories into atomic physics. I should like to explain what we are hoping for in our work and what will have happened when our hopes and wishes have been fulfilled.

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[1] Lecture delivered at the Eidgenössische Technische Hochschule, Zürich, on July 9th, 1948.