"The Debate Between Plato and Democritus", Werner…

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Werner Heisenberg

It was here in this part of the world, on the coast of the Aegean Sea, that the philosophers Leucippus and Democritus pondered about the structure of matter, and down there in the marketplace, where twilight is now falling, that Socrates disputed about the basic difficulties in our modes of expression and Plato taught that the Idea, the form, was the truly fundamental pattern behind the phenomena. The problems first formulated in this country two and a half thousand years ago have occupied the human mind almost unceasingly ever since and have been discussed again and again in the course of history whenever new developments have altered the light in which the old lines of thought appeared.

If I endeavor today to take up some of the old problems concerning the structure of matter and the concept of natural law, it is because the development of atomic physics in our own day has radically altered our whole outlook on nature and the structure of matter. It is perhaps not an improper exaggeration to maintain that some of the old problems have quite recently found a clear and final solution. So it is permissible today to speak about this new and perhaps conclusive answer to questions that were formulated here thousands of years ago.

There is, however, yet another reason for renewing consideration of these problems. The philosophy of materialism, developed in antiquity by Leucippus and Democritus, has been the subject of many discussions since the rise of modern science in the seventeenth century and, in the form of dialectical materialism, has been one of the moving forces in the political changes of the nineteenth and twentieth centuries. If philosophical ideas about the structure of matter have been able to play such a role in human life, if in European society they have operated almost like an explosive and may yet perhaps do so in other parts of the world, it is even more important to know what our present scientific knowledge has to say about this philosophy. To put it in rather general and precise terms, we may hope that a philosophical analysis of recent scientific developments will contribute to a replacement of conflicting dogmatic opinions about the basic problems we have broached, by a sober readjustment to a new situation, which, in itself, can even now be regarded as a revolution in human life on this earth. But even aside from this influence of science upon our time, it may be of interest to compare the philosophical discussions in ancient Greece with the findings of experimental science and modern atomic physics. If I may already anticipate at this point the outcome of such a comparison; it seems that, in spite of the tremendous success that the concept of the atom has achieved in modern science, Plato was very much nearer to the truth about the structure of matter than Leucippus or Democritus. But it will doubtless be necessary to begin by repeating some of the most important arguments adduced in the ancient discussions about matter and life, being and becoming, before we can enter into the findings of modern science.

The Concept of Matter in Ancient Philosophy

At the beginning of Greek philosophy there stood the dilemma of the “one” and the “many.” We know that there is an ever-changing variety of phenomena appearing to our senses. Yet we believe that ultimately it should be possible to trace them back somehow to some one principle.

The founders of atomism, Leucippus and Democritus, tried to avoid the difficulty by assuming the atom to be eternal and indestructible, the only thing really existing. All other things exist only because they are composed of atoms. The antithesis of “being” and “non being” in the philosophy of Parmenides is here coarsened into that between the “full” and the “void.” Being is not only one; it can be repeated infinitely many times. Being is indestructible, and therefore the atom, too, is indestructible. The void, the empty space between the atoms, allows for position and motion, and thus for properties of the atom, whereas by definition, as it were, pure being can have no other property than that of existence. This latter part of the doctrine of Leucippus and Democritus is at once its strength and its weakness. On the one hand, it provides an immediate explanation of the different aggregate states of matter, such as ice, water, and steam, since the atoms may lie densely packed and in order beside each other, or be caught in disorder and irregular motion, or finally be separated at fairly large relative intervals in space. This part of the atomic hypothesis was therefore to prove exceedingly fruitful at a later stage. One the other hand, the atom becomes in this fashion a mere building block of matter; its properties, position, and motion in space turn it into something quite different from what was meant by the original concept of “being.” The atoms can even have a finite extension, and here we have finally lost the only convincing argument for their indivisibility. If the atom has spatial properties, why should it not be divided? At least its indivisibility then becomes a physical, not a fundamental property. We can now again ask questions about the structure of the atom, and we run the risk of losing all the simplicity we had hoped to find among the smallest parts of matter. We get the impression, therefore, that in its original form the atomic hypothesis was not sufficiently subtle to explain what the philosophers really wished to understand: the simple element in the phenomena and in the structure of matter.

Still, the atomic hypothesis does go a large part of the way in the right direction. The whole multiplicity of diverse phenomena, the man observed properties of matter, can be reduced to the position and motion of the atoms. Properties such as smell or color or taste are not present in atoms. But their position and motion can evoke these properties indirectly. Position and motion seem to be much simpler concepts than the empirical qualities of taste, smell, or color. But then it naturally remains to ask what determines the position and motion of the atoms. The Greek philosophers did not attempt at this point to formulate a law of nature; the modern concept of natural law did not fit into their way of thought. Yet they seem to have thought of some kind of causal description or determinism, since they spoke of necessity, of cause and effect.

The intention of the atomic hypothesis had been to point the way from the “many” to the “one,” to formulate the underlying principle, the material cause, by virtue of which all phenomena can be understood. The atoms could be regarded as the material cause, but only a general law determining their positions and velocities could actually play the part of the fundamental principle. However, when the Greek philosophers discussed the laws of nature, their thoughts were directed to static forms, geometrical symmetries, rather than to processes of space and time. The circular orbits of the planets, the regular geometrical solids, appeared to be the permanent structures of the world. The modern idea, that the position and velocity of the atom at a given time could be uniquely connected by a mathematical law with its position and velocity at a later time, did not fit into the pattern of thought of that era since it employs the concept of time in a manner that arose only out the the thinking of a much later epoch.

When Plato himself took up the problems raised by Leucippus and Democritus, he adopted the idea of smallest units of matter, but he took the strongest exception to the tendency of that philosophy to suppose the atoms to be the foundation of all existence, the only truly existing material objects. Plato's atoms were not strictly material, being thought of as geometrical forms, the regular solids of the mathematicians. These bodies, in keeping with the starting point of his idealistic philosophy, were in some sense the Ideas underlying the structure of matter and characterizing the physical behavior of the elements to which they belonged. The cube, for example, was the smallest particle of the element earth and thereby symbolized at the same time the earth's stability. The tetrahedron, with its sharp point, represented the smallest particle of the element fire. The icosahedron, which comes closest among the regular solids to a sphere, stood for the mobility of the element water. In this way the regular solids were able to serve as symbols for certain tendencies in the physical behavior of matter.

But they were not strictly atoms, not indivisible basic units like those of the materialist philosophy. Plato regarded them as composed from the triangles forming their surfaces; therefore, by exchanging triangles, these smallest particles could be commuted into each other. Thus two atoms of air, for example, and one of fire could be compounded into an atom of water. In this way Plato was able to escape the problem of the indefinite divisibility of matter. For as two-dimensional surfaces the triangles were not bodies, nor matter, any longer; hence matter could not be further divided ad infinitum. At the lower end, therefore, in the realm, that is, of minimal spatial dimensions, the concept of matter is resolved into that of mathematical form. This form determines the behavior, first of the smallest parts of matter, then of matter itself. To a certain extent it replaces the natural law of later physics; for without making explicit references to the course of time, it characterizes the tendencies in the behavior of matter. One might say, perhaps, that the fundamental tendencies were represented by the geometrical shape of the smallest units, while the finer details of those tendencies found expression in the relative position and velocity of these units.

This whole description fits exactly into the central ideas of Plato's idealist philosophy. The structure underlying the phenomena is not given by material objects like the atoms of Democritus but by the form that determines the material objects. The Ideas are more fundamental than the objects. And since the smallest parts of matter have to be the objects whereby the simplicity of the world becomes visible, whereby we approximate to the “one” and the “unity” of the world, the Ideas can be described mathematically—they are simply mathematical forms. The saying “God is a mathematician,” which in this form assuredly derives from a later period of philosophy, has its origin in this passage from the Platonic philosophy.

The importance of this step in philosophical thought can hardly be reckoned too highly. It can be seen as the decisive beginning of the mathematical science of nature, and hence be made responsible also for the later technical applications that have altered the whole picture of the world. By this step it is also first established what the term “understanding” is to mean. Among all the possible forms of understanding. Whereas all language, indeed, all art and all poetry in some way mediate understanding, it is here maintained that only the employment of a precise, logically consistent language, a language so far capable of formalization that proofs become possible, can lead to true understanding. One feels the strength of the impression made upon the Greek philosophers by the persuasive force of logical and mathematical arguments. They are obviously overwhelmed by this force. But perhaps they surrendered too early at this point.

The Answer of Modern Science to the Old Problems

If we trace the history of physics from Newton to the present day, we see that, despite the interest in details, very general laws of nature have been formulated on several occasions. The nineteenth century saw an exact working out of the statistical theory of heat. The theories of electromagnetism and special relativity have proved susceptible of combination into a very general group of natural laws containing statements not only about electrical phenomena but also about the structure of space and time. In our own century, the mathematical formulation of quantum theory has led to an understanding of the outer shells of chemical atoms, and thus of the chemical properties of matter generally. The relations and connections between these different laws, especially between relativity and quantum theory, are not yet fully explained. But the latest developments in particle physics permit one to hope that these relations may be satisfactorily analyzed in the relatively near future. We are thus already in a position to consider what answers can be given by this whole scientific development to the questions of the old philosophers.

During the nineteenth century, the development of chemistry and the theory of heat conformed very closely to the ideas first put forward by Leucippus and Democritus. A revival of the materialist philosophy in its modern form, that of dialectical materialism, was this a natural counterpart to the impressive advances made during this period in chemistry and physics. The concept of the atom had proved exceptionally fruitful in the explanation of chemical bonding and the physical behavior of gasses. It was soon, however, that the particles called atoms by the chemist were composed of still smaller units. But these smaller units, the electrons, followed by the atomic nuclei and finally the elementary particles, protons and neutrons, also still seemed to be atoms from the standpoint of the materialist philosophy. The fact that, at least indirectly, one can actually see a single elementary particle—in a cloud chamber, say, or a bubble chamber—supports the view that the smallest units of matter are real physical objects, existing in the same sense that stones or flowers do.

But the inherent difficulties of the materialist theory of the atom, which had become apparent even in the ancient discussions about smallest particles, have also appeared very clearly in the development of physics during the present century.

This difficulty relates to the question whether the smallest units are ordinary physical objects, whether they exist in the same way as stones or flowers. Here, the development of quantum theory some forty years ago has created a complete change in the situation. The mathematically formulated laws of quantum theory show clearly that our ordinary intuitive concepts cannot be unambiguously applied to the smallest particles. All the words or concepts we use to describe ordinary physical objects, such as position, velocity, color, size, and so on, become indefinite and problematic if we try to use them of elementary particles. I cannot enter here into the details of this problem, which has been discussed so frequently in recent years. But it is important to realize that, while the behavior of the smallest particles cannot be unambiguously described in ordinary language, the language of mathematics is still adequate for a clear-cut account of what is going on.

During the coming years, the high-energy accelerators will bring to light many further interesting details about the behavior of elementary particles. But I am inclined to think that the answer just considered to the old philosophical problems will turn out to be final. If this is so, does this answer confirm the views of Democritus or Plato?

I think that on this point modern physics has definitely decided for Plato. For the smallest units of matter are, in fact, not physical objects in the ordinary sense of the word; they are forms, structures or — in Plato's sense — Ideas, which can be unambiguously spoken of only in the language of mathematics. Democritus and Plato both had hoped that in the smallest units of matter they would be approaching the "one," the unitary principle that governs the course of the world. Plato was convinced that this principle can be expressed and understood only in mathematical form. The central problem of theoretical physics nowadays is the mathematical formulation of the natural law underlying the behavior of elementary particles. From the experimental situation we infer that a satisfactory theory of the elementary particles must at the same time be a theory of physics in general, and hence, of everything else belonging to this physics.

In this way, a program could be carried out that in modern times was first proposed by Einstein: a unified theory of matter—and hence, simultaneously, a quantum theory of matter—could be formulated, which might serve quite generally as a foundation for physics. We do not yet know whether the mathematical forms proposed for this unifying principle are already adequate or will have to be replaced by forms more abstract still. But our present knowledge of the elementary particles is certainly enough for us to say what the main content of this law has to be. It must essentially set forth a small number of fundamental symmetry properties in nature, which have been known empirically for some years; in addition to these symmetries, it must contain the principle of causality as understood in relativity theory. The most important of the symmetries are the so-called “Lorentz group” of space and time, and the so-called “isospin group,” which has to do with the electric charge on the elementary particles. There are also other symmetries, but of these I shall say nothing here. Relativistic causality is connected with the Lorentz group but must be considered an independent principle.

This situation reminds us at once of the symmetrical bodies introduced by Plato to represent the fundamental structures of matter. Plato's symmetries were not yet the correct ones, but he was right in believing that ultimately, at the heart of nature, among the smallest units of matter, we find mathematical symmetries. It was an unbelievable achievement of the ancient philosophers to have asked the right questions. But, lacking all knowledge of the empirical details, we could not have expected them to find answers that were correct in detail as well.

Consequences for the Evolution of Human Thought in Our Own Day

The search for the “one,” for the ultimate source of all understanding, has doubtless played a similar role in the origin of both religion and science. But the scientific method that was developed in the sixteenth and seventeenth centuries, the interest in those details which can be tested by experiment, has for a long time pointed science along a different path. It is not surprising that this attitude should have led to a conflict between science and religion, as soon as a law contradicted, in some particular and perhaps very important detail, the general picture, the mode and manner, in which the facts had been spoken of in religion. This conflict, which began in modern times with the celebrated trial of Galileo, has been discussed often enough, and I need not repeat this discussion here. One may recall that, even in ancient Greece, Socrates was condemned to death because his teachings seemed to contradict the traditional religion. In the nineteenth century, this conflict reached its peak in the attempt of some philosophers to replace traditional Christianity by a scientific philosophy, based upon a materialist version of the Hegelian dialectic. It might be said that, in directing their gaze upon a materialistic interpretation of the “one,” the scientists were attempting to find their way back again to this “one” from the multitude of details.

If modern science has something to contribute to this problem, it is not by deciding for or against one of these doctrines; for example, as was possibly believed in the nineteenth century, by coming down in favor of materialism and against the Christian philosophy, or, as I now believe, in favor of Plato's idealism and against the materialism of Democritus. On the contrary, the chief profit we can derive in these problems from the progress of modern science is to learn how cautious we have to be with language and with the meaning of words. I would therefore like to devote the last part of my address to a few remarks about the problem of language in modern science and ancient philosophy.

If we may take our cue at this point from Plato's dialogues, the unavoidable limitations of our means of expression were already a central theme in the philosophy of Socrates; one might even say that his whole life was a constant battle with these limitations. Socrates never wearied of explaining to his countrymen, here on the streets of Athens. That they did not know exactly what they meant by the words they were employing. The story goes that one of Socrates' opponents, a sophist who was annoyed at Socrates' constant reference to this insufficiency of language, criticized him and said: “But Socrates, this is a bore; you are always saying the same about the same.” Socrates replied: “But you sophists, who are so clever, perhaps never say the same about the same.”

The reason for laying such stress on this problem of language was doubtless that Socrates was aware, on the one hand, of how many misunderstandings can be engendered by a careless use of language, how important it is to use precise terms and to elucidate concepts before employing them. One the other hand, he probably also realized that this may ultimately be an insoluble task. The situation confronting us in our attempt to “understand” may drive us to conclude that our existing means of expression do not allow for a clear and unambiguous description of the facts.

The tension between the demand for complete clarity and the inevitable inadequacy of existing concepts has been especially marked in modern science. In atomic physics we make use of a highly developed mathematical language that satisfies all the requirements in regard to clarity and precision. At the same time, we recognize that we cannot describe atomic phenomena without ambiguity in any ordinary language; we cannot, for example, speak unambiguously about the behavior of an electron in the interior of an atom. It would be premature, however, to insist that we should avoid the difficulty by confining ourselves to the use of mathematical language. This is no genuine way out, since we do not know how far the mathematical language can be applied to phenomena. In the last resort, even science must rely upon ordinary language, since it is the only language in which we can be sure of really grasping the phenomena.

This situation throws some light on the tension between the scientific method, on the one hand, and the relation of society to the “one,” the fundamental principle behind phenomena, on the other. It seems obvious that this latter relation cannot and should not be expressed in a precise and highly sophisticated language whose applicability to the real world may be very restricted. The only thing that will do for this purpose is the natural language everyone can understand. Reliable results in science, however, can be secured only by unambiguous statements; here we cannot do without the precision and clarity of an abstract mathematical language.

The necessity of constantly shuttling between the two languages is, unfortunately, a chronic source of misunderstandings, since in many cases the same words are employed in both. The difficulty is unavoidable. But it may yet be of some help always to bear in mind that modern science is obliged to make use of both languages, that the same word may have very different meanings in each of them, that different criteria of truth apply, and that one should not, therefore, talk too hastily of contradictions.

If we wish to approach the “one” in the terms of a precise scientific language, we must turn our attention to that center of science described by Plato, in which the fundamental mathematical symmetries are to be found. In the concepts of this language we must be content with the statement that “God is a mathematician”; for we have freely chosen to confine our vision to that realm of being which can be understood in the mathematical sense of the word “understanding,” which can be described in rational terms.

Plato himself was not content with this restriction. Having pointed out with the utmost clarity the possibilities and limitations of precise language, he switched to the language of poetry, which evokes in the hearer images conveying understanding of an altogether different kind. I shall not seek to discuss here what this kind of understanding can really mean. These images are probably connected with the unconscious mental patterns the psychologists speak of as archetypes, forms of strongly emotional character that, in some way, reflect the internal structures of the world. But whatever the explanation for these other forms of understanding, the language of images and likenesses is probably the only way of approaching the “one” from more general domains. If the harmony in a society rests on a common interpretation of the “one,” the unitary principle behind the phenomena, then the language of poetry may be more important here than the language of science.

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