does not express the essence of thunder; there are noises in the heavens which are not thunder. Similarly, we speak of a solar or lunar eclipse as being a privation of light. But not every privation of light is an eclipse.[54] In both cases, one may add, we have reached a cause that is coherent with the effect. But we have not demonstrated the essential relationship between the two. We have not made the distinction between *formal content* and *existent essence*. So long as we rely on the empirical level alone, the appearances themselves can only be saved by appearances. Thought is compelled, as Bradley wrote, to "take the road of indefinite expansion."

Taking these words of Aristotle and Aquinas and applying their principles, though not their facts, to today's problems, we may well inquire whether a given effect now ascribed to one hypothesis may some day prove explainable by another. If that is so, then, our logic in physics has generalized the major term in the process of establishing this theory now in use. It has generalized it beyond the range it had in its premise, and this is at least possible with every hypothesis. It is the illicit process of the major term.

The recent history of science affords ample caution against too great a faith in a single hypothesis as a distributed principle governing the whole range of phenomena in question. The theory behind Newton's principle of gravitation was believed to apply universally before Einstein. Now it is only a special case of the theory of relativity, while the relativity hypothesis itself is believed to be universally distributed. One may also say, in the language of Aristotle and Aquinas, that thunder is only a special case of noises in the clouds and that eclipses are only a special case of the privation of light. Before the advent of quantum theory, scientists were divided on the nature of light. As Bragg expressed it, they used the wave theory three days a week and the particle theory during the rest. Now the two ideas have been welded together in the quantum system. Classical physics had won the universal assent of nineteenth-century physicists, who felt on the whole more confident than their successors today. Now, according to the correspondence principle, classical mechanics is a special case of quantum physics.

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[54] *In II Anal. Post.* 17.

Though contemporary physics, despite the efforts of Dirac and others, has not yet succeeded in uniting the mechanics of the quantum and relativity theories, the two may yet be transcended in future studies. The danger that scientific theories may not reach a properly distributed term of demonstration lurks in the failure of scientific technique to reach abstract essences where the range of application is guaranteed by the nature of abstraction and universality. Though we believe our present hypotheses to be true, we may still reserve our unqualified acceptance lest they be restricted at some future date, exactly as the classical theories of the last century. It is provisions against another revolution in physics that motivates what Maritain has called the "delusive purism" of the logical positivists and others of the same spirit. There is, in fact, a contradiction between relativity and quantum theories which shows that one or both must be modified in a most profound way.

Experiment has made rapid strides since the days when Aristotle and Aquinas wrote. By proper variation of conditions in the experiments we conduct, we can eliminate unsatisfactory explanations and more or less verify the satisfactory ones. But even if careful checks may justify a high degree of practical certitude in the value of our theories, the certainty must nevertheless fall short of an absolute category, if only for the reason which Aquinas and Aristotle allege against the explanation of thunder and eclipses, by an illicit process of the major term.

Aquinas elsewhere strikes the weakness in more telling fashion. If the middle term is wider than the major, our reasoning is not valid. For we cannot conclude to one cause when the same effect may be due to several causes, just as we cannot conclude that a person has fever from his rapid pulse.[55] Again it must be kept in mind that modern experimental technique may eliminate the unessential aspects of a given causal sequence as far as our present knowledge goes. But so long as we are ignorant of the true and not merely suppositional relation between the cause and the effect in question, our certitude can never reach absolute proportions but must always be clouded by the possibility, however small or large,

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[55] *In I Anal. Post.* 22.

that the effect we observe could spring from a different cause of which we are now ignorant. In this light, Aquinas says that the knower must grasp the "application of the cause to the effect."[56] Then indeed we can have genuinely scientific and certain knowledge. In the reasoning of physics, this requirement cannot be fulfilled in the strict sense because, being ignorant of true causes, we are unable *a fortiori* to grasp them in the productions of their effects.

Demonstration, as we saw, must establish the necessary nexus between a subject and its proper (necessarily inherent) attributes. In the arguments for verifying a hypothesis, this insight into the necessity of the so-called causal sequence is not absolutely guaranteed. Perhaps the subject (theories) is not the proper cause which produces the effect that should be demonstrated by the very definition of this subject itself.[57] Theories by their nature are only tentative. The effects may possibly be explained by another cause. In such a case, the subject is not the proper cause of the attribute or fact that we observe in experience. Hypotheses are conditional causes which are posed to explain effects. They may be elaborated into a precise explanation of a phenomenon or group of phenomena; but the explanation is never absolute because it rests on an assumption.

Analogy plays a fundamental role in the formation of hypotheses. From analysis of sensed phenomena, the scope of a hypothesis can be widened and tested by comparison. Even in the so-called mathematical theories of quantum physics and of relativity, the imagination plays an important role in the process of comparing old data and discovering new ones. Electrical theory is often presented in textbooks by a comparison with a system of hydrodynamics. Einstein employs analogy to explain his general theory of relativity in its physical significance. Maritain has well shown that even the so-called non-Euclidian geometries must revert to the so-called Euclidian space of the imagination to check their conclusions.[58] Otherwise, there is danger that they may lose the consistent character that is the test of their validity.

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[56] *In I Anal. Post.* 3.

[57] *In II Anal. Post.* 7.

[58] *Op. cit.*, p. 332.

Boltzmann employed physical analogy in working out his statistical system, and so did his quantum successors who formulated the Einstein-Bose and Fermi-Dirac systems of contemporary statistics. Fourier's so-called mathematical theory of heat flow is based upon a supposed distribution of particles separated by minute intervals and upon physical presuppositions as to the behavior of both. Only after these postulates have been made, as in the case of statistical theory in physics generally, can conclusions be mathematically developed for further application to the physical world. In the Schroedinger equation, the factors H (an operator), E (energy), and Psi (probability amplitude) all trace their origins by however devious a route back to the sense perception of ordinary experience. Analogy is a tool in the service of microphysics: entities, not visible in themselves but known only by their effects, are pictured—or if the word "picture" is unpalatable let us say intuited—by comparison with sense perception to which ultimately they owe their logical origins. Theories in physics must have a physical character. Because they are suppositions, however, we can only know this character, not directly, but by analogy to something which we directly know. True, in the so-called mathematical theories in contemporary physics, the physical background is deemphasized and analogy is played down by the desire to eliminate anthropomorphism. But the analogy is still there in some way. Physics is physical, and the physicist requires an imaginative support to carry out his reasoning about the material world which he studies.

Analogy in this sense is a fruitful source of knowledge in discovery and a ready servant in both teaching and learning, especially in dealing with atomic and subatomic phenomena which elude direct observation. But if it is a good working guide, it is not infallible. "Its strength," writes Stebbing, "depends upon the character of the initial resemblance and upon the relative comprehensiveness of the properties which are asserted to be connected."[59] The problem is to determine whether a deep or purely accidental similarity exists. Here the number of instances has a peculiar role. It is a means of testing analogy because the more we increase the

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[59] Stebbing, L. S., *A Modern Introduction to Logic*, p. 253.

instances, the more we are likely to find differences between analogue and analogate, if such differences exist; thus we may correct the initial analogy itself. In this way, we feel safest in predicting when the force of our argument "depends not so much on the number of past experiences upon which we rely, as on the degree in which the circumstances resemble the known circumstances in which the prediction is to take effect."[60]

Modern physics, blessed, as Whitehead remarks, with potent mechanical instruments, can carry out a good check on the essential or merely accidental character of a hypothecated analogy. But there still remains the possibility that another way may be found to "save the facts."

It is analogy in its logical implications which provides the backdrop for interpreting the problem of models and constructs in modern physics. The physicist cannot carry on his work without them. He needs the support which they provide in guiding his thought to new discoveries and in suggesting problems and solutions for his so-called mathematical theories. Yet they need not, and doubtless do not, correspond exactly with the real world. They are not carbon copies. But there has to be a resemblance, even in the midst of differences, between reality and the physicist's *working* construct or model. Only if we admit this resemblance can we find a sufficient reason for the success of physics in predicting phenomena from a consideration of, say, the wave-particle aspects of subatomic entities. We cannot find an exact picture to combine the undulatory and corpuscular aspects of matter and of light. But when the physicist works now with the wave-picture, now with the particle-construct, to guide his thought and suggest new theories and new applications of mathematics, there is in some way a resemblance between the *working* model and the real thing.

Though the analogated entities of the microphysical world seem to tally in some respects with our ideas of what they should be, it does not follow that they correspond to our ideas of what they are in their complete wholes. The present-day physicists, even though some of them take the extreme view in denying resemblances of model and thing and in throwing out models altogether,

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[60] Keynes, J., *op. cit.*, p. 241.

are more logical than their nineteenth-century predecessors in this criticism of "mechanical" pictures. Aquinas, at one here with the modern physicist, noted that "it is not necessary for things similar in one respect to be similar in all respects."[61] The criticism by modern physics of the tendency to view models as exact copies of reality is based on incontrovertible logic. There are resemblances between model and thing. But there may also be differences.

Applying the dictum of Aquinas to the baffling problems of present-day quantum and relativistic mechanics, we find that our conclusions concerning the physical bases of modern theories must be carefully restricted. Electrons were found in the Davisson-Germer experiment to obey a wave equation; but this does not mean that electrons are waves: "it is not necessary for things similar in one respect to be similar in all respects." Light rays were found in the solar eclipse of 1919 to be curved; but it cannot be apodictically inferred that the space through which they passed is curved. This principle of Aquinas strikes a nerve center in modern science. Though experiment may aid in throwing out accidental differences between analogue and analogate and in thus reaching more essential resemblances, yet so long as we are reasoning from effect to cause and using analogy to describe the cause, our conclusions must always suffer from the possibility that our conclusions may be defective. There is an obvious danger, then, in concluding from the properties of the analogate to the corresponding properties of the analogue, except for those precise features in which they are found to agree. In the strict logic of demonstration, we cannot conclude that electrons are waves but only that they obey a wave equation. Similarly, we cannot reason immediately from the curvature of light waves to the curvature of space. In the case of the electrons, for instance, our reasoning would be thus: waves obey wave equations; electrons obey wave equations; therefore electrons are waves. Cursory inspection shows that the middle term is not distributed. This formal fallacy characterizes every false analogy.

Finally, the traditional notion of analogy as a method of reasoning provides in physical science a meeting ground for the coher-

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[61] *II Anal. Post.* 16.

ence and conformity doctrines of truth, both of which have their place in the assessment of scientific theory. The hypothetical character of a theory involves, as we saw, the coherence doctrine as a formal standard. But as far as there are resemblances, as resemblances there must be, the theories are in a material correspondence with reality. Analogy applies here not only to the so-called "mechanical" but also to the "mathematical" theories of physics. As far as the Schroedinger equation, which is fundamental to modern quantum mechanics, is a theory, it can only be said that it posits a "cause" consistent with "effects." But as far as it works out in practice, it bears at least a *resemblance* to something real, it has some material correspondence with reality, though there may also be the differences which would enable another theory to "save the phenomena."

It has also been pointed out that if we cast the reasoning process of the scientist into the form of a strict hypothetical syllogism, the arguments by which hypotheses are verified involve the formal fallacy of affirming the consequent. "The scientist says, 'If matter is constituted in the way I suppose, then this will be the result; but this is the result; therefore matter is constituted in this way.' There is, of course, the possibility of making the syllogism valid, by making it read, 'Only if matter is constituted in this way.' The difficulty is to justify the 'only.' "[62] The antecedent in a hypothetical proposition can be proved by affirming the consequent only when it is a necessary condition of the consequent. This means, applied to the present problem, that to justify his theories as true the physicist must establish that they are the only ones which can explain (predict) phenomena. Under such harsh restrictions imposed by the very act of correct thinking, the practical certainty which we place in the value of our theories, even the well-established ones, can never attain an absolute status.

Finally, hypotheses are expressed eventually in terms of physical nature; they are also applied to nature. They cannot be considered apart from nature's order. The concepts in a theory represent physical entities and can be reduced to them. These entities are, it was noted, only hypothetically necessary in their ac-

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[62] McWilliams, J. A., "Mathematics and Metaphysics in Science," *The New Scholasticism,* II, 1937, pp. 363-364.

tivities. It may well be that in modern theories in physics, to use Tennant's significant words, "the intelligibility which science assumes the word to possess and seeks to reveal, is not that of a teleological reasonableness, but rather a quasi-logical rationality."[63] Physics seeks to arrange its concepts with a view to the deduction of facts. But the logical order is dependent on the ontological order as to its origin and to its application.

Physicists maintain that the aim of a theory is to predict phenomena. But in view of the contingency of the laws of nature, it is possible that a hypothesis may fail in its forecasting for reasons mentioned in the discussion of cosmic order. Aquinas himself suggests further material for a critical approach to the predictive aspects of scientific theories. He points out that the present, past, and future, which are involved in every temporal sequence, are not in the same genus, and that the passage from one to the other leaves room for the variations in nature's laws. Although the following example can be applied to law as well as theory, it is deserving of special mention here in view of the insistence of contemporary scientists on the predictive function of their hypotheses: It does not follow, Aquinas writes, that because a sick man has taken a certain medicine, he will be cured. Causes which give rise to their effects necessarily are simultaneous with the latter. Here we have a temporal sequence. It is important that the middle term be homogeneous, i.e., of a single genus; if one wishes to establish something from the past, the middle or causal terms should be taken from the past. The same order should be observed in dealing with future things. When, however, it is argued that *this* phenomenon has occurred, therefore we can predict what will follow, the genera are not the same but are related by priority and posteriority (time). Hence, even if the prior conditions are posited, the posterior effects need not follow since effects may be impeded. The words of Aquinas concerning sequence in time can be aptly applied to the predictive aspects of theories in physics. Such a sequence enters into the explanation of the hypothetical necessity of the order of nature. In material beings, which exist and act in time, we cannot guarantee an absolute, inexorable regularity in

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[63] Tennant, F., *The Philosophy of Science,* Cambridge, 1932, p. 145.

the course of nature. As Aquinas pointedly declares, from the before to the after, in time, there is no syllogism.[63a]

Such a dictum is in direct contrast to the Laplacian ideal of scientific determinism in which, from a knowledge of a system at one moment of a purely homogeneous time, its states at all future moments are predictable. Modern physics, of course, no longer accepts this view. Though the statements of the physicists sometimes give the impression that this prediction is impossible because the passage from the present to the future is affected by chance and indeterminism, this is not an exact report. Nature is ordered. Chance by its very nature eludes science, even probability-calculations. Our inability to predict the future from the present is not due to the indeterminism of the future in terms of the present but to our ignorance of the present as it is in complete form. Probability and indeterminism are subjective. They lie in the conclusions which we draw only because of the premises which we formulate. Laplace's ideal still holds under the qualification of hypothetical necessity. He erred not in his faith in prediction but in neglecting the fact that our knowledge of the present is inexact. It is our knowledge which is not determined. But even if we reject the view that indeterminism is an objective fact and accept the reality of the hypothetical necessity of nature's order, the predictive value of our theories must always be tempered, even in probability calculations, by the contingency of the causal sequence which Aquinas well summed up in his dictum: *A priori ad posterius non syllogizatur.*

The conditional character of an hypothesis attends upon it everywhere. It is applied to the physical world which exists contingently. Therefore, the beings to which it refers may exist or not, may be impeded or not, in particular cases. We cannot conclude that because a man is healthy, he has taken medicine; but knowing that he was ill and that he took medicine, we can then infer their causal connection.[64] The same conditional qualifications govern our knowledge of the future. We cannot say that a given phenomenon will occur, but only that if it does occur, then a certain causal sequence has taken place. This difficulty merely underscores

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[63a] *In II Anal. Post.* 10.

[64] *In II Anal. Post.* 11.

once anew that physics deals with contingent being, i.e., with being that may or may not exist. This hypothetical character of empirical data pervades the theories of physics no less than its laws.

Aquinas' discussion of temporal sequence in relation to logic contains an indirect reference to the fallacy of affirming the consequent. In such a fallacy, the conditioned is mistaken for the absolute. We could not argue thus: If a house has been built, stones have been cut. But stones have been cut; therefore a house has been built.[65] We could not argue thus unless we proved that the building of the house necessarily followed the cutting of the stone. Obviously we could not prove this. The same pitfall threatens our modern scientific theories. Admittedly, Aquinas' example of building a house or curing the sick appears to be rather naive when compared to the elaborate scientific theories that have arisen since his day. But if new and apparently more complicated facts have been discovered, the principles remain the same. Aquinas merely shows in his clear and lucid fashion a truth that might elude us in view of the success of our modern theories: that the affirmation of the antecedent does not follow from the affirmation of the consequent in a hypothetical proposition. To proceed thus to forget that the contingently existing is conditioned by the existence of something else and is not an absolute necessity of being which is independent of temporal sequence and cannot be otherwise than it is.

The foregoing discussion has established the fact that enumerative induction is impossible in practice and that in theory it involves a vicious circle. Hence a pure empiricism is insufficient for genuine science. It was then shown that though scientific laws, because they do not reach essences, cannot in themselves confer necessity for possible experience, they nevertheless can confer a hypothetical necessity in the light of the order of nature. This hypothetical necessity, it was shown, is not the probability equations of statistics and of quantum theory. The indeterminism of wave mechanics does not contravene the order of nature.

In appraising theory, it was observed that hypotheses, not attaining existent essence, involved a "leap into the unknown" and

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[65] *Ibid.*

could not guarantee the proper distribution of terms in our efforts to establish a theory as true. As instruments for prediction, hypotheses involve the sequence of time which makes their action subject to the hypothetical necessity prevailing in the course of nature. They also involve a sequence of thought in which the proper order of being can be reversed and the conditional mistaken for the absolute—the fallacy of affirming the consequent.

So far in this work, the method of modern physics as viewed by traditional logic has been exposed and examined. But the philosopher can ask still another question. What is the ontological significance of the physical picture of matter? The answer is necessarily interlaced with the question of method. Method is only a means to an end, and depending on the method we employ is the end we attain. The end of the knowing process should be knowledge. But what is our idea of matter as attained by the empirical method? The question of how the method of physics actually works may now be examined with a view to discovering the general terms in which physics answers the problem of the nature of the existent world. Accordingly, let us take the physical picture of matter, appraising it obediently to the advice of Cicero, "I will follow reason, wherever it leads me."

CHAPTER IX

ATOMISM, THE END OF A FRONTIER

Socrates was not content with a mere picture of the Platonic republic. He wanted, Plato records, to see it in action. So it is with modern physics. If we observe the physicist at work, noting how he proceeds from premise to conclusion, we can best grasp the significance of his method.

Though the concept of the atom, like the word itself, goes back to the Greeks, chiefly Democritus and Epicurus, it was John Dalton in the early nineteenth century who founded modern atomic theory. Reasoning from the fact that chemical substances always combine in proportions (definite and multiple), Dalton arrived at the ideas that: a) elemental substances are made up of tiny individual bodies called atoms: b) all atoms of a given element are alike, having the same weights, but atoms of different elements are different; c) chemical combination of two elements is the synthesis of a small, determinate number of atoms of one element with a small, determinate number of atoms of another element to form each individual particle of the compound.

The discovery by Faraday of the laws of electrolysis—which showed that for each univalent atom there is an electrical charge, or a multiple thereof for a multivalent atom—laid the groundwork for modern subatomic ideas. With the discovery of the electron in 1897 by J. J. Thomson, attention shifted from the description of the macroscopic world in terms of atoms to the resolving of atoms themselves into simpler quantities. On the basis of results obtained by the scattering of X-rays passing through matter, Thomson wrote the next chapter in modern physics: "(1) The atom contains electrons, the number being of the order of magnitude of, but probably smaller than the atomic weight; (2) The neutral atom must contain as much positive electricity as there is negative electricity associated with its negative electrons; (3) The ensemble of the positive charge and negative electrons which make up the atom must be stable; the electrons, for example, must be held by (electrostatic?) forces in fixed positions of equilibrium about which they may vibrate, when disturbed, with definite frequencies required to explain the characterisic line spectra of the elements; (5) Except when so disturbed, the electrons must be at rest, since, otherwise, they would emit radiation as required by the electromagnetic theory."[1]

The Thomson atom failed to account for the large angle of deflection observed in the scattering of alpha particles (positively charged particles equal in mass to the helium atom and numerically equal in charge to two electrons) emitted from radioactive substances. It became apparent that the alpha particles must encounter forces larger than the Thomson atom was able to explain. To meet this difficulty, Rutherford in an historical article published in 1911 rejected the Thomson idea of the uniform distribution of positive charge throughout the atom. He postulated that: 1) the positive charge must exist in a small region at the center which he called the nucleus; 2) the electrons are held in configuration about the nucleus.[2] Since like charges repel each other while unlike charges attract (Coulomb's law of electrostatics), it was apparent that the electrons were endowed with motion. Moreover, they do not "fall into" the nucleus. Therefore, it was argued, this movement had to be orbital. So the Thomson atom, because of its inability to explain the scattering of alpha particles, was superseded by the Rutherford model in which the positive electrical charge is centered in the mass of the nucleus while the electrons revolve about the nucleus in a way analogous to the planetary motion about the sun.

Rutherford's planetary atom model, though in broad outline it has survived the revolutions in modern atomic physics, was still far from perfect. It was, in fact, in disagreement with the then unquestioned electromagnetic theory which would demand that an electron in circular motion, hence accelerated, emit radiation. This process would result in a loss of energy. The electrons would be

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[1] Richtmyer, F. K., *Introduction to Modern Physics,* New York, 1934, p. 349.

[2] *Phil. Mag.,* XXI, 1911, pp. 669-688.

pulled toward the nucleus, continually giving off radiant energy. The spiral movement of the electrons would result eventually in the collapse of the atom. Rutherford's model appeared to correct the Thomson theory. Yet if it obeyed the accepted laws of motion and radiation, it would have made an atom impossible.

Physics thrives on dilemmas. So long as no exceptions can be found to existing theories, the physicist sometimes rests his oars. But once variations are found in experiment, he is spurred anew to action. At the beginning of the present century, the Michelson-Morley experiment, showing that the velocity of light was a constant, stood in direct opposition to classical physics. Out of the conflict came the theory of relativity. At the same time, the radiation of a perfectly black body could not be reduced to classical laws. The dilemma gave to the quantum theory. The quantum theory was extended by Einstein, because of the difficulties of explaining all the phenomena of light on the basis of the wave theory of classical optics. Finally, the duality of matter and light has inspired the theory of wave mechanics. Much of the great work in modern theoretical physics thus bears a resemblance to Hegelian dialectic, in which the opposing views are united into one embracing synthesis, and the coherence theory takes its bow. It was the dilemma facing the Rutherford atom which challenged the world of physics and produced the Bohr theory.

Meanwhile, a new development had taken place which enabled Bohr to formulate his answer. In 1900, Planck worked out an equation for black-body radiation[3] which demanded as a physical basis that the frequency of the energy of emitted and absorbed light have discrete values, multiples of a definite amount. Energy was thus envisioned as being emitted in discrete packets, called quanta. The quantum theory, describing the emission of radiant energy in a discontinuous stream, was at variance with the continuity hypothesis of the classical system. Since, however, physical

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[3] This is simply radiation from a perfectly black body. It was studied experimentally in the so-called *Hohlraum,* a spherical cavity having a small aperture permitting the rays of light to enter but not allowing them, after their interplay between the walls, to escape. An absorber, the *Hohlraum* simulates a black body.

theories must stand trial before the jury of experiment, the quantum theory was accepted. A new era in physics was proclaimed.

Einstein vindicated the quantum theory. He was inspired by one of those dilemmas which have become the stimulus of scientific progress toward the analogue what Joachim terms a "significant whole." The photoelectric effect had been a puzzle to physicists. A beam of light causes the emission of electrons from a metal plate at a rate proportional to the intensity of the incident light. To increase the velocity of the emitted electrons, a beam of higher wave frequency, that is of shorter wave length, must be used, even though it may be feebler than the former beam. Until Einstein applied quantum theory to the photoelectric effect, no equation in harmony with experimental evidence had been worked out. Einstein proposed in place of the classical electromagnetic waves that light was emitted in particles called quanta (quants) or photons. On such an assumption a strikingly simple equation could be set up.[4]

The quantum theory was likewise confirmed by the Compton effect. In this phenomenon, a beam of scattering X-rays is found to have two wave lengths, one the same as the original, the other slightly longer. Compton was able to interpret these results in terms of the quantum theory. He supposed that the photon, after colliding with an electron, lost some of its initial energy with the result that it had a lowered frequency when deflected. These now historic interpretations of Einstein and A. H. Compton put quantum theory on a firm basis. The new theory was much more embracing than the old one.

In the light of the quantum theory, Bohr, in 1913, corrected Rutherford's model of atomic structure. Bohr was interested in the problem of spectral lines. They are emitted by substances when excited by thermal agitation or electronic bombardment. The lines are specifically different for each element.[5] To correct the Rutherford atom model in which the accelerated electrons obedient to electromagnetic laws should constantly radiate energy, he proposed two important postulates: 1) For every electron there is a limited number of orbits in which it does not radiate but is stable; the energy of an electron in such an orbit is anchored to a certain energy level and is said to be in a stationary state; 2) when an electron rises from a lower orbit to a higher one, it absorbs energy; when it falls back again, it descends to a lower level and the lost energy is emitted as radiation.[6] Bohr's theory proposed that the orbits and the angular momentum of an electron had discrete instead of continuously variable values. He called this interrupted character of mensurable matter *quantization*. It was another development of the quantum theory.

From his mathematical interpretations, Bohr was able to deduce the so-called Rydberg constant, found experimentally in spectroscopy. This constant occurs in equations for lines in the hydrogen spectrum. It became a relatively simple task now to derive on theoretical grounds the mathematical statement, hitherto empirically known, of the Lyman, Balmer, and Paschen series of lines for hydrogen. The normal orbit of hydrogen's solitary electron is 1. In falling into orbit 1 from orbits 2, 3, and 4, it was computed, lines of the so-called Lyman series appear. In dropping into orbit 2, the so-called Balmer lines appear. And so on. Bohr's theory passed the test of physics. It agreed with experiment, could predict its results.

The motion of a particle of sufficiently small kinetic energy and under the influence of a central force traces in general an elliptical curve. Sommerfeld extended the Bohr theory to ellipses. Making corrections demanded by the theory of relativity (in which mass varies with velocity), he was able to calculate the differences in energy between the various elliptical orbits.

Bohr's mathematical simplifications make it impossible to apply the theory to larger atoms because of the mathematical complexity of the many-body problem. Then too contemporary physics has come to believe that the laws governing subatomic phenomena are so different from those of the macroscopic world that it is no

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[4] Einstein proposed that each released electron receives just one quantum of incident energy and that the energy of this electron is equal to the energy of the incident quantum minus the work done in dislodging the electron from the atomic configuration. Surprisingly simple, this equation of Einstein has been experimentally verified.

[5] Physics is able to differentiate one element from another by spectroscopy.

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[6] Ruark and Urey, *op. cit.*, p. 14.

longer possible to think of atoms in terms of a mechanical model. But the Bohr theory has been so fruitful, especially in simpler atoms, that its usefulness has not been completely outlived. Its fundamental concept, of energy levels and of the emission of photons when electrons drop down toward the nucleus from their higher orbits, remains fairly firmly established in modern physics. References will be made further on in this chapter to later developments of quantum theory. After the foregoing description of the Rutherford-Bohr atom model, it is necessary to continue with an outline of the fundamental units of the material world as viewed by the contemporary physicist.

The nucleus of the hydrogen atom, bearing a positive charge sufficient to equalize the negative charge of one electron, has been called the proton. Two new facts, discovered in very recent times, have raised problems as to the nature and number of particles in the atom. Until the early 1930's, the atom had been regarded as a composite of a nucleus, in which the protons outnumbered the electrons, and an orbital configuration of electrons in just the right number to neutralize the excess positive nuclear charge. In 1932, Anderson, after a cosmic-ray bombardment of a piece of lead, obtained a photograph of tracks which could only be interpreted as the paths of positive electrons or so-called positrons. Subsequent photographs indicated that the release of positrons under the impact of high-velocity cosmic rays was no rare phenomenon. Physicists began to speculate about the place of the positron in the subatomic world.[7]

In 1934, Chadwick showed that the difficult problem of accounting for the high penetrating power of rays produced when alpha particles (from polonium) bombard certain light elements like beryllium, boron, and lithium, could be solved on the assumption that the high-powered alpha rays disrupted the atom's nucleus and released a particle having a mass but no charge. This particle became known as the neutron.[8]

The exact relations of the positron, the proton, and the neutron have not thus far been accurately traced. A proton has been believed to yield, on disintegration, a neutron plus a positive electron (positron); a neutron yields a proton plus a negative electron. But these disintegration equations have not yet been accepted as final. As Lindsay and Margenau write, "The view seems current among physicists that, of the proton and the neutron, one is elementary and the other complex. But whether the proton is a neutron combined with a positron, or whether the neutron is a proton combined with an electron is a much debated question."[9]

In beta-ray radiation, emitted electrons are found to vary in energy. The spectrum runs from zero up to a certain maximum of electron volts. The resulting curve for energy distribution against frequency, in contrast to a similar curve for alpha particles, seems at variance with the law of the conservation of energy. Energy seems to have been lost. Suggestions have been made, by Dirac among others, that the law of conservation does not hold in the case of the continuous beta-ray spectrum. However, this view has not been generally accepted. To solve the problem and to preserve the law of conservation, a particle called the neutrino, having energy but a very small mass, has been postulated.[10] On this view, whenever an element loses a beta-particle, it also loses a neutrino. In such an explanation, the law of energy conservation holds true. Tuve has referred to the neutrino as a name that we have invented for lost energy.[11]

The disintegration of atoms has been known since the discovery of radioactivity. Radium, for instance, emits, among other rays, the so-called alpha-particles. Each of these is a helium nucleus, combining with two electrons to form an atom of helium. The residual atom, radon, is also radioactive. It breaks down progressively into different atoms, either isotopes of the preceding atom in the disintegration series or an atom of a different atomic number. With the loss of each succeeding alpha-particle there is

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[7] *Phys. Rev.*, vol. 43, p. 491.

[8] *Proc. Royal Soc.*, London, vol. 136, p. 692.

[9] *Op. cit.*, p. 513.

[10] *Royal Soc. Proc.* 161 A, pp. 447-460, Aug. 20, 1937.

[11] The neutretto, "a neutral particle with the same mass and other similar properties as the heavy electron," has been postulated to account for the "fact that the forces between two protons seem to be equal to those between a proton and a neutron," *Nature*, vol. 142, p. 157.

a new isotope or new element. The end product of the radium series is an atom of lead.

These facts suggest the picture of the atom accepted by modern physics. Differences in elements are the results of the number of electrons and protons which the atoms contain. For physics, differences are additive, not formal. They are numerical, not substantial. Diversity of property and activity is a function of the number of particles that constitute the atom, more precisely the number of nuclear particles, since these determine ultimately the electronic phenomena.

Physics believes to have verified its additive concept of differences in the fact of atom-smashing. By means of the van der Graff generator, extremely high electrical potentials can be developed. With this voltage, positive ions are accelerated until they have sufficiently high energy to penetrate to the nucleus of a bombarded atom and there to dislodge nuclear particles. The cyclotron accelerates positive ions by driving them in circular paths instead of the linear ones used in the van der Graff machine. By means of a strong electromagnet, the ions may be accelerated a great number of times using relatively low voltages. When energized sufficiently to pierce an atomic nucleus, the ions are released against the target atoms. In the phenomenon of atom-smashing, the loss of every proton, for instance, brings a corresponding release of an electron from the extra-nuclear region. The new atom, with a different constitution and different physical and chemical properties, moves lower down in the periodic table in the same way as the transmuted elements in the natural, radioactive series of disintegration. In accounting for differences in elements, physics is true to its atomizing method.

Atomic physics took a new turn in recent years. If we wish to trace the present status of the science, we must now follow it along the astonishing highway that leads to wave mechanics.

The nineteenth century had abandoned Newton's corpuscular theory of light. It had accepted the undulatory theory of Huygens because a wave hypothesis was better able to explain experimental data. The phenomenon of interference—the alternate light and dark bands produced when a single beam of light passes through

two pin-holes and is then observed on a screen—was believed explainable only in a wave vocabulary. Two systems of waves, meeting in opposite phases—when the crests of one system correspond with the troughs of the other—neutralize each other (the dark band). Waves in the same phases—where the crests of the two systems occur together—reinforce each other (the light band).[12] Fresnel interpreted diffraction rings, the alternate light and dark bands in shadows, in a similar way, as a phenomenon of interference. The wave theory of light, chiefly because it could account for these two phenomena, interference and diffraction, thus went almost unquestioned throughout the nineteenth century.

But while radiant energy was conceived as waves, the physics of matter was always interpreted on an atomic basis. The atomic hypothesis of Dalton, the kinetic molecular theory, and finally the atomic hypothesis of the constitution of electricity divided physics into two apparently unrelated systems, that of radiation based on waves and that of matter based on particles. Matter and energy were two separate phenomena. The early quantum theory complicated the problem even more. It revived the corpuscular theory of light. But it failed to explain interference and diffraction. So physics had a two-front conflict in which there was not only a rift between the physics of radiation and the physics of matter but a fundamental conflict within the study of radiation itself. It was another of the dilemmas which head the great chapters of contemporary physics.

In 1925, de Broglie announced a wave theory of matter. In reaching the idea of so-called matter waves, which has gone far to remove the old antinomies in atomic physics and unify it as a branch of knowledge, de Broglie reasoned that since whole numbers were associated with interference and vibrations in general it was necessary that the electron also, because it would be represented by whole numbers, have a periodic property.[13] De Broglie was also impressed by the parallelism between Maupertuis' principle of least action in particle phenomena and Fermat's principle,

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[12] Wood, R. W., *Physical Optics*, New York, 1934, pp. 157 ff.

[13] de Broglie, L., *op. cit.*, p. 185.

in radiation, of least time.[14] Such considerations led him to the bold conclusion that just as light exhibits wave and corpuscular properties, so matter may be said to have a dual nature. He then set out to find a suitable mathematical expression for his conclusion. He reached the formula that for an electron with mass m and velocity v, the division of Planck's constant h by the electron's momentum mu yields the wave length associated with a stream of electrons.[15]

Up to this point, de Broglie's novel idea remained a mere speculation. What was lacking was the circumstantial evidence for the physicist's court, experiment. The American physicists, Davisson and Germer, finally supplied proof of de Broglie's idea. They performed an experiment which confirmed the wave hypothesis. They bombarded the surface of a nickel crystal with a low-voltage electron-gun, measuring the deflected electrons by means of a "collector" having a very small aperture.[16] Their data agreed with de Broglie's equation. The theory was subsequently confirmed anew in the work of Kukuchi and Rupp who obtained photographs of diffraction bands that resembled the interference rings noted a century earlier in classical optics.

But what is the physical significance of the electron-waves? There are several possible interpretations as de Broglie himself observes.[17] Schroedinger, author of a mathematical theory that has done much to perfect the theory of wave mechanics, had advanced the idea that an electron is made up of a group of waves. Another hypothesis is that the particle is a singular factor in a larger undulatory phenomenon. Kennard has advanced the idea that the whole problem can be avoided if, instead of employing the terms *motion* and *trajectory*, we merely resort to the abstract expression, *probability elements*, to cover both. Finally, there are

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[14] The principle of least action states that of all the possible paths between two points for constant energy, a projectile will follow the path which makes the "action" a minimum as compared with its value for any other length. Fermat's principle states that a ray of light, passing between two points, will take the path requiring the least time.

[15] *Op. cit.*, p. 201.

[16] *Phys. Rev.*, vol. 30, p. 707.

[17] *Op. cit.*, pp. 204-205.

the views of Heisenberg and Bohr that since the matter-waves are not to be thought of in the ordinary physical sense of the term *wave*, the conception of wave is merely a symbolical representation of our knowledge of the particle. According to the Heisenberg principle, the velocity (momentum) and position of a particle cannot be computed simultaneously. In practical problems of atomic physics where energy is of great importance, matter is thought of in terms of particles; and where position is of major interest, the concept of wave comes to the fore.

In the views of Heisenberg and Bohr, wave and particle properties are not opposed but complementary. If we wish to study particle properties, then we cannot observe the wave properties simultaneously and *vice versa;* we cannot detect the particle properties in an experiment designed to study electrons as waves. The Heisenberg principle is thus especially fruitful in supporting what Bohr has called the Principle of Complementarity.[18] On this point, Schroedinger has written: "One may believe either (1) that matter has *really* a wave structure. Then the uncertainty principle is an immediate consequence. Or (2) one may think that the uncertainty principle is more fundamental. The wave theory then is simply an auxiliary construction for the convenience of grasping and representing the principle."[19] According to the Principle of Complementarity, wave and particle properties are not contradictory. They represent two different ways of looking at a reality which we can never study experimentally as it is in its ontal whole. We can never study it thus because according to the principle of indeterminacy our measurements interfere with the phenomenon we have set out to study. By the very conditions of experiment, as the Heisenberg principle says, we can study reality only in its parts and can never reach empirically the real relations which the parts bear to each other in ontal combination.[20]

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[18] *Naturwissenschaften*, vol. 16, p. 245; *Nature*, vol. 121, p. 580.

[19] *Op. cit.*, pp. 162-163; Frank, P., *Interpretations and Misinterpretations of Modern Physics*, pp. 14-15.

[20] "Perhaps the best description can be made by the use of a commercial expression; an electron is a particle 'and/or' a wave. We must be ready all the time to think of it as either or both, but we must not mix the ideas. There are two half-worlds, each of which gives a partial view of the whole

The mathematics of wave mechanics, as developed by Schroedinger, Dirac, Heisenberg, Jordan, and Born, does not propose to mold a model of reality. The language of physics has become more and more abstract and abstruse in its symbolic figures and their combinations. Physics now speaks of wave- or psi-functions as "probabilities" and particles as "probability-packets." It apparently abandons its attempt to trace out the physical counterparts of its language which become lost in what has been called the "shadowy jungle" of indeterminism. Classical physics is only an approximation to reality. It is satisfactory for practical purposes, when energy is large and velocities are low. But it is not theoretically correct.[21]

The use of the Schroedinger equation to provide accurate prediction for large aggregates of particles and the concept of the statistical method, especially that of the Fermi-Dirac system, may suggest that physics is abandoning its atomizing method, is thinking instead, in terms of wholes. But this is by no means the case. We are dealing here with quantitative "wholes," with sums. The whole is still regarded as being determined by its partitive processes.[22] These individual units cannot be accurately measured because of the Heisenberg principle and because of additional experimental and computational complexities which a measuring procedure would involve.[23] But they and they alone determine the collection.

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world: they are related to one another and interdependent, but they are expressed in different languages. We call the two half-worlds the 'particle-aspect' and the 'wave aspect,'" Darwin, C. G., *New Conceptions of Matter*, New York, 1931, p. 96.

[21] This is a physical interpretation of the Bohr correspondence principle. Strictly speaking, it is representable by tracing the energy curves on the basis of quantum mechanics. "We may assume, however, that if we go to a very high quantum number, so that we are far out on the axis of the abscissas, any ordinary energy curve will become asymptotically fairly smooth and straight, so that the chord and the tangent to the curve will more and more nearly coincide," Slater and Frank, *Introduction to Theoretical Physics*, New York, 1933, p. 361.

The mathematical description of the correspondence principle given above merely means that as the energy increases in a low-energy system quantum mechanics will approach classical mechanics and become, for practical purposes, equivalent to it. An asymptote of a curve is a concept of analytic geometry. It means "a straight line which the curve approaches indefinitely near as its tracing point passes off to infinity," Smith, Gale, Neeley, *New Analytic Geometry*, New York, 1928, p. 39. A similar reasoning can be applied to the Theory of Relativity which applies only to systems in which the velocity approaches that of light. As these high velocities decrease, Relativity mechanics approaches the classical system asymptotically.

Thus far in the outline of the atomizing tendencies in modern physics, no mention has been made of the factors which hold the particle-waves together. Physics tends to reduce reality to categories of number and measure. "Man" for example, means for the physicist a mere assembly of measurable quantities or quantum states. So does iron, copper, or any other substance. But if reality is conceived as a mere lattice-work of microscopic units, the physicist is none the less confronted by the problem of the coherence of the atom in a stable configuration and the binding of the atoms themselves into molecules. This problem is solved in a manner analogous to that in the problem of structure—by supposing the existence of mechanical (or quasi-mechanical) forces which cement the parts.

A fundamental principle invoked to explain the coherence of the atom into a system is the law of electrostatics that like charges repel each other while unlike charges attract. In this way, positive and negative electrical units are conjugated into a stable configuration which is electrically neutral. Though physics holds that the electrons are endowed with kinetic energy of motion, the electrical nature of the atomic phenomena, on well-founded evidence, is even more fundamental than its motor properties. In order to explain the effect of a magnetic field on spectral lines emitted by an atom, it was necessary to postulate that associated with the electron is a magnetic field produced by its rotation (electron-spin). The Stern-Gerlach experiment, a study of an atom's behavior in a magnetic field, had shown, before the advent of the spin-hypothesis, that the atom had magnetic properties. The electromagnetic forces within the atom are quite basic, if indeed they are not the fundamental dynamic elements in our present picture of the atom. It is

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[22] Tolman, R. C., *op. cit.*, pp. 43 ff.

[23] Darrow, K. K., "Statistical Theories of Matter, Radiation, and Electricity," *Phys. Rev.*, vol. 1, pp. 90-155.

difficult to speak of picturable phenomena in contemporary physics. "Yet in the picture of the universe as now presented," Darrow writes, "there are particles possessed of charge and mass; there are electromagnetic forces between the particles; there is radiation . . . ; and outside of the realm of "nuclear" phenomena there is nothing else. The stability of the world, that is to say, of the picture, is assured by the attractions and repulsions, electrical in nature, and by motion, with radiation playing an essential part."[24]

But the question of the coherence of the atom is not only one of keeping the particles together. Since there is an excess of positively charged particles in the nucleus, why do they not repel each other, exploding the atom by the sheer force of electrostatic repulsion? Here one finds the central problem in modern atomic physics—the problem of the nucleus. The cohesion of the positively charged particles is the result of so-called "exchange forces." This is a quantum-mechanical concept. It has no classical analogue. Depending on the behavior of the given wave functions to an interchange of electrons, it is possible to calculate whether this exchange force will keep the particles together or drive them apart. As used in physics, the term "exchange force" lends itself much more readily to mathematical description than to a physical picture. Darrow states the problem of intra-nuclear attraction and repulsion in summary fashion: "It is possible . . . to compare the amount of energy required for tearing apart a cluster of two protons and a neutron with that required for tearing apart a cluster of two neutrons and one proton. The two amounts differ by only a few percent; and more surprisingly, yet, the former is the greater! Though the first-named of the clusters contains the inherent explosive power of two protons trying to drive themselves apart by long-range repulsion, it is stuck tighter together than the other which contains nothing of the sort. As a minor detail, this shows that the cohesive forces depend to some extent on whether the particles are neutrons or protons; but the major conclusion is, that the cohesive forces are the masters."[25]

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[24] "Forces and Atoms: The World of the Physicist," *The Bell System Technical Journal,* vol. 20, p. 348.

[25] Darrow, K., *art. cit.,* p. 352.

One of the most promising of recent suggestions in nuclear physics is the "meson theory." The meson, the heavy electron found experimentally thus far only in cosmic radiation, has been advanced by Yukawa and others as associated with the binding fields of nuclear particles, probably giving rise to the exchange forces themselves. Whether the so-called nuclear meson is the negative particle of cosmic radiation or whether it is neutral in charge is not a matter of agreement. However, future theoretical developments may be expected with regard to the meson theory,[26] or some other such particle (i.e., partitive and mechanical) theory of atomic binding energies. Apart from its present significance, the meson theory is thus a powerful suggestion that energy is 'substantialized' in physics, i.e., is viewed like matter to be particle-units.

The role of gravity in subatomic phenomena is too small to be appreciable in its effects. There is, however, a very important quantum-mechanical principle which plays a fundamental role in particle interaction. It is the Pauli "exclusion principle" which states that no two electrons can have exactly the same states of motion (quantum numbers). This is a repulsive force acting between similar articles. Its reason for existence is not known, but it may some day be deduced from a more general hypothesis.[27] From the Pauli principle, the periodic system of the chemical elements can be built up in deductive fashion. It has also been fruitful, with reference to the repulsive actions of electrons on each other, by providing helps for computing the probability-distributions of the four co-ordinates (or quantum numbers) of electrons.

The energy required to release a particle from an atomic configuration is called the binding energy of that particle. A philosopher may ask the question: what is energy? The physicist would define it in his mathematical language as "the space integral of the force acting on the particle."[28] But the philosopher, holding that physics is physical and has to have an empirical something to measure, must ask about the concept of energy in a *physical* sense.

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[26] For a discussion of early and pre-war meson theory, cf. Bethe, H., *Phys. Rev.,* 57 (1940), pp. 260-272.

[27] Lindsay and Margenau, *op. cit.,* p. 121.

[28] *Ibid.,* p. 121.

According to the theory of relativity, energy itself has mass. The decrement in mass observed in nuclear reactions is found to be exactly equal to that which corresponds, relativistically, to the released kinetic energy. According to the theory of relativity, matter and energy are therefore considered as equivalent.

In speaking of electrical energy, Millikan writes that, "when we combine the discovery that an electrical charge possesses the distinguishing property of matter, namely, inertia, with the discovery that all electrical charges are built up out of specks all alike in charge, we have made it entirely legitimate to consider an electric current as the passage of a definite, material granular substance along the conductor. In other words, the two entities which the nineteenth century tried to keep distinct, begin to look like different aspects of one and the same thing."[29] In a similar vein, it may be noted that the most recent treatment of the problem of electrical conduction tends to regard it as a phenomenon of an "electron gas." This postulate is employed in the Fermi-Dirac statistics. "It involves," Darrow writes, "the volume V which the assemblage of particles pervades. For this we set the volume of the piece of metal—a decision which is tantamount to ignoring the atoms, to supposing the metal in a vacuum inhabited by free electrons only."[30] In its attitude toward energy, physics bears testimony to its views of the structure of matter as purely partitive. Rougier speaks of physics as having achieved in the quantum theory and in the theory of relativity "the materialization of energy."[31] This is a parallel of Millikan's opinion that energy is substantialized in scientific method. Energy has mass, inertia, and even structure; matter is regarded in terms of waves and fields.

The field concept of the general theory of relativity becomes, when it is considered no longer as an *empirical* hypothesis for measurement but as an *ontology* of matter, a system of dynamism like the energetism of Ostwald. "Matter is where the concentration of energy is great; fields where the concentration of energy is small."[32] Matter is in itself not the fundamental stuff it was thought to be by classical physics. It is a phenomenon of field. It is concentrated energy. A complete and consistent field theory has not been worked out. Even in the attempts—by men like Weyl and Mie—to unite gravitational and electromagnetic fields into a single system, there are lacunae. In spite of the failures, the aim of relativity physics is to elaborate a field-concept for the explanation of all phenomena.[33]

The restricted theory of relativity denied the existence of ether as an unobservable. The general theory restores it in new form. It becomes not a medium but the very stuff of the universe. It constitutes the space-time continuum which is the fundamental reality. Relativity may be said to geometrize the real, in a way that approaches the ideal of Descartes: the reduction of matter to extension. The fundamental science is world-geometry. A phenomenon is accounted for when its properties can be expressed in the geometry of the four dimensional manifold. But in another sense, the concept of material things in the general theory of relativity is not Cartesian. It is dynamistic like the monadology of Leibniz. It is the field, not matter, which is fundamental.

The field theory is not atomic. But it is partitive in the dynamistic sense of conceiving structure as a composite of divisible point-events expressible in world geometry. In the second place, it is not, in contemporary physics, the fundamental science of structure in the material world, at least in a verifiable sense. If the physicist is asked to determine the make-up of matter, he can only perform the task by empirical means. When he begins to experiment, he encounters the problem of the Heisenberg principle which contradicts the theory of relativity. In this point one finds the reason why quantum theory in its present form, despite the efforts of Dirac and others, cannot reach a meeting-ground with the theory of relativity. According to Einstein's hypothesis, a material entity is specified by space-time. In the quantum theory, position (space) and velocity (time) can never be specified simultane-

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[29] *Electrons (+ and —), Protons, Photons, Neutrons, and Cosmic Rays,* Chicago, 1935, p. 168.

[30] "Statistical Theories of Matter, Radiation, Electricity," p. 115.

[31] *La Matière et l'Enérgie,* Paris, 1921, p. xi.

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[32] Einstein, A., and Infeld, L., *The Evolution of Physics,* New York, 1932, p. 257.

[33] Weyl, H., *Raum, Zeit, Materie,* Berlin, 1923, p. 216.

ously. The simultaneous determination of these two co-ordinates has no meaning in quantum mechanics. In the theory of relativity, it is the most meaningful statement that can be made. Quantum mechanics has the upper hand today. We seek to determine experimentally what the world is made of. Experiment is the only standard which physics can employ. So we break up reality, and as we proceed with this process into the subatomic field, relativity loses its meaning. The profundity of this conflict should make us especially wary of accepting as final either quantum theory or relativity.

De Broglie has suggested that wave mechanics provides a means for overcoming the age-old conflict in physics between continuity and discontinuity.[34] Can matter-waves, like light waves, conjugate to form a continuum? The answer depends on our concept of waves both in matter and light. De Broglie suggests an answer based on wave mechanics. The existence of such a continuum, he points out, cannot be rigorously determined because of the Heisenberg principle. Because of this indeterminacy factor, one can only make successive and discontinuous measurements that result in probability values but never in a definite answer. Thus, the theory of wave-mechanics which pacified the conflict between matter and light may, if we may believe one of its leading spirits, also synthesize the continuum and discontinuum in modern physics.

But the continuum suggested by de Broglie is still only an aggregate. It is a sum, not a formal whole. The totality is reducible to the parts that make it up—reducible that is in a non-empirical sense because, practically, the principle of indeterminism impedes exact measurements. A similar answer may be given to the statement that whether the protons and neutrons retain their identity in the nucleus, "or whether they melt into a composite mass surrounded by an electron-neutrino atmosphere is not clear from general arguments."[35] A "composite mass" might well exist in

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[34] "Physique Ponctuelle et Physique du Champ," in *Revue de Métaphysique et Morale*, v. 45, p. 331.

[35] Breit, "Some Recent Progress in the Understanding of Atomic Physics," *Rev. Scientific Instr.*, vol. 9, p. 65.

this sense. But how does the physicist account for it? He reduces it to parts and then adds the parts together to make the whole.

The purpose of this chapter was to pass in review the present tendencies in physics toward the study of matter. New discoveries will be made in the immediate future. They are being made at this moment. They will add new facts to the picture of the world as the physicist paints it. They will not alter the general approach of physics. Nor will they force any changes in the philosophy of this method. They will only show further the atomizing method of modern physics which Planck has well described in the words, *Divide et impera.*

CHAPTER X

Beyond the Frontiers

It was fashionable up to very recent times to consider the atom as a miniature planetary system in which the orbital electrons revolved about a "nuclear" sun. This figure still applies, *mutatis mutandis,* even to the atom of wave mechanics. The component particles may not be exactly measurable. But physics tends to consider a material thing as a composite of disparate parts like the bodies of the solar system. The parts are held together by mechanical forces.[1]

The protest of Dirac that quantum mechanics is able "to give an absolute meaning to size"[2] does not employ the word *absolute* in the strict sense. "We may define an object to be big," he writes, "when the disturbances accompanying our observation of it may be neglected, and small when the disturbances cannot be neglected."[3] But this so-styled absolute meaning of size is in reality relative to our measuring instruments. Hence it is not truly absolute. With particle-guns operated by ever higher and higher voltages, it is possible that the units now considered ultimate may themselves be divided. It is entirely in the direction of the present method of physics that electron-, neutron-, and proton-smashers may replace the atom-smashers in use today.[4] It is true that it may be impractical to build instruments that will continue to divide matter indefinitely. Indeed with present-day facilities, attempts to divide the electron have been brought to failure.[5] But this does not mean that matter is not indefinitely divisible.[6] As d'Abro has stated the paradox of physics, if the supposedly ultimate elements had no structure, we could not study them empirically; if they had structure, then they would not be ultimate but divisible.[4] Indeed, the atomizing method implies in its own way the indefinite regress into smaller and smaller particles and the forces holding them together.

As it was noted in the foregoing chapter, not only in dealing with the entitative character of structure is science atomistic. Its whole treatment of dynamic phenomena is in parallel. Electrostatic attraction between proton and neutron holds the atom together. Exchange-forces keep the nucleus from exploding. The interplay of electrons between orbits accounts for radiation, according to the Bohr theory; motion and the theory of stationary states keeps the atom from collapsing. The spin-hypothesis accounts for certain spectroscopic phenomena. The neutrino helps to explain the continuity in the beta-ray spectrum. The Pauli exclusion principle accounts for certain variations in state as represented by the mathematics of wave-mechanics. Gravity helps to explain attraction. The concept of energy as possessing mass ac-

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[1] "The state of a physical system cannot well be otherwise defined than as the aggregate of all those physical quantities; through whose instantaneous values the time changes of the quantities, within given boundary conditions, are uniquely determined," Planck, M., *Eight Lectures on Theoretical Physics,* New York, 1915, p. 48.

[2] *The Principles of Quantum Mechanics,* p. 3.

[3] *Ibid.,* p. 4.

[4] "It may happen that further experiment will enable us to determine which of the various hypotheses corresponds to concrete reality. Such, indeed, was the hope of the scientists of the eighteenth and early nineteenth centuries. And in our days the practical isolation of electrons and molecules is a proof that these hopes were not always unfounded. Yet, even so, we should have advanced but a step and should again be faced with the problem of determining the structure of these electrons, and so *ad infinitum.* It would be of no avail to say that *our* aim had been realized when the ultimate constituent elements were isolated. For either these supposedly ultimate elements would have no structure, in which case we could never know anything further about them, or else they would present a structure; but then they would not constitute ultimate elements, since this structure would imply relationships between their various parts, and we should not be at the end of our journey," d'Abro, A., *Evolution of Scientific Thought from Newton to Einstein,* p. 402.

[5] Millikan, R. A., *op. cit.,* p. 161 ff.

[6] "It appears then that present experimental evidence makes very probable structures beyond the electron and the quantum; we may even go further and say that there is no experimental evidence that the sequence of phenomena in nature as we go to ever smaller scales is not in itself essentially infinite," Bridgman, P., *The Logic of Modern Physics,* p. 207.

counts for the decrement of mass in certain nuclear reactions. The concept of light as a wave explains the phenomena of interference and diffraction. The concept of light as corpuscular explains the photoelectric phenomenon and the Compton effect. The same duality is employed in the treatment of matter by quantum mechanics. In its analysis of matter, physics stops at atomistic *ad hoc* explanations. Even if they possess a species of unity like that of "content," they are only provisional accounts that can be altered, like the concept of ultimate particle, as physics proceeds further and further in dissecting matter. "It is the essence of the whole quantum theory that '*ad hoc*' explanations are made, *ad libitum*, where such assumptions serve a useful purpose."[7]

Such a system of concepts is not to be condemned as a scientific technique. It is the only method possible in a science that seeks after content and systematization. It has been a fruitful source of progress in both a theoretical and practical sense. The achievements of modern science are one of the wonders of the ages. But in philosophy, we must recognize physics for what it is. It is by no means a stigma that science employs a series of *ad hoc* explanations for phenomena that a philosopher, with a different purpose, would regard under a different light.

It is the contention of traditional philosophy that matter cannot be explained in terms of atomism. As Aristotle argued against the atomists, "in trying to state the causes of generation and destruction, and in giving a physical account of all things, they do away with the cause of movement. And in trying to state the case further, they err in not positing the substance, i.e., the essence, as the cause of anything. . . ."[8] The method of modern physics implies the indefinite regression. If material beings have no other realities except those empirically counted and correlated, then we cannot have an atom, we cannot have matter, we cannot have a universe. This idea may also be expressed in terms of the principle of inertia. If every material being is determined here and now only by the external forces acting on it, then every being is in itself a pure potentiality. If all material beings are purely potential, then

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[7] Richtmyer, F., *op. cit.*, p. 429 n.

[8] *Met.* 988 b, 26-28.

there is nothing in the material universe except the inert and the passive. The conclusion of scientific method, if in itself it is considered adequate to determine the constitution of matter, must eventually reach the absurd conclusion that it is made of nothing. In this sense, physics, unless there are realities outside of what it studies, leads to absolute nihilism. Genuine philosophy, on the other hand, while recognizing and admitting the obvious achievements of scientific method, avoids this contradiction of nihilism. It attains through its method of intellectual insight (abstraction) the realities of being, form, unity, act, value, and finality. Scientific theories are constructed to "save the facts." But if we want to "save the universe," then we must transcend the empirical level to the order of being.

In keeping with the view of a material thing as a mere sum, physics accounts for phenomena by a method of coordination and system (*ad aequivalens ab aequivalenti*). It remains, as it were, on the surface of reality without penetrating deeper down into its ultimate ontological foundations. In accounting for experience, it remains on the level of experience. Mathematics only equates (*ad aequivalens ab aequivalenti*). Equations in mathematics and physics are based on postulates that are neither mathematical nor empirical. A mathematical equation presupposes the ontological principles of being; and a physico-mathematical equation presupposes a subequational and subactional—as opposed to interactional—something which conjugates into a single unit the phenomena which physics treats as entirely partitive. Physics of itself tends to regard the world atomistically, without regard to the need for a principle of unity in being. Physics thus does not penetrate behind the mensurable wave-particles and their laws of interaction to their ontal foundations in *being*.

Being is referred to as that which is, *id quod est*. It has various meanings in the history of philosophy and in common usage. Here we may distinguish between being as considered by common sense (*ens commune*)[9] and the being of metaphysics (*ens in quantum ens*). The former notion is a primary idea.[10] Common sense rec-

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[9] Cajetan, *In De Ente et Essentia*, proemium, q. 2.

[10] *de Ver*, q. 1 a. 1.

ognizes that something is. It refers to a dog, a stone, a house, as beings. But the idea of being as being is attainable only by a most difficult abstractive process.[11] The two concepts of being—the vague concept of common sense and the formal concept of metaphysical science—do not differ in kind; for nothing can be added to being in the real sense. Metaphysics deepens and purifies the plain man's notion of being and explores its reasons and relations. The idea of being as being can be grasped and studied only in abstraction from all properties pertaining to this or that thing, only when we come to examine reality in its pure character of "is-ness"; but the confused idea of being is implied in every intellectual operation. The first principles—the principles of identity, of non-contradiction, and of excluded middle—are but the considerations in judicial form of this primary idea. Every one, scientist, philosopher, and peasant has, as far as he is an intelligent being, this common idea of *ens commune*.

Metaphysics studies being as being. Being in this sense is transcendental. It rises above all determination to this or that category of reality. Disengaged from the flux and flow of the world of time and space, this being is the stark reality of that which is, that which can be, in other words existential essence. It is not measureable in terms of quantity; it itself is not quantified.

Physical science does not attain to this deep reality in the material world. Because it does not reach down to the metaphysical substructure of the world we perceive with our senses and study in such instruments as cloud-chambers, physics attains only limited aspects of reality and fails to embrace the fundamental, not-directly-qualified facts which make the aspects real.[12] But this does not mean that the scientist as a man and as a scientist is wholly out of touch with being in the general sense. An idea of being plays the fundamental role in all intellectual operations. The scientist as far as he studies *something* certainly has a notion of being. It has in fact become almost a truism to say that the empirical sciences

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[11] Cajetan, *op. cit.*, proemium q. 2.

[12] "If, with science, we consider that our knowledge of the external universe can be arrived at only by a rational synthesis of facts of experience, we must recognize that substance escapes us completely; all we can hope to approach is structure or relationships," d'Abro, *op. cit.*, p. 400.

are concerned with a special kind of being. Thus biology is said to study living beings; chemistry and physics, corporeal beings; and so on. But the physical sciences do not study their objects *qua* beings. If physical science is concerned with *ens sensibile*, the accent is, as Maritain says, on the *sensibile* and not on the *ens*.[13] Being serves only as a remote material object to physics. As in the case of hylemorphism, whether literally in its application to bodies, or analogically, in its application to the form-matter character of definition by specific difference and genus as is here the case, the material serves only as an indeterminate principle. It is the determinations which flow from form that knowledge attains. In the knowledge proper to empirical physics in the widest scope of such a science, the remote material object, being, is neglected, and the formal object, corporeality, is the unique concern.

Aquinas defined being as the actuality of a thing.[14] In this point, his system stands in sharp contrast to the regressive, atomizing study of structure in contemporary atomic physics where the only realities, it was noted, are those viewed as mere recipients, acted on from the outside; mere potentialities. Being and operations are viewed as being determined by smaller partitive processes and so on ad infinitum. In the recognition of being in terms of actuality, genuine metaphysics transcends the scientific method which regards material being as purely passive and ends by reducing the universe to a vacuum. In acknowledging the reality of something that is simple, that is something one, in being, genuine metaphysics gives proof of its realism. If atomism and inertia are adequate to the plenary nature of reality, then our study of matter must end by explaining it away.[15] Such realities as actuality, undividedness, it

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[13] *Les Degrés du Savoir*, p. 77.

[14] I, 5, 1.

[15] *Inertia* is being taken in the Newtonian sense of mere passivity. Relativity theory in its field concept has given a somewhat different interpretation to inertia. It has equated gravitational and inertial mass. It recognizes that in a given coordinate system, the law of inertia holds (local inertia), but the transformations (Lorentz equations) from one co-ordinate system to another cannot be made in terms of the law of inertia, which has no meaning in this sense but only in terms of the gravitational field (accelerated motion). But Relativity has no meaning on the contemporary quantum study of micro-structure; its admission of local inertia for individual co-ordinate

may be noted, are by their very being outside the ambit of scientific method. They do not, in d'Abro's sense, have "structure." They cannot be measured and reduced to mathematics. They can be studied only by intellectual insight (abstraction). Only an intellect can attain to the actuality which is being. Only the power of a simple substance is adequate to grasp the undividedness.

But if every intellectual activity presupposes a notion of being and if the physicist does not attain to being as being, it may be asked what conceptual basis is employed in physics to represent the "structure" of the universe. What corresponds in the real world to the *something* envisioned by atomic physics? Perhaps it can be called schematological being as opposed, if the pleonasm will be pardoned, to the ontological being of metaphysics. Why it should be so-called may be argued from the atomizing character of modern physics in which matter, in its ultimate make-up, is regarded as a mere lattice-work of wave-particles where the dynamic, infra-atomic phenomena are accounted for by *ad hoc* explanations that must continually be multiplied like the particles themselves. If physics pulverizes reality, it does not, as physics, attain to a true conception of being in the conceptual framework it employs for working operations. Plurality is opposed to entity as a contrary opposite because being is one.[16] This is additional proof that physics, because it pluralizes matter, does not attain to matter's ultimate reality, its being-ness. The account which physics gives of microstructure (and therefore of the macrostructure which is reducible in physics to the study of subatomic particles) is only a *schema* of the real.[17] This is the reason for the term *schematological,* to characterize the concept of being that the physicist must logically accept as a physicist, obedient to his atomizing method.

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systems brings it, as far as the purely empirical aspects of physics are concerned, under the same laboratory treatment as any inertial system. *Inertia,* as a physical concept, need not refer only to local motion as in Newton's first law but to the scientific view of a thing as having no actuality in itself but as being completely determined from the outside. The theory of relativity accepts this view for local systems.

[16] I, 11, 1 ad 2.

[17] Riezler says in his imaginary dialogue of Aristotle with the modern physicist: "These distinctions, transplanted from their native soil to your scheme of nature, would lose their interconnection and correlation in the notion of substance. Separated from substance they become separated from one another and can no longer say what they want to say—like single letters which have lost their word," *op. cit.*, p. 105.

The unity of being may be thought of in two ways, corresponding to the two references it has in reality. It may be the transcendental unity of being as being, or the predicamental unity in the order of quantity. Predicamental or categorical unity is the principle of number and is found in every being as far as it is this or that *determinate* (i.e., categorical) being in the material order. It adds something real to the determinate being. It is the basis for enumeration and also classification.[18] Modern physics may be likened to ancient Pythagoreanism. With its tendency to disregard all but the mathematical aspects of the real, it is formally occupied with this predicamental or categorical unity. Here indeed lies a principal reason for its circumscribed character.

Transcendental unity, on the other hand, pertains to being as being. It is defined as the undividedness of being itself.[19] Nothing can be added to being which is not already included in being. Unity expresses a general mode of being, the negation of division.[20] That unity is convertible with being is proved by Aquinas in a very simple but forceful fashion. All being is either simple or composite. If it is simple, it is already one. If it is composite, then it does not have being so long as its parts are divided but only when they are put together. This may be exemplified by the instance of a house. As long as the stones and other structural units are not put together, the house is not a being. It is only a being when put together.[21] Aquinas hints that this is only a figurative example since the house is an artifact. The unity of being is "like" a house. A house is an aggregate. It is not a per se unity. Nevertheless, the example suggests in its own way the deep metaphysical meaning of *Ens et unum convertuntur*. The realities of potentiality and actuality shed clearer light on the fact that transcendental unity does not add a real determination to being but *is* being itself when the mind inspects it from the viewpoint of its undividedness. If we example being as it is in man, we find it to be a composite of

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[18] I, 11, 1.

[19] I, 30, 3.

[20] *In Met.* IV, 21.

[21] I, 11, 2 ad 2.

animality and rationality. Neither constitutes man itself. Nor does each possess a unitary self-subsistent character in the composite. The animality of man is not terminated in itself as the unity of a dog or horse. In man, animality is indeterminate when considered in itself.[22] It is subsumed as a potential principle in the species man. It is only when so actuated that man, the substantially united rational animal, becomes a being.

From the fact that being is one, it is apparent that being, for the physicist as such, is not the deep transcendental reality studied by the science of metaphysics. The physicist's account of the world is not ontological. It pluralizes being. It presents only a schema. The physicists may assert that they do not make pictures or models in the exact sense. But here the question is not the physicist's working representation of reality but the way reality is representable according to the method of physics. Obedient to its atomizing nature, physics must regard its units as composite things held together by unifying forces (superadded to being and not convertible with it). With ever more refined technique, it is possible that the ultimate particles will themselves be "smashed" like the atoms. So *ad infinitum*. Aquinas, in a passage remarkably adapted to this problem, declares: "If a being were one in virtue of something else and if this unifying something which is also one, were one in virtue of still something else, the process would go on ad infinitum."[23] Being is one by its nature, not in virtue of additions. As Riezler states in his imaginary dialogue of Aristotle with the modern physicist: "The little word 'is' has a double meaning. Corresponding to this double meaning are two senses of the word 'nature.' First yours: the order of Many in time and space, nature as a world. Then mine; nature as 'Physis,' the structure of concreteness so far as the concrete is concrete, nature as Being: Physis, born together, as Plato says."[24]

We cannot claim to have found the simplest particles of matter in the units so common in the vocabulary of contemporary science. All we can say is, in the words of Millikan, "*There has appeared*

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[22] *de Pot.* 9, 4.
[23] I, 11, 1.
[24] *Op. cit.*, p. 60.

up to the present time no evidence for the existence of a sub-electron."[25] But until the end of the nineteenth century, the atom itself was thought to be indivisible. All this shows the typically changing character of scientific ideas. Physics is like a serial story that reaches climax in each installment but never comes to a final conclusion. Because we cannot make the divisions in matter, it does not follow that a given particle is indivisible, for the so-called ultimate particles have, in d'Abro's language, structure. Hence being for the physicist, prescinding from the ideas which he might have as a man, is divided being (*ens divisum*)—a contradiction in terms if fully analyzed. It is not the true being of metaphysics. It is schematological.

Unity, undividedness, act elude the scientific method. Physics studies material realities which are composite unions in themselves. But it studies these realities not as they are unities but as they are composites. Unity, as such, escapes scientific technique because it, like being, does not derive its reality from another determination (it is in itself convertible with being). Being and its attributes (which are really identical with being but differ only logically, as far as we look at being in different ways) cannot be discussed in terms of addition and subtractions. Science can only study that which is definable in terms of superadditions, that which is, in itself, inert, deriving its reality from the outside. It cannot study being. It cannot study unity. Its conceptual system does not reach being as being but only a *schema* of reality. Compared to the fullness of the real, the conception of reality, according to the method of physics, is, in a simile suggested by Aristotle, like a string of syllables that are considered apart from the word they form.[26] Such an appraisal of the conceptual structure of physics does not mean that scientific theories and constructs are wholly out of contact with reality. It was already noted that they have a material correspondent in the real world. But the scientific method does not exhaust the riches of reality. It does not reach the ultimate principles of the real which exist on a level which physics cannot attain.

True knowledge should proceed from the complex to the simple.

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[25] *Op. cit.*, p. 181.
[26] *Met.* IV, 1014 a 30-31.

Philosophy begins with the discrete data of sense and ascends to the unity of being itself. But being as being, the object of metaphysics, is not simple under every aspect when regarded as an analogue. If it leaves room for the projection of the analogates, it has an aspect of complexity. Aquinas speaks of the references between analogue and analogates as being partly the same and partly different.[27] The expression "partly" may be misleading if given spatial significance. But perhaps this difficulty proceeds more from language than from thought since we must necessarily express all our concepts by means of ideas, either affirmative or negative, borrowed from the sensible order. As far as each analogate has reference to the same analogue, we preserve the unity of being. But as far as each reference differs, beings can be diversified and multiplied, and pantheism can be refuted. But if being as being is analogical, it is primarily one and only secondarily (an analogically) complex. The schematological being of science, on the other hand, is primarily multiple, so to speak, and only secondarily one—one, that is, because only in terms of mental unity can the mind understand the multiple.

To specify this or that apparently unified being in the inorganic world as bearing substantial unity is another and far more difficult question. Do the elements differ from one another merely by the addition and subtraction of nuclear particles? Does the proton, if it is a composite of neutron and positron, differ specifically from the parts that make it up; or is it a mere mechanical aggregate of its component parts as the physicist would describe it? The physicist, as such, can rightly refrain from pronouncing on the character of the composition in the matter he studies. Such a question is beyond the compass of his science. On the other hand, the philosopher because of the evidence available in the present status of atomic physics, may not be able to determine whether the parts of an atom (or proton, etc.) are substantially or only accidentally united. In order to study the electron, the neutron, the proton, the physicist must remove it from its natural context within the atom. Hence by the very conditions of the problem, the philosopher cannot decide the question of the relation of the particles to the whole of the atom.

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[27] *In Met.* IV, 1.

Do they become subsumed under a formal character in an element, losing their identity in the potentiality of matter? Or are they mere mechanical parts of an accidental union, like the bodies of the solar system?[28] Eddington has asked the question whether the electron is discovered or created, whether the scientist takes reality as it is, or shapes it as a sculptor carves a statue out of marble.[29] Though Eddington aims to establish by his argument that knowledge is *a priori,* his question is not wholly meaningless even for the realist in philosophy. We cannot speak of the creation of an electron from matter. But we may well bring about a change in the constitution of an atom so that the electron which was potentially an electron in its status within the substantial unity of the atom, now becomes actually an electron, a whole in itself and no longer a part. The attempt to interpret present-day atomic physics entirely as a partitive mechanical aggregate, like the solar system, is based upon analogy and is subject to its logical pitfalls. "A model of this kind, for example, a system of mechanical, wave, or vortex motions, implies inexact or incomplete argument by analogy from a macroscopic to a different *microscopic* situation."[30]

A decision on this mooted question is not essential to present purposes. If the atom is a substantial union or not, if the proton is a mechanical aggregate or not, it is sufficient to have established that somewhere within the matter studied by scientific method there is the being, the unity, the actuality, the undividedness which escapes physics but without which the cosmos would be emptied of the real. Since this being is a material being, its quantity may be further divided, because quantity, as such, is indefinitely divisible. But its being cannot be divided without changing it into something else.[31] If an atom may be considered, by way of mere example, to be a substantial union, it may, as far as it is quantified, be indefinitely divided. But when we divide the parts from one an-

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[28] The philosopher need not necessarily indicate the level of reality, molecular, atomic, or subatomic, where form appears. It suffices to show that, if the macroscopic world is mechanical, we eventually, in breaking it up, come to a point where mere mechanism is insufficient and where form must be recognized.

[29] *The Philosophy of Physical Science,* pp. 106 ff.

[30] Whyte, L., *op. cit.,* p. 122.

[31] *de Pot.* IV, 1, ad 5.

other, we may, as we see in the phenomenon of atom-smashing, change the nature of the original atom so that it becomes an atom of a different element.[32] A certain minimum of quantity would be necessary to preserve the substantial unity of such a being, and the indefinite division in the order of quantity as such, changes the nature of the atom and perhaps also, if the division is carried far enough, the nature of the subatomic particles.

In cases of substantial union between parts, new species are not formed by mere addition of mechanical parts to mechanical parts but by substantial changes. For the substantial being of a thing is indivisible.[33]

Indivisibility cannot be studied by scientific method. Physics can only attain to the inert, the quantified, the divisible. For physics differences between realities are additive, and quantified, not specific and substantial. In our present knowledge of particle phenomena, we must isolate the fundamental units before we can study them. Their nature as part of the atom is not amenable to scientific method. Though by the very terms in which the problem is stated, one cannot expect the physicist to determine the relationship of electrons, waves, neutrons, and exchange-forces, and so on, within the atom itself, for the very same reason we cannot follow along with the physicist in his reduction of the atom to mere partitive phenomena.[34] It is only of importance to establish here that there are realities which the physicist, as such, does not attain and which are guarantees against the nihilism of the method of atomic physics, if it alone is adequate to the real. As Riezler has written to the contemporary physicists: "If you expect your concepts to reach the realness of reality, they ought to be conjoined as a whole in a logical structure that shows each concept as one-to-others. Such a logic builds up concreteness; wherever you meet concreteness you have to do with such a structure. I might say: your concepts have to grow together—*concrescere*. If they did, your world would no longer lack reality. But they cannot. A link is missing—substance."[35]

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[32] *In Met.* V, 15.

[33] I, 76, 4 ad 4.

[34] I, 76, 3 ad 4.

[35] *Op. cit.*, p. 74.

If there are in the world of matter beings which are one and substantially one, then there is a principle in each substantially different being which makes it to be what it is and which cannot be reduced to the mere addition of particles in the realm of the quantified. For this principle which makes a thing to be what it is cannot be itself determined and dependent (like the inert, passive realities which are conceived by physics). It is a principle which is not determined but determining, not inert but active, not quantitative but simple and indivisible.[36] This is entelechy or form.[37] It is the principle of perfection in matter, the principle of union, a principle of intelligibility and not of number and quantitative measurement. It is not superadded to an already actualized matter, as the Drieschian entelechy is superadded in a living thing to the mechanical energies. Nor it is not compounded with matter as sodium combines with chlorine to form salt. The problem of hylemorphism is not on the empirical level. It can neither be raised not settled by pointer-readings.

Opposed to the actualizing entelechy or form is a potential substrate, the thing that the form determines. Because it must be united immediately to the form and not, as a mechanical union would have it, through a medium that would, as in physics, involve us in an infinite regress, because of this immediacy, the potential substrate has no actuality of its own, apart from the entelechy. Hence, there can be a substantial union—a union that is on a different level from the mechanical aggregation which physics believes to exist in compounds and in atoms.[38] The empirical physics of

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[36] "Et forma, per quam unaquaeque res continetur in suo esse *terminus* dicitur," *In De Div. Nom.*, 1, 2, 3. (Italics are mine.)

[37] The English word "form," like the Latin "forma," does not convey the thought of traditional philosophy in speaking of substantial form. The original Greek term, ἐντελέχια, entelechy (ἐν τελει ἐχείν to be complete) is much clearer. The term, entelechy, has been popularized by Driesch in psychology. In this context, the name has acquired an unfortunate meaning which is not in accord with Aristotelian concepts nor with the reality designated by the word "form." However, despite its confusion, entelechy is perhaps less awkward in English as a rendering of "forma substantialis" which conjures up, in an age accustomed to quantity, the connotation of spatial figure and shape.

[38] *In Met.* VII, 2.

Aristotle has been jettisoned by the facts discovered and the theories advanced in the modern science of physics. But man's mind is challenged today by the same dilemma that confronted Aristotle and his master, Plato—the problem of the bifurcation in matter. We observe in material beings inertia and activity, quantity and quality, extension and indivisibility, flux and permanence, corruption of individuals and the recurrence of a type or species. Whitehead has perceived this problem, viz., "that there is an essential atomic property in nature which is independent of the dissociation of extension. There is something which in itself is one, and which is more than the logical aggregate of entities occupying points within the volume which the point occupies."[39] He recognizes that there are so-called "prehensive" and "separative" characters in the world, the limitations of things by their "modalities." But his philosophy of organism is monistic and even pantheistic. Aristotle's answer was dualistic.

The method of physics cannot study the entelechies of material things. It cannot study substantial composition. It can neither accept nor reject the idea of a primary substantial substrate. Its work is carried out on a different level from that of the philosopher with his analytico-synthetic method of intellectual insight. Entelechy is a terminus. The physicist cannot find meaning in this idea. It does not have structure. It is not determined by something else, acting on it as on an inert passive body. Substantial differences are not matters of addition of particles in the mechanical sense. Entelechy as such is not the result of juxtaposition as such. It is educed from the potentialities of the substrate.[40] As Aristotle wrote, "But we maintain that if 'combination' has taken place, the compound *must* be uniform in texture throughout—any part of such a compound being the same as the whole, just as any part of water is water; whereas if 'combination' is composition of the small particles, nothing of this kind will happen."[41] If the physicists reject the scientific view of Aristotle that water is a compound in the sense described, the philosophical view of substantial combination remains unchanged. Somewhere within the particles studied by physics, whether it be on the level of the macroscopic bodies, of molecules, of atoms, or of subatomic particles, this substantial composition exists. The philosopher may not be able to put his finger on the level of reality where we can no longer discover accidental unity in things but must come to that higher, inner, active unity that flows from form. But he can say with certitude that somewhere down in the deep reaches of matter this unity, this form, this entelechy, this non-inertial reality resides.

It is the reality of this entelechy or form that saves matter from the infinite mechanical regression which would render it a void. As Aquinas in following Aristotle remarks, "Substantial form is not only the perfection of the whole but of every part."[42] It confers being by its immediate union with matter. There is no indefinite mediation of particles and forces as we have in modern physics, both in method and result.[43] "Form by itself renders a thing actual, since by its essence it is not act, nor does it confer being through a medium."[44]

The immediacy, the termination, the directness of form evades the technique of physics. Entelechy, because it is immediate, can only be grasped by the faculty of immediation, viz., abstraction. Abstraction directly apprehends reality without the middle term and without the enumeration which are demanded by physics. As Aquinas says, between the individual and the species, there is no middle term.[45] An immediate thing does not have what d'Abro calls "structure." It cannot be apprehended by physics. It can only be attained by abstraction.

Because entelechy confers being, because it combines with the primary potential substrate to form a reality which is the same in its whole and in its parts, entelechy also confers unity.[46] Such a unity, which is not a mere mechanical aggregation, is made possible by the fact that one of the principles is purely potential.[47]

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[39] *Concept of Nature*, p. 23.

[40] I, 66, 1.

[41] *On Gen. and Corr.*, 328 a, 10-13.

[42] I, 76, 8.

[43] I, 76, 4.

[44] I, 76, 7.

[45] Cf. *supra*, p. 134.

[46] *Quodl.*, I, 6.

[47] *In Met.* VIII, 5.

Quantitative parts are present within such a unity. But they are present as parts. Division is necessary to render them wholes. Until then they do not bear an actual existence as something definite and distinct in themselves.[48] It may be affirmed only that the quantity in such a unified being is divisible. It is not actually divided. Quantity may be divisible *ad infinitum*. But it is never actually so divided. This terminus is a substantial being, this undividedness in quantity and indivisibility in being is supplied by the entelechy. There must be immediation in such a being. With the mediation of parts and forces, there would be an infinite regress.

Such an infinite regress results if we equate reality and the subject-matter of physics. Thereby we negate reality altogether. There could, as Aquinas says, be no knowledge either. It is form or entelechy that unifies matter and makes it intelligible.[49] As Plato noted, if the one (unity) does not exist, then nothing can be or be conceived.[50]

Only in the plenitude of being which embraces everything that exists or can exist do we have a science of totality, a science of that which is. Recognizing limits where limits exist, the philosopher does not lay claim to an exhaustive knowledge of the infinite recesses of being, of unity, and of form. But his knowledge which grows by an *intensive*[51] deepening of the universal whole has already brought him into contact with reality's farthest depths. He is truly in the order of the ultimates. His knowledge, however, is imperfect because incomplete. The physicist on the other hand, whose knowledge grows by an *extensive* passage from part to part does not touch the level of being, of unity, and of form. He deals only with mediations, never with immediacies. His knowledge is imperfect, not, because it is incomplete in its own order, but because the very empirical order itself is not adequate to reality, being, unity, and entelechy. His knowledge is not only imperfect in degree but also in kind. The schematological being of the science

of physics, while having a real counterpart in nature, is not the ontological being of the science of metaphysics. If it is transferred to the level of ontology, it becomes an *ens divisum,* a contradiction in terms, like a square circle.

Galileo has won his battle with Aristotle in the modern mind, trained as it is to regard scientific method as the only technique of study and the subject-matter of physics as the only reality. But such an attitude over-simplifies the cosmos and fragmentizes knowledge. Galileo and Aristotle can join hands if we look to principles. By making distinctions where distinctions exist, we can have both modern empirical science and the traditional sciences of metaphysics and cosmology. The method of modern physics in theory and in practice has given the modern mind both knowledge and practical achievements hitherto undreamed of. Yet it has clear-cut philosophical frontiers within which it will continue to advance but beyond which it may not go. It is only to be reasonable, it is only to be realistic, to recognize limits imposed by the nature of things. When that is done, the disputed frontiers between science and philosophy will no longer be the battle ground they now are. The poet, philosopher, and the scientist can again work together.

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[48] *In Sent.* IV, d. 10, 1, 3 ad 3 sol. 3.

[49] *I Anal. Post.* 36.

[50] *Par. op. cit.*, p. 140.

[51] Maritain, J., *Sept Lecons sur l'Etre*, pp. 5 ff.

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