MATTER AND COSMOLOGY PART I

THE ORIGINS OF THE KINETIC-CORPUSCULAR VIEW OF MATTER AND ITS RE-INTERPRETATION UNDER RELATIVITY AND QUANTUM THEORY

by

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"Systems, scientific and philosophic, come and go. Each method of limited understanding is at length exhausted. In its prime each system is a triumphant success. in its decay it is an obstructive nuisance. The transitions to new fruitfulness of understanding are achieved by recurrence to the utmost depths of intuition for the refreshment of imagination. In the end - though there is no end - what is being achieved, is width of view, issuing in greater opportunities. But opportunity leads upwards or downwards. In unthinking nature 'natural selection' is a synonym for 'waste'. Philosophy should now perform its final service. It should seek the insight, dim though it be, to escape the wide wreckage of a race of beings sensitive to values beyond those of mere animal enjoyment."

Alfred North Whitehead
Adventures of Ideas

INTRODUCTORY REMARKS

This article is the first of a series of three within which an attempt will be made to summarise some of the many questions and answers which have been raised over the past two thousand years regarding the nature of matter, the origin of its forms and the associated concept of cosmology – the formation of the universe, our place within it, and its course of evolution. Realising that it would be impossible to present, in these few pages, anything like a detailed discussion of these topics, the first article will restrict itself to an examination of the development of the classical concept of matter and its subsequent transformations within the space-time fields of relativity and quantum theory. This section, which should acquaint us with the extremely tenuous nature of our common-sense concepts of physical reality, will be followed by a more empirical foray into the processes by which the various forms of matter, the chemical elements, come into existence. The third and final section will attempt to relate these processes to current cosmological theories and so will serve also as a summary of the major points covered in the preceding sections Being well aware of the limitations set, both by my own capabilities and the sheer volume of past and present work which should be included in any rigorous discourse of this nature, I would, nevertheless, like to think that the series will be of use to students and teachers of science who wish to obtain some insight into the basic principles underlying their respective fields of endeavour. The use of technical language has been kept to a minimum in order to enable the series to be intelligible to anyone possessing a working knowledge of upper high-school science. Hopefully, it will be possible to arrive at conclusions which, although presenting only a small part of a very complex picture, will provide us with a clearer insight into some of the most profound questions ever posed by man.

CONCEPTUAL SYSTEMS, THEORIES AND MODELS

Before commencing upon the main text of this article, it will be necessary to provide a little of the philosophical backdrop against which we will find it useful to compare the various attempts which have been made to explain the construction of the world and the nature of the fundamental processes by which changes were stated to occur. A primary pre-requisite for any such backdrop is a knowledge of the basic entities, their properties and relationships which constitute the limit to meaningful explanation within a particular cultural epoch. These basic premises form what Harre calls a 'general conceptual system',[1] Hempel's 'internal principles'[2] and the 'substantive content' of Nagel[3]. To exemplify their function, we may compare the premises which constitute the conceptual systems utilised by Aristotelian, Newtonian and Einsteinian physics in the following manner.

		Aristotle[4]	Newton[5]	Einstein
i	List of classes of independent individuals.	matter* forms.	atoms	energy field.
ii	List of classes of properties. of individuals.	potential of matter for form.	mass extension shape.	forms e.g. mass heat, light
iii	List of classes of relations between individuals or properties	replacement of forms, natural place.	impact motion gravity.	replacement of forms, space-time curvature.

It should now be obvious that the choice of any particular conceptual system will determine the type of questions which may be asked concerning the nature of any observed phenomena. Within the Newtonian

* Not to be confused with the current usage of the term. Aristotle's argument held that all we perceive is form and matter is simply that which constitutes the underlying reality. This concept is closely analogous to that ascribed to energy in Einstein's physics.

conceptual system the observed variation of gas pressure with temperature could validly be investigated by reference to the collision of gas atoms on the walls of the container - but an Aristotelian could not accept any results from this procedure because he would not recognise the existence of atoms in the first place.

In addition to the three basic premises, a general conceptual system needs also to specify certain properties or entities as invariant, that is, they are conserved throughout any process allowed within the system. That any viable conceptual system must specify some invariant can most readily be seen if we consider that the process of prediction requires the conservation of some entity. For, in order to make a prediction, we need to assume that some relationship exists between the current situation and that which is expected to follow; the existence of some invariant enables the future state(s) to be predicted from currently available data. Take, for example, the conservation of momentum principle of Newtonian physics. A knowledge of the momenta of the constituents of a system at any time allows the momenta at any future time to be calculated. It is also clear that the mathematical description of natural processes necessarily assumes an invariance of some quantity; otherwise how could relationships of equality be formulated? A simple chemical equation - for the burning of coal in air to give carbon dioxide, $c + o_2 = co_2$ + **energy** - assumes the conservation of mass-energy in order to be understandable and meaningful symbolisation of an experimental process.

Following the assumption of a conceptual system, we utilise its premises for the construction of theories which are felt to provide an explanation for the occurrence of some chosen phenomenon. Carl Hempel[6] argues that a theory is introduced to explain a system of uniformities that can be expressed in the form of an empirical law - as, for example, the law that the pressure of a gas at constant volume varies directly as the absolute temperature - and it does so by reducing experimental observables to some function of the basic entities contained in the accepted conceptual system. However, it is also evident that a number of theories can be set up which account for the observed facts and so we must add to the above definition by stating that an acceptable theory must also provide a predictive framework against which its viability may be tested. Where a number of theories with similar predictive ranges exist, that with the least number of auxiliary hypotheses is preferentially chosen because it is more readily testable and freer from ambiguity than one which relies on supporting statements for its formulation.[7,8] This is not to decry the validity and utility of **ad hoc** hypotheses, but rather to emphasise that their inclusion in the theory, while extending its scope of prediction and explanation, also produces a diminution in the clarity of definition achieved by a simpler one. Perhaps the following example[9] will make the situation a little clearer. Newton's theory of gas pressure required the supporting hypothesis that the atoms in the gas exerted a repulsive force upon each other which was inversely proportional to the distance between them, that is, he asserted the existence of a relation between his basic entities which was not contained in the accepted conceptual system. This addition made his theory somewhat more 'clumsy' than the opposing theory proposed by Bernoulli which stated that pressure could be seen as the collision of gas atoms with the walls of the container, an explanation not requiring an auxiliary hypothesis. Both theories accounted for the facts and both possessed similar predictive scopes at the time, but the simplicity of Bernoulli's system and its greater applicability in other areas eventually led to its preference over that of Newton.

It should, however, be added that the introduction of auxiliary hypotheses is often justified where this prevents the dismissal of a well-validated theory and if it is anticipated that the experimental anomaly, which led to the addition of such hypotheses, could eventually be subsumed within the original theory, or a modification of it. When reliable observations indicated that the planet Uranus had strayed from its predicted orbit,[10] it was postulated that an undiscovered planet was responsible for this deviation since very good reasons were available for holding that the theory of gravitation was not at fault. This anomaly in Uranus's orbit was resolved at a later point in history with the discovery of the planet Neptune exactly at the co-ordinates calculated from the theory. On the other hand, and this was the case where classical mechanics was superseded by relativistic mechanics, if a theory becomes too cumbersome by the addition of **ad hoc** hypotheses, it will probably be scrapped and a simpler theory (in the utilitarian sense), able to account for the anomalies which led to the inclusion of the hypotheses to the previous theory, will take its place - but this process will require a modification of the basic premises which constitute the general conceptual system in use at that time.[11]

While theories provide an explanatory framework which enables us to answer 'how' observed phenomena occur, we cannot arrive at the 'why' unless we accept that the basic premises upon which the theories are founded require no further explanation. These basic premises constitute, for the present moment, the ultimate knowable reality and are justified only because their assumption provides the basis for the current level of sophistication attained by science. This viewpoint has been very concisely described by A. d'Abro.[12]

> "Consider the phenomenon of gravitation. Does anyone really imagine that Newton or Einstein has ever attempted to explain gravitation? To say that gravitation is a property of matter or a property of space-time in the neighbourhood of matter is just as much of an explanation as to say that sweetness is a property of sugar. for in the last analysis, what is matter - what is space-time? If we say that matter is an aggregate of molecules, atoms, electrons, protons, what of it? What are electrons? What are protons? We can only confess to our complete ignorance and, while attempting to reduce the number of these unknown fundamental entities to a minimum, content ourselves with describing the properties which appear to characterise them and the relationships which appear to connect them. Clearly, those who seek explanations will find no comfort in science They must turn to metaphysics."

In other words, we must not expect our theories to do that which they are unable to achieve. But theories are not just sterile descriptions. They are creative and fertile inasmuch as they enable us to attain some modicum of control over nature even if we are unable to understand the ultimate reality underlying it. Theories, then, provide us with a knowledge as to the 'how' of things and they generally achieve this result by the utilisation of models which allow the process requiring explanation to be seen as analogous to one commonly accepted as being self-evident.

It will be convenient, at this stage, to introduce the concept of a model and to illustrate the employment of the kind of model commonly used to exemplify the processes with which physical theories are concerned. A scale-model is probably the most familiar type, consisting only of an exact copy of something but of reduced size. We shall, however, concern ourselves with a kind of model usually called a paramorph,[13] which is used extensively in scientific theory construction and represents the process under consideration by means of some analogous system. We can illustrate the use of such a model by a consideration of Bernoulli's theory of gas pressure to which we referred earlier in a different context. In this theory, the gas atoms can be considered to be analogous, with respect to properties deemed relevent for the description, to hard, elastic spheres approximating to the billiard balls of everyday experience. Obviously, there are certain features of billiard balls which are not intended to be useful features of the model, but we can say that the gas molecules and the billiard balls have sufficient properties in common (within the confines of the particular theory) to enable the latter to be a useful paramorph of the former. It should also be noted that the above analogy could only be forwarded as such if the general conceptual system currently in use recognised the existence of atomistic entities and other fundamental properties and relationships, for example, motion and transfer of momentum by physical contact.

The type of model just described suffers from the limitation in that it is derived from our everyday experience and thus can be used only to partially represent the behaviour of some entity far removed from any direct experiential contact. While in some instances it is convenient to speak of atoms or molecules as being analogous to billiard balls, we need to use other models if we wish to attain some visualisation of other aspects of these entities. Thus, in speaking about the electronic structure of atoms, we may find a convenient paramorph in the solar system, but now we are faced with an unexpected difficulty. Whereas the billiard ball analogy provided us with a paramorph which was able to account for the majority of the facts which constituted the empirical content of the theory, the solar system - atom analogy falls far short of the degree of correspondence required for it to qualify as a viable paramorph. To attain a clearer visualisation of atomic structure, we need also to introduce the concepts of 'stable electron standing wave patterns', 'energy quantisation', 'non-identifiability of individual electrons', in short, concepts which are alien to our everyday experience of particles. The two models, particle and wave, are logically incompatible when applied simultaneously to the atom, but both are required if anything approaching a viable description of the atom is to be achieved. This logical problem of quantum physics has been described by Mary Hesse in the following manner.[14]

"What has happened is that the models of particles and waves, which are inherited from classical physics, have both thrust themselves upon our attention as obvious explanations of certain kinds of experiments in atomic physics; but when the next steps are taken to try to decide between the alternatives, and to extend one or other of them to cover new data, we find that both succeed and both fail, in a way unheard of in classical physics. When we try to describe in detail the processes going on in an experiment, for example the one with electrons passing through the two holes, we find that both models are required, and yet this seems to involve us in saying that the electrons are sometimes particles and sometimes waves, and that what they are observed to be depends entirely on the way we choose to investigate them."

We are able, of course, to utilise a mathematical model which can be developed from consistent axioms and rules and will, therefore, be fully self-consistent, but this approach requires the abandonment of any hope of arriving at a visualisable analog. The resulting formalisation, which enables the interconnection of various observed states to be achieved, is a constructed model whose analogy is not forced upon us (as are the models of classical physics) nor derived by abstraction from experimental results. The formalisation must be deliberately sought and this rules out the use of macroscopic processes as models in situations far removed from everyday experience.[15] It may, of course, be argued that this latter concept of a model is not really a model at all but merely constitutes a restatement of the definition of a theory. The point is debatable. Whether a theory uses a physical system as a model or whether it utilises its own formalised infrastructure to draw correspondences between what is observed and the entities, properties and relations it holds as basic, the end result is the same. Although we may feel more comfortable if we are able to attain some degree of visualisation of the process under investigation, is our understanding of the underlying 'reality' really more enhanced if we explain the emission of light by an atom in terms of 'electron jumps' or by the manipulation of matrix mechanics variables? Maybe so. But this would have to be justified by a purely subjective feeling on our part because neither explanation can tell us more about the phenomenon than can the other.

In the discussion to follow, it will be of interest to see how the various conceptual systems determine the questions which may be asked regarding the nature of the world. At any particular time in history, more than one general conceptual system may be in use. Often no justification for the choice of one over the other can be given because a precedence (logical or otherwise) of one set of premises over the other does not exist at the time. Both sets are equally valid and a choice between them is possible only in retrospect. It is also important to remember that, given a change of conceptual systems, a change in the meaning of the entities, properties and relations also occurs even though the same descriptive words and phrases may still be used in the new system.[16]

THE GREEK HERITAGE

To begin our survey into the history and philosphy of natural science, we shall take as our point of departure the speculations of Greek thinkers, from about 600 BCE. For it was, perhaps, at this time in that part of ancient Greece known as Ionia, that the questions concerning the nature of the physical world were initially raised and hotly debated. The earliest metaphysical systems attempted to derive the various forms of matter from a single primary 'stuff'. The exact nature of this material varied with the whims and fancies of its proponents, but perhaps an idea of the essence of primary 'stuff' can be gleaned from this description of it by Aristotle (third century BCE), who wrote.[17]

"Of the first philosophers, then, the most thought the principles which were of the nature of matter were the only principles of all things. That of which all things that are consist, the first from which they come to be, the last into which they are resolved (the substance remaining, but changing in its modifications), this they say is the element and this is the principle of things, and therefore they think nothing is either generated or destroyed, since this sort of entity is always conserved....."

We can see now that at the first stage of philosophy, the physical world was to be explained with the use of a primary substance. This substance was regarded as given, i.e. its origin was not sought, and from it all other things came to be via the agency of various transformations which left the primary substance unchanged. What we observe, as constituting our physical world, are merely forms resulting from these transformations.

Interestingly enough, the candidate for primary substance chosen by Thales was none other than water.[18] Though perhaps it was too concrete a concept to allow compatability with the rather nebulous idea of primary substance, this choice does justify itself by a number of observations made at the time:[17]

> "... getting the notion perhaps from seeing that the nutriment of all things is moist, and that heat itself is generated from the moist and kept alive by it (and that from which they come to be is a principle of all things). He got his notion from this fact, and from the fact that the seeds of all things have a moist nature, and that water is the origin of the nature of moist things."

If the choice of Thales was a little too concrete, that of his contemporary Anaximander[19] was characterised by the 'indefinite' (perhaps a little too vague to be operationally useful). Anaximenes[20] proposed that primary substance was 'the breath'. This concept, although still somewhat vague (did he mean air or something more metaphysical and elusive?), nevertheless proved to be an extremely important one because, in order to enable the 'breath' to produce particular forms of matter, two related but opposing concepts needed to be introduced: condensation and rarefaction. The necessity of these accompanying postulates marked the withdrawal of philosophers from the aim of explaining the world in terms of a single, all embracing concept. Later philosophers realised that any satisfactory explanation of the origin of matter and its forms required a plurality of basic concepts.

In the mid fifth century BCE, Empedocles[21] proposed as elements of nature the four substances, fire, earth, air and water. Two accompanying postulates, characterised as 'love' and 'strife', accounted for the association or disassociation of the elements which resulted in the formation of the observed forms in nature. Were it not for the development of this system into a coherent and rational one by Aristotle, it seems doubtful that the scheme as proposed by Empedocles would have retained many adherents. Aristotle's elegant transformation of this system was to last some two thousand years before being overthrown by experimental mechanics in the seventeenth century. He refined Empedocles' concept of element, preferring to consider fire, earth, air and water not as simple but already blended.[22]

> "Thus the 'simple' body corresponding to fire is 'such-as-fire', not fire, that which corresponds to air is 'such-as-air', and so on with the rest of them".

Basically, this refinement means that all that we perceive in the world of phenomena is only formed matter. The actual matter, the primary substance, should only be partly identified with some special property such as fire or air; its only attribute is to be that from which everything is made. Primary matter must not be considered to be a reality but only a possiblity, a 'potentia'; it exists only by means of form.[3] In addition to this refinement of the concept of primary substance, Aristotle further elaborated upon Empedocles' scheme and introduced combining qualities (which governed the type of combinations allowed between his elements) and integrated these concepts into a consistent deductive system.[22,24]

> "The elementary qualities are four ... contraries, however, refuse to be coupled, for it is impossible for the same thing to be hot and cold, or moist and dry ... the couplings of the elementary qualities will be four, hot with dry and moist with hot, and again cold with dry and cold with moist. And these four couples have attached themselves to the apparently 'simple' bodies (fire, earth, air and water) in a manner consonant with theory. For fire is hot and dry, whereas air is hot and moist (air being a sort of aqueous vapour); and water is cold and moist while earth is cold and dry".
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> "Air, for example, will result from fire if a single quality changes, for fire, as we saw, is hot and dry while air is hot and moist, so that there will be air if the dry be overcome by the moist. . . "

As may be seen, Aristotle's system had considerable predictive and explanatory powers which its precursor (that of Empedocles) never possessed. In fact, it has been proposed that the Aristotelian concept of 'potentia' can be reconciled with that of energy within modern relativity. For when matter, the elementary particle of modern physics, is created from the high energy of impact during collisions, we may interpret this phenomenon as the 'potentia' (energy) getting into 'actuality' by means of the form (the elementary particle).[25] However, we must now move on to consider another philosophy of matter which was being formulated at about the same time as Empedocles proposed his scheme of four elements. This was atomism.

Parmenides had exposed a paradox which was implicit in the various theories of primary matter. It ran something like this.[26] Primary matter was all-pervasive and constituted the **plenum**, the 'full'. As formulated, it admitted of no void and hence, necessarily, of no changes. From 'what is' there could not arise 'what is not' and this contravened the evidence of the senses. This paradox arose because the concept of 'fullness' did not admit of degrees and so the various processes by which transformations of the primary substance were postulated to occur (such as compression or rarefaction) could not logically occur at all. This conclusion exposed a major flaw in the philosophies of people like Thales, Anximander and Anaximenes because their concepts of primary matter, whether vague or concrete, were too closely modelled on the tangible stuff of nature and naturally led to the paradoxical conclusion already described. Aristotle, however, by reducing his concept of primary matter to the abstract 'potentia', could overcome this paradox since his **plenum** was constructed of an entity devoid of quality and physical reality. It merely possessed the ability to attain form and so could not be thought of as occupying space in the same manner as the primary matter of the earlier philosophers. However, since this paradox was noted before the advent of Aristotle's philosophy of matter, another approach was attempted.

Leucippus and Democritus proposed that the whole of experience could be described by the changing associations of minute particles which they called atoms.[27] These tiniest particles were thought of as being indivisible and eternal. They were impenetrable and each atom was identical with every other atom - the latter description differing from that of the atom in modern chemistry which is considered to consist of three fundamental particles (proton, neutron and electron). It is of interest to note that the concept of the atom in ancient Greece, rather than being derived from experience as were the four elements of fire, earth, air and water, was in fact, a pure figment of metaphysical fancy which provided a fruitful answer to the paradox of the Parmenedian changeless **plenum**. Change could now be explained by invoking the concept of the atom as being the smallest indestructible amount of matter, the re-arrangement of these atoms accounting for the perceived changes on our macroscopic scale. However, the very suggestion of atoms in motion required the presence of a void within which these atoms could move about. This concept of a void was, of course, in direct contrast to the **plenum** of primary substance philosophy and so explained the unacceptability of atomism to Aristotle. As we shall see at a later stage in this article, the atomists also needed to account for the origin of motion, a postulate not required by Aristotle who had introduced the idea of 'natural place' to explain this phenomenon.*

Slightly antedating the ideas of Leucippus and Democritus were those of the Pythagorean school. Its ideas were the most abstract and mystical of this period of Greek thought. Geometric and arithmetic concepts were combined and number was given a reality, an existence of its own, apart from the everyday objects that it served to quantify.[28] Plato[29] combined the ideas of this school with the four traditional elements and associated a geometrical solid with each element. fire - a tetrahedron, earth - a cube, water - an icosahedron and air - an octahedron. These associations were made on the basis of the defining qualities of the elements and he supposed that all these bodies were sufficiently small that a single body of any one of these kinds was invisible. However, another step was taken by then reducing each of these bodies - the geometrical solids - into their component triangles from which the bodies could be reconstituted by combination of the triangles. This effectively reduced the concept of matter to one of elementary mathematical form (the equilateral triangle) and so, at the end of this process, we arrive at something which is no longer material but purely an intellectual construct. In the final triumph of the abstractive faculty, matter, the tangible, had been reduced to an intangible form, the latter being then argued to possess a greater claim to reality than the matter from which it had been abstracted. From these speculations arose the controversy of dualistic philosophy, mind and matter, idealism and materialism, which has in its history produced such contrasting views as those of Berkeley,[30] who argued that the very existence of matter depended on its perception by mind, and Hobbes's materialistic arguments for the undeniable reality of the world of matter.[31]

* Compare with the interpretation of motion in general relativity theory **(vide infra)**.

THE CLASSICAL VIEWPOINT

In the mid seventeenth century, Descartes[32] clearly distinguished between matter and mind within the framework of the recently developed science of mechanics and the mathematical experimental method pioneered by Leonardo da Vinci, Tartaglia, Benedetti and Galileo Galilei. Descartes saw that mind and matter were two complementary aspects of the world. Since the matter of this period (atomistic) was regarded as being already formed (contrasted against the unformed 'potentia' of Aristotle), it could be considered as a reality independent of mind. At this point, it will be convenient to discuss the rise of the Newtonian conceptual system and the status of matter within it. We will be able to see that the obvious successes of this system and the relative simplicity of its models imbued it with an attraction which has survived the advent of relativity and quantum theory. It is precisely its attractiveness as an explanatory system that has produced some of the confusion inherent in the concepts of modern physics because the terms of reference of classical physics are invoked for situations where they are no longer relevant or applicable. The understanding of the status of matter in classical or Newtonian physics requires some appreciation of its relation to the associated concepts of space, time and motion and it is with these points in mind that we begin an examination of the Newtonian synthesis.[33]

In classical physics, space was regarded as an homogeneous medium which existed independently of its physical content. The axioms of Euclidean geometry described it and the resulting three-dimensional co-ordinates defined any position within it. Because space was homogeneous, each position in space was geometrically equivalent to every other position which, in turn, required that space be also infinite and unbounded. Since all positions in space were qualitatively identical, their only distinctions consisted of their relations of juxtaposition or co-existence. Two simultaneous events could be distinguished only through their juxtaposition in space. Put another way, all points in space were qualitatively similar and distinguished only by the mere fact that they lay outside each other. The homogeneity of space also implied its infinite divisibility and this result led to an interesting paradox. Juxtaposition related any pair of geometric points, and, no matter how close they were, there was always an interval which separated them. Moreover, these points were external to each other and so the claim that certain intervals of space were indivisible indicated that, within these intervals, no juxtaposed points could be discerned. But this conclusion meant that these intervals were therefore devoid of spatiality, 'holes' in space, if you like. Hence the attribute of indivisibility can belong only to the points which must therefore be of zero length, whatever that may mean.

Space, in classical atomistic science, was logically prior to matter, its material content. Matter was defined as 'full space', a concept which accounted for a small sub-class of tactile sensations - those of contact and resistance - and so possessed the special privilege of disclosing the nature of physical reality. The objectification of resistance was impenetrability ('full space') and this was regarded as the very essence of matter. Matter was regarded as occupying space and this made it into an almost accessory concept; for if matter was 'full space', then it necessarily required space for its existence. Conversely, space could exist without matter, but simply the existence of space could not logically imply the existence of matter. When contrasted with the homogeneous, immutable and eternal space, matter became a contingent, rather than necessary, concept. For a consistent kinetic-corpuscular theory of nature, it was assumed that certain volumes of space were filled and thus constituted what we call physical bodies. The indivisibility of the constituent particles followed from the basic definition of matter, for what is 'full' cannot be 'fuller', and the proposition that two bodies cannot occupy the same space at the same time was a logically necessary one. Although Leibniz[34] and Descartes[35] argued that matter shared with space its infinite divisibility, their claim may be dismissed by distinguishing between geometric and mechanical divisibility, for the very fullness of the constituent particles of matter precluded their further **physical** division. Furthermore, the constituent particles were considered to be constant in their mass, shape and volume. Even when the various chemical elements were shown to differ in their relative weights and volumes, Prout[36] was led to suppose that the so-called elements were, in fact, multiples of a more basic unit for which he proposed the atom of hydrogen. On this topic we may also recall the earlier statement of the chemist Robert Boyle who was the first to give an essentially modern definition of the atom, a substance perfectly homogeneous and not, so far as we know, capable of further simplification.[37] Maybe, through some intuition of the difficulty of recognising a substance for what it was, he wisely contented himself with defining the concept. Despite the problems inherent within the concepts of constituent particles, atoms and elements, there was nevertheless a strong belief in the permanency of matter which could be traced back to ancient Greece.[38]

Being is and cannot be thought of as nonexisting, nothing can be predicated of it except that it exists in an eternal and changeless fashion. This belief was formulated into the Law of Conservation of Matter by Lavosier when he wrote [39]

> "We may lay it down as an incontestable axiom, that, in all the operations of art and nature, nothing is created, an equal quantity of matter exists before and after the experiment; the quality and quantity of the elements remain precisely the same; and nothing takes place beyond changes and modifications in the combination of these elements."

Dalton expressed a similar view perhaps a little more concisely.[40]

> "We might as well attempt to introduce a new planet, or to annihilate one already in existence, as to create or destroy a particle of hydrogen."

A paradoxical difficulty of the atomistic philosophy lay in the fact that the properties of atoms could be derived from the basic definition of matter but the existence of the atoms themselves was not implied in it. Their existence must be assumed and then many of their properties logically follow - except the size of the atoms. In fact, the only justification for choosing atoms of minute dimensions was of an empirical nature: they were required by our experience. In the final analysis, the existence of atoms of a finite size was no more than a stubborn and irreducible datum.

Another fundamental concept of classical physics is that of time. Whereas the defining property of space was that of juxtaposition, the defining property of time was succession. In space, the various referential points were beside one another; in time, the instants followed one another. Like space, time was regarded as homogeneous and the basic properties of time - its independence of physical content, infinity, continuity and uniformity - followed from its homogeneity. Changes took place in time but were not time itself (here we are speaking of Newtonian absolute time and not the apparent time which may be estimated by the motion of physical bodies) and the absence of change did not effect the flow of time. Just as matter could not be derived from the concept of space so motion could not be derived from time - "time, if not de facto, at least de iure, is empty".[41] For it was only the independence of time from change that made it possible to assign different moments of duration to events persisting without change. The experience and its repetition were different if only because of their successive relationship in time. In this sense, time was analogous to space, being a principle of differentiation of a kind other than qualitative. From the homogeneity of time followed its infinite divisibility for, no matter how small a temporal interval was considered, it always fell into the realm of succession and so each interval could always be further sub-divided. If, perchance, some smallest interval did exist, an 'atom of time', then within this interval the temporal flux would be stationary - which led to the contradictory conclusion that there existed intervals of time which were not temporal. Time was also thought to contain space for, when it was said that motion occurred in space, it was thereby implied that the successive positions of the moving body were associated with successive instants in time. This meant that physical reality could be represented by an infinite series of successive instantaneous spaces which were qualitatively identical and differed only in their temporal placement. This interpretation required that there existed a universe-wide instantaneous 'now', which in turn required that time was absolute or that time was relative but instantaneous causal chains (no upper limit of velocity) operated. Needless to say, the classical concept of time was changed beyond recognition under Einstein's relativity theory. Even within the kinetic-corpuscular theory, the status of time was degraded to being merely a human convenience after the advent of Laplacian determinism. The philosophy of materialistic determinism will be further discussed after a consideration of motion from the stand-point of Newtonian mechanics.

The reality of motion may be said to have been the rationale for the postulation of discontinuous primary matter. The basically relative nature of motion derived from its necessary reference to a set of spatial co-ordinates. Absolute space was totally immovable and entirely independent of its physical content and so a body in motion, with respect to absolute space, was in absolute motion. For Newton, this absolute motion was, at least in principle if not in practice, calculable.[42] However, he was unable to give any indication as to how the origin of the spatial co-ordinates of absolute space could be operationally defined. In any case, even the concept of absolute motion (rest) possessed a certain amount of relativity because the very definition of absolute motion (rest) required its relation to a certain reference system, even if this system happened to be a unique and privileged one.

Motion was continuous and admitted of infinite divisibility. The path of a moving body consisted of a series of successive moments in time which possessed a 1:1 correspondence with the associated series of juxtaposed points. The world-line of the body was regarded as the series of juxtaposed points resulting from the series of successive instantaneous spaces. Space and time were held to be the containers of motion and the thing which moved was a material body. Again we can see the logical separation of matter and motion from space and time. Movement was the displacement of something which, although it existed in space and time, was not identical with it. We may indeed ask of motion, as we did earlier with matter, why does it exist? Motion was, therefore, in the same epistemological boat as was matter. Space and time were logically prior concepts from which the existence of matter and motion could not be derived. The postulation of the existence of matter and motion was one of empirical, but not logical, necessity. Of course, once this step was taken, the rest of nature could be derived from these four concepts.

The principles of conservation of matter and motion which, in combination, explained the physical world as consisting of forms of primary 'stuff' whose secondary qualities were changed by the redistribution of motion throughout the universe, were themselves derivable from the basic postulates of matter and motion. Even the early Greek atomists were aware that the constancy of the atomic masses implied that the total amount of matter in the universe was constant. In a similar fashion, it was obvious that, since nothing but motion could be a cause of motion, and nothing but motion could be an effect of motion, the total amount of motion in the universe must necessarily also be constant. At this point we can digress momentarily and investigate one world-view which was the logical consequence of mechanism, the elimination of past, present and future as unique temporal occurrences. The name of this philosophy was materialistic determinism (also called Laplacian determinism).

THE ELIMINATION OF TIME

Briefly, determinism was derived from the principles of conservation of matter and motion when they were examined within the conceptual framework of temporal spatialisation. The tendency of the mechanists to picture time as a one-dimensional axis reaching from the infinite past to the infinite future easily lead to the suggestion that all future states of the world were, in fact, already formed. It was only the inability of physical beings to perceive these future states of the world that gave rise to the concept of novelty. Since the future was assumed to be causally related to the present, it was thought that a complete knowledge of the present state of the universe must enable the prediction of any future state to be made. But if a future state of the world could be predicted, it would mean that all the qualities by which it would be recognised must exist now - the very word 'future' becomes meaningless. Logically, when it is stated that a conclusion follows from its premises, we mean that the conclusion is **entailed** in the premises, i.e. the conclusion and the premises are **contemporaneous** and it is absurd to claim that the word 'follows' has any temporal significance whatsoever. Moreover, since time was considered to be of infinite duration and the phenomenal content of the universe (matter and motion) was constant, probability theory led to the conclusion that every possible state of the universe must necessarily repeat itself an infinite number of times. At this stage, any concept of time became merely a convenience which no longer possessed any operational meaning. Novelty was a meaningless concept and eternal recurrence was the logical consequence of mechanism, the iron-clad rule of absolute necessity replaced the contingency of world configurations.

THE MECHANICAL MEDIUM

The last feature of the kinetic-corpuscular philosophy which should be considered was its repeated attempt to eliminate the idea of 'action at a distance' by maintaining that every interaction between material bodies was due to direct mechanical impact or pressure. The illusory nature of 'action at a distance' was repeatedly stressed. Electromagnetic radiation moved through space only by virtue of the underlying 'aether', an hypothetical medium consisting of 'aether particles' of undefined size and mass. Indeed, so imbued with the mechanical spirit were scientists of the last century that the ingenious 'aether' model constructed by Maxwell was a remarkable piece of engineering - wheels within wheels.[43] This 'aether' also needed to provide an explanation of the transfer of gravitational energy and now its mechanical properties became more extraordinary and self-contradictory. Gravitational energy, unlike electromagnetic energy, was thought to be transmitted instantaneously over all space. This type of transmission (infinite velocity) required that the 'aether' be massless and continuous, i.e., there could be no void between material bodies, only the 'aether'. Needless to say, such a proposal was totally unacceptable within a corpuscular philosophy. The only way out of this conundrum was to accept that gravity was transmitted with finite velocity for this would again allow a corpuscular 'aether' to the medium of transfer.

These mechanical 'aether' models were, however, an unavoidable consequence of the kinetic-corpuscular philosophy. When radiant energy was transferred between two bodies, the question necessarily arose as to what happened to the energy in the interval between its emission by A and its reception by B. The only answer consistent within a mechanistic framework was that the energy existed as the kinetic energy of the surrounding medium, i.e. the 'aether' particles. Potential energy, although often used in classical physics as a convenient mathematical device for keeping the total amount of energy constant, was only at best a disguised form of kinetic energy. For example, the raising of a weight above the surface of the earth was stated to increase its potential energy. However, the source of the potential energy came, not from the gravitational field, but from the kinetic energy of the 'aether' particles which, by impinging on the weight, caused it to fall (the view of Leibniz).[44] A similar view of potential energy was held by Huygens[44] who explained the motion of a pendulum as being due to the reciprocal transfer of kinetic energy between the pendulum bob and the surrounding 'aethereal' particles. It comes as no surprise that the cumbersome 'aether' theory was the first victim of the relativity theory. Deprived of a troublesome but essential concept, the kinetic-corpuscular theory was open to the further transformations required to erect the conceptual framework of contemporary physics.

SPECIAL RELATIVITY – MASS IS ENERGY

After Maxwell had developed his mathematical field equations to describe the variation of electromagnetic potential around a charged body, it was found that these equations were not valid when applied to a charged body in uniform motion.[45] This result was not reconcilable with the basic requisite that every physical law of nature remained valid irrespective of whether the system in which the law was applied was stationary or in uniform motion. The difficulty arose because one of the co-ordinate transform rules of classical physics, the additivity of velocities theorem, could not be applied in the case of inordinately high velocities approximating to the speed of light. Einstein, by holding in addition to the postulate of equivalence of inertial systems, the new postulate that the speed of light was a limiting and constant velocity irrespective of the velocity of the particular inertial system,[46] was able to derive a set of co-ordinate transform equations (the Lorentzian set) which made Maxwell's equation valid for moving charges. At the same time, the special relativity theory also eliminated the electromagnetic 'aether' because, the properties of empty space being always the same, the 'aether' became superfluous and unobservable.*

The main impact of special relativity, as far as the theory of matter is concerned, arose from the type of transform equations used by it. As a logical consequence of Einstein's new law for the composition of velocities, the mass of any particle of matter became a function of its velocity.[47] What now of the fundamental postulate of classical atomistic physics, the masses of the elementary units of matter are constant? It must also be mentioned that, in the kinetic-corpuscular theory, the absence of any upper limit to the velocity of a body was merely another indication of the indifference of classical space to physical changes taking place within it. Now, however, with the existence of an upper limit to increasing velocities, it may be implied that there is a structure of some sort inherent within the space-time manifold of relativity theory which manifests itself through this limiting property. Furthermore, special relativity showed that matter and energy were interconvertible and so further dimmed the distinction between material bodies and their surrounding space. That total mass of any aggregate was no longer the simple arithmetic sum of its corpuscular components, but depended also on the equivalent mass of the energy which bound these corpuscles together.

* For a fuller discussion, interested people may consult any textbook on modern physics for a description of the Michelson Morley experiment and its re-interpretation under special relativity.

Other classical concepts which were altered under special relativity were those dealing with successive instantaneous spaces, temporal irreversibility of noncausally related events, the world-wide 'now' and the simultaneity of distant events. The physicist's view of the world was transformed beyond recognition.

GENERAL RELATIVITY – GRAVITY AND SPACE-TIME CURVATURE

With the development of general relativity theory, acceleration and gravity became indistinguishable in effect and Euclidean space was replaced by the curved spatial geometry of Reimann. An interesting interpretation of matter and motion now became possible. Under general relativity the gravitational **field**, not the associated **matter**, became the important concept for describing physical phenomena.[48]

> "We could regard matter as the regions in space where the field is extremely strong. In this way a new philosophical background could be created. Its final aim would be the explanation of all events in nature by structure laws valid always and everywhere. A thrown stone is, from this point of view, a changing field, where the states of greatest field intensity travel through space with the velocity of the stone. There would be no place in our new physics, for both field and matter, field being the only reality."

In other words, the space-time equations of Einstein's general relativity theory represent energy distributions throughout the universe. The energy field is the reality and matter is the 'form' it takes where it is highly concentrated. Moreover, the curvature of the space-time field is particularly accentuated in the vicinity of these 'pockets' of matter. Since motion can only occur along the curved space-time geodesics (which are equivalent to the shortest distance between two points, the straight lines, of Euclidean geometry), an explanation of uniform and accelerated motion can be presented in the following manner. A small mass occupies a given portion of the space-time field at the position A and there are no other masses nearby. The energy field in the vicinity of this mass is nearly uniform (**i.e.**, the surrounding four dimensional potential surface is 'flat') and so the mass remains stationary. For a visualisable analogy, consider the energy field as a stretched rubber surface and the mass as a small marble lying on this surface. There is a slight depression around the marble and this serves to illustrate the space-time curvature associated with the energy field which constitutes the particle. Now place a heavy iron ball on the rubber surface in the vicinity of the marble. The large depression so formed causes the marble at the top to accelerate towards the iron ball under 'gravitational' attraction. If the iron ball is removed before the marble collides with it and stops, the marble (assuming a frictionless surface) will now continue to move in uniform motion. Returning to the situation where the mass occupies position A and now, if another mass is placed in the vicinity of A, the resulting curvature of the surrounding four dimensional potential surface will cause the phenomena we identify with gravity and motion.

We now see that mass can be interpreted as the focus of curvature of a space-time potential field, and, because the field equations become discontinuous at the 'interface' of matter and field, we can interpret the impenetrability of matter as resulting from the non-existence of real solutions of the field equations, **i.e.**, there is no space-time within matter. Matter may represent the boundary between space-time and a region where space-time has no meaning, impenetrable in a meaning of the word which is **not understandable** from either the standpoint of **language** or **dimensionality**.

THE QUANTUM CONCEPT

The second major transformation of the kinetic-corpuscular theory came from the development of Planck's quantum theory by Einstein, Bohr, Heisenberg and others. In 1900, Planck had published a paper in which he re-examined the problem of accounting for the energy distribution that was experimentally observed in black-body radiators.[49] Classical theory had predicted that the energy emitted by these radiators should be continuous, **i.e.**, all energy values should be represented in the emission spectrum. The observed emission spectra could not, however, be reconciled with the classical scheme. Planck's radical contribution to physics was the introduction of the concept of small finite units (the **quanta**) of energy which accounted for the observed black-body radiation. Needless to say, the suggestion that energy could be emitted only in discrete 'packets' or quanta was quite unacceptable within the traditional framework of physics. Planck himself was dissatisfied with this concept and attempted to reconcile his new hypothesis with the older laws of radiation but was unable to do so. It was not for another five years that further development of the quantum concept occurred when Einstein showed that the well-known photo-electric effect (the emission of electrons from metals under the influence of light) could be explained using the quantum idea.[50] Earlier experiments had shown that the energy of the emitted electrons depended not on the **intensity** of the incident light but on its colour, **i.e.**, on its **frequency**. This result could not be understood within the classical interpretation of radiation but could be explained by assuming that light consisted of quanta or 'packets', the absorption of which transferred a discrete amount of energy to the electron (equal to Planck's constant multiplied by the frequency of the incident light).

It was, perhaps, with this application of the quantum hypothesis that the breakdown of the classical wave picture of light became evident. The continuous light wave and the discontinuous energy packet were two quite incompatible concepts and yet both together accounted for the then known properties of light – the wave theory for diffraction and interference and the quantum hypothesis for the photo-electron effect and, at a later stage, the Compton effect (scattering of electrons by electron-quantum collision). These 'particulate' effects of light may be understood a little more readily if we remember that energy and mass are interconvertible through Einstein's mass-energy equation ($\mathbf{E=mc^2}$) and so we are able to calculate the mass of a light 'particle' (now called the photon) for light of any frequency; the energy of this light being given by the Planck equation ($\mathbf{E=h}\nu$ where $\mathbf{h}$ is Planck's constant and ν is the frequency of the light).

WHEN IS A PARTICLE NOT A PARTICLE?

Of course the obvious question now arises, if light has particle properties, does matter have wave properties? The Frenchman, Louis de Broglie, published an important paper during 1924 in which he stated that all matter in motion (**i.e.**, possessing momentum) had associated with it wave-like properties.[51] The wavelength of this 'matter-wave' was given by the equation $\lambda = h/\mathbf{p}$ where λ is the wavelength, $\mathbf{h}$ is Planck's constant and $\mathbf{p}$ is the momentum (the product of mass and velocity) of the particle. The viability of de Broglie's postulate could be demonstrated by passing a stream of electrons through a crystal lattice (which served as a diffraction grating) and noting that a diffraction pattern was formed on a screen set behind the crystal.[52] So now matter could no longer be identified with the impenetrable little ball of the kinetic corpuscular theory. Not only had matter been transformed into a space-time discontinuity under general relativity, a material manifestation of an underlying space-time energy manifold, it also possessed wave properties. With the advent of de Broglie's postulate, it became possible to provide some explanation for the quantisation of the electron orbits in the Bohr atomic model.

In 1913, Neils Bohr had proposed an atomic model which accounted for the observed emission spectrum of hydrogen but which also remained somewhat of an enigma because the model required that certain regions of space surrounding the nucleus were forbidden to the electron.[53] In the classical concept, space was homogeneous and indifferent to any physical content. Hence the suggestion that 'privileged' and 'underprivileged' spatial zones occurred stood in contradiction to the postulate of the equivalence of all spatial points. Put another way, the quantisation of the electron orbits accounted for the observed experimental data, but was not explainable within the classical paradigm. Through de Broglie's work, it became possible to account for these allowed electron orbits by considering the electron as a wave and not as a particle.[54] For just as the wavelength of a musical note determined the lengths of the organ pipes which allowed stable standing wave systems to be set up, the wavelength of the electron determined the sizes of its orbits since only orbits of certain dimensions could support stable standing wave patterns. An electron could change from a higher to a lower energy orbit only by the emission of electromagnetic radiation, the energy of which was equal to the energy separating these two orbits. The emission of a smaller amount of energy would not enable the electron to reach the next lowest stable orbit and so these emissions were 'forbidden' and, consequently, not observed.

The concept of electron waves was taken a step further by Schrodinger who developed a mathematical description of electronic structure later called wave mechanics.[55] By treating the electron orbits as standing wave systems, Schrodinger was able to derive the quantisation conditions mathematically. The solutions to his wave equation were mathematical functions which could be used to describe the probability of 'finding' the electrons at chosen spatial positions around the nucleus. From these calculations, contours of equal 'electron probabilities' could be constructed around the nucleus and these defined the general shapes of the electron orbits, or more correctly, the stable standing wave patterns. Note, however, that the electron of wave mechanics is no longer a definitely localisable entity and should rather be considered to be 'smeared' over regions of high electron occurrence probabilities. Within wave mechanics, the electron is interpreted to be a standing wave energy pattern and not a defined particle occupying a certain spatial position.

THE PARTICLE IS NOT AN IDENTIFIABLE INDIVIDUAL

Perhaps the modification of our concept of particle that we are most loath to dispense with is one which requires us to abandon the hope of being able to locate it within space-time to an arbitrary degree of accuracy. Even if the particle is to be considered as a discontinuity within a space-time energy manifold, or as 'smeared' over regions of high occurrence probability in Schrodinger's wave mechanics, it is still felt that at least some definite localisability can be ascribed to it. Erwin Schrodinger has stated the problem in this manner.[56]

> "I believe the situation is this. We have taken over from the previous theory the idea of the particle and all the technical language concerning it. The idea is inadequate. It constantly drives our mind to ask for information which has obviously no significance. Its imaginative structure exhibits features which are alien to the real particle. An adequate picture must not trouble us with this disquieting urge; it must be incapable of picturing more than there is; it must refuse any further addition."

Within the framework of classical physics, the momentary state of a particle could be fully described because two independent data were simultaneously obtainable to an arbitrarily high accuracy. These independent data sets, like momentum and position, or energy and time, cannot be simultaneously determined to a high degree of accuracy within the framework of modern quantum physics. The product of the components of either of the above data sets can never be smaller than Planck's quantum of action constant, **h.** This means that either one component of the data set may be determined with arbitrary accuracy provided no store is set on the other. Both components of the data set cannot be determined together with absolute precision. The mathematical description of this indeterminacy condition was formulated by Werner Heisenberg in the following manner.[57]

$$\Delta p . \Delta x \geqslant h \quad \text{or} \quad \Delta E . \Delta t \geqslant h \qquad (\geqslant \text{ means greater than or equal to})$$

where **E** represents energy, t is time and **x** is position. The other symbols have been identified in the preceding pages. The indeterminacy relationship expressed above should not be interpreted as being due to a lack of finesse in experimental techniques which can be remedied, at least in principle if not in practice, by more sophisticated technology. This relationship refers to the particle, but the particle is not an **identifiable individual.**

It would, perhaps, be helpful if this lack of individuality concept could be somewhat clarified, and it is to this end that a detailed examination of a section of Schrodinger's 1934 Nobel Prize Address is now presented. An epistemological analysis of the concept of matter is presented in the following manner.[58]

> ". . . a piece of matter is the name we give to a continuous string of events that succeed each other in time, immediately successive ones being as a rule closely similar. The single event is an inextricable complex of sensates, of associated memory images, and of expectations associated with the former two."

Carrying on with this line of argument, these sensates prevail and we eventually come to classify the perceived matter into a number of categories once recognition of its nature is achieved. Certain expectations associated with this recognition then come into existence and are subsequently fulfilled or disappointed. Familiarity with the object grows and the increasing esoteric informational content derived from it gradually causes a decrease in dependence upon the momentary sensational aspects of it. The object has now achieved an existence irrespective of whether it is sensed or not. Its esoteric informational content, **e.g.,** melting point, solubility, crystalline structure, now serves to identify the object.[59]

> "After a certain wealth of association has come to outshine the core of sensates, the latter is no longer needed to keep the complex together. It persists even when the contact of our senses with the object temporarily ceases. And more than that, the complex is latently

conserved even when the whole string is interrupted by our turning away from the object to others and forgetting all about it . . .
When a familiar object re-enters our ken, it is usually recognised as a continuation of previous appearances, as being the same thing. The relative permanence of individual pieces of matter is the most momentous feature of everyday life and scientific experience."

It is, however, not possible to transfer the characteristic of identifiability from the gross matter of every-day experience to the sub-atomic particles of modern physical theory. For although single particles are implicated in the formation of a cloud-chamber track or in the practically simultaneous discharge of a couple of Geiger counters placed several metres apart, the dignity of being an identifiable individual is denied to the particle. The reasons for this change in attitude derive from the type of statistical counting system the elementary particles are experimentally observed to obey. To illustrate this statement, Schrodinger distinguishes between classical statistics and the two newer counting systems (called Bose-Einstein and Ferm-Dirac statistics respectively) in the following manner.[60]

"(a) The two rewards are two memorial coins with portraits of Newton and Shakespeare respectively. The teacher may give Newton either to Tom or to Dick or to Harry, and Shakespeare either to Tom or to Dick or to Harry. Thus there are three times three, that is *nine*, different distributions (classical statistics).

(b) The two rewards are two shilling-pieces (which, for our purpose, we must regard as indivisible quantities). They can be given to two different boys, the third going without. In addition to these three possibilities there are three more. either Tom or Dick or Harry receives two shillings. Thus there are six different distributions (Bose-Einstein statistics).

(c) The two rewards are two vacancies in the football team that is to play for the school. In this case two boys can join the team, and one of the three is left out. Thus there are three different distributions (Fermi-Dirac statistics)."

In these examples the **rewards** represent the particles and the boys represent the various **states** the particles can assume. It now becomes a relatively simple matter to determine which statistical system the elementary particles obey by counting the number of observed distributions of the particles between the various states. In this manner, it has been found that those elementary particles regarded as 'genuine particles' **(e.g.,** the proton, neutron, electron, neutrino and their antiparticles) follow Fermi-Dirac statistics and must therefore be regarded as individually uncharacterisable. Pauli's exclusion principle, which was needed to reconcile experimental fact with the theory of electron distribution over the atom's energy states, says that *there can never be more than one electron in a particular state.* This means that the electron's *individuality* is solely dependent upon the type of state assumed by the electron; the quality of the membership in the football team depends upon which person the membership falls, but the **membership,** and also the **electron,** is in itself **without** any defining quality. The two electrons 'surrounding' the helium atom cannot, by the exclusion principle, occupy **exactly** the same energy level (although both electrons occupy the 1s energy level, they differ in total state content because their 'axial' spins are opposed) and hence are qualitatively different (but **not** distinguishable since the electrons themselves cannot be identified). The two **states** are distinguishable since two **electrons** can be differentiated by means of them - **not** because the electrons are identifiable individuals.[61]

". . .the actual statistical behaviour of electrons cannot be illustrated by any simile that represents them by identifiable things. That is why it follows from their actual statistical behaviour that they are not identifiable things."

In other words one must not even think of the electron as being in any way 'marked' because this ideation cannot account for its observed behaviour. With regard to the Bose-Einstein statistical system exemplified by case (b) in the earlier excerpt (above) from Schrodinger's Nobel Address, this system accounts for the observed behaviour of the photon, graviton and the various pions (these particles are associated with electromagnetic, gravitational and nuclear energy fields respectively). The statistics show these particles to possess quantity but not individuality and agree with our usual concept of energy.

THE NATURE OF UNCERTAINTY

The uncertainty principle of Heisenberg has often been interpreted within the framework of operationalism, a philosophy which asserts that the meaning of any statement is identical with the operations by which it is verified, a statement which cannot be operationally verified being, therefore, meaningless. P. W. Bridgman, a leading exponent of this philosophy, has phrased his viewpoint of operationalism thus.[62]

> ". . . if we restrict the operations we use in describing physical situations to physical operations actually performed, we shall be certain not to land in contradiction. We have also suggested that we may, if we like, give up the certainty of never making mistakes, and construct our concepts in other ways, defining them perhaps in terms of properties, as is often done in mathematics, and then experiment with the structures we may erect in terms of such concepts to see whether the concepts are useful. We still have operational meaning for our concepts, but the operations are mental operations, and have no necessary physical validity.
>
> . . . operational analysis is applicable not only to the meaning of terms or concepts, but to other matters of meaning, as for example, the meaning of questions. From this point of view, I do not know what I mean by a question until I can picture to myself what I would do to check the correctness of an answer which might be presented to me."

This philosophy leads to an interpretation of the uncertainty principle which states that the experimental procedure for determining the momentum and position (or, conversely, the energy and temporal location) of the particle necessitates a transfer of energy between the particle and the measuring device and the resulting physical disturbance of the particle leads to the observed uncertainty relationship. Within quantum mechanics, the smallest energy transfer is one quantum - the actual energy content of this quantum is, however, continuously variable (energy increasing with the decrease in wavelength of the electromagnetic radiation) - and so the following situation obtains. To define the position of the particle, we need to use radiation with a wavelength equal to the size of the particle. If the particle is an electron, this wavelength must be of the order of 10^{-15} metre and the radiation quantum is, therefore, of extremely high energy. The interaction of one quantum of this energy with the electron will define the position of the electron but the momentum of the electron will be totally undetermined because of the large amount of energy transferred to it by the incident photon (Compton scattering). If we wish to define the momentum of the electron, we must use low energy radiation but now the associated increase in wavelength does not allow any exact position to be ascribed to the electron.

This interpretation of the uncertainty principle logically implies that the particle had certain values of the physical quantity being measured **before** it was interfered with - an implication not justifiable within quantum mechanics. Because the particle is not an identifiable individual, to say that the particle had such-and-such momentum or was in such-and-such a position previous to its observation is a meaningless statement; if the particle cannot, **in principle,** be individuated, it makes no sense to speak of its momentum or position except in relation to the actual process of measurement. The uncertainty relationship is, therefore, not a consequence of any operational difficulty but is, rather, a description of a limit to physical measurement inherent within the space-time field. Milic Capek, professor of philosophy at Boston University, has placed this interpretation upon the uncertainty principle.[63]

> ". . . its significance is far deeper (. . . than a mere technical limitation imposed on human observation) and indicates the presence of a real contingency in the nature of things. But if we accept this interpretation, it is evident that the impossibility of determining simultaneously the position and the velocity, or energy and time, is equivalent to the impossibility of determining the instantaneous states of the individual world lines **for the simple reason that such instantaneous states do not exist in nature.**"

A little further on, Capek adds a very concise quote taken from a 1934 paper by Sigmund Zawirski on the evolution of the concept of time.[63]

> "If the instantaneous cut of the temporal flow according to Heisenberg's formula [the form relating energy and time] leaves energy completely undetermined, does this not prove that the universe needs a certain time to take on precise forms? "

LANGUAGE AND REALITY

It is at this point that we arrive at a conceptual limit which is imposed upon us by the necessarily descriptive function of ordinary language. For,just as we are unable to explain the concept of 'red' except by example - 'this is a red object', so we are also unable to arrive at any clear concept as to the 'nature of matter' - we cannot exemplify it and we cannot concisely define its meaning. I feel that any attempt to achieve a visualisable concept of matter must necessarily result in an incomplete picture,because this procedure requires that the part (the brain) understand the whole (that of which it is composed). Nevertheless, it is possible, with the aid of mathematical constructs,to attain an understanding of the basic processes by which matter achieves its relative permanency within the space-time energy manifold, but we must not expect that these mathematical constructs correspond to any objective reality - they are merely a useful formalism which enable correlations to be made between experimental observables. The linguistic difficulties inherent in any description of physical reality within the framework of modern physics have often been noted by scientists and philosophers and the interested reader should consult the tenth chapter in Heisenberg's book, **Physics and Philosophy**, for a concise presentation of the problem.[64]

THE FIELD CONCEPT

To conclude this discussion on the concept of matter, it remains only to add a short summary of the role which the field concept plays in modern physics. These fields are really a physical description of mathematical energy distribution equations and, as such, suffer from the linguistic limitations previously alluded to. However, we may attempt to give an outline of their function by showing how the field concept allows a theoretical framework to be constructed within which matter-energy interchanges may be explained, predicted and systematised. Whether the field is the 'reality' is problematic; we can only say that the mathematics provides us with a method which, starting with empirical premises, arrives at experimentally observable conclusions - the process itself may have no counterpart in the physical world.

Briefly, then, two types of field exist. The classical field with an essentially continuous distribution of energy is associated with electromagnetic and gravitational phenomena. This type of field acts over large distances (of astronomical order) and can be invoked to explain aspects of the physical world which do not require consideration of its sub-atomic structure. The long-range effect of the classical field is connected with the type of particle associated with it - the photon (electromagnetic) and the graviton (gravitational) - which, having no rest mass, travels with the speed of light. The second type of field is the quantum field which, as its name suggests, consists of a quantised or discontinuous energy manifold. Quantum fields are effective over only extremely short distances (of sub-atomic order - say 10^{-15} metre) and account for the forces binding together the nucleons (e.g. proton and neutron). Indeed, the particles themselves - not to mention the large number of sub-atomic particles - are products of these quantum fields. The electron may interchange its quantum states by the emission or absorption of light quanta or photons. In a similar manner, a neutron may enter a more stable quantum state by the emission of energy to form a proton - this energy being lost as an electron and an anti-neutrino (the lepton pair). The next article of this series will present a discussion of elementary particles as a preamble to nucleosynthetic processes,and it is sufficient for our purposes, at this stage, simply to mention that quantum field theory may be able to provide a satisfactory explanatory framework to accommodate them.

Whether we are prepared to accept the field concept as a basic reality of nature, discontinuities within the field being manifestations of particles and/or charges, depends upon what function we ascribe to the mathematical constructs which formulate it. Or is, perhaps, the whole question of the existence of any reality underlying the mathematics unanswerable and, possibly, even meaningless? We have certainly transformed the classical concept of matter beyond recognition but, if this transformation brings us closer to understanding the essence of matter, it also shows that we must necessarily be limited in our final approach to it since we are also integral components of the energy manifold.

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