

# Element

## INTRODUCTION

THE words "atom" and "element" express basic notions in the analysis of matter. To some extent their meanings seem to be the same. Atoms or elements are usually understood to be ultimate units, the parts out of which other things are formed by combination. But as soon as further questions are asked—about the divisibility or indivisibility of these units, or about their number and variety—we are confronted with differing conceptions of the atom, and with a theory of the elements which is opposed to the atomic analysis of matter.

Even when the two notions are not opposed to one another, they are not interchangeable. "Atom" has a much narrower meaning. It usually designates a small particle of matter, whereas "element" signifies the least part into which anything at all can be divided. It is this broader meaning of "element" which permits Euclid to call his collection of the theorems in terms of which all geometric problems can be solved, the "elements" of geometry. According to Aristotle, this is true, not only of geometric proofs, but also "in general of the elements of demonstration; for the primary demonstrations, each of which is implied in many demonstrations," he says, "are called elements of demonstration." From this it follows that elements will be found in any subject matter or science in which analysis occurs, and not only in physics.

"An element," writes Nicomachus in his *Introduction to Arithmetic*, "is the smallest thing which enters into the composition of an object, and the least thing into which it can be analyzed. Letters, for example, are called the elements of literate speech, for out of them all articulate speech is composed and into them

finally it is resolved. Sounds are the elements of all melody; for they are the beginning of its composition and into them it is resolved. The so-called four elements of the universe in general are simple bodies, fire, water, air, and earth; for out of them in the first instance we account for the constitution of the universe, and into them finally we conceive of it as being resolved."

This explains why books in so many different fields have the word "element" in their titles. There are the elements of grammar or logic, the elements of language or music, the elements of psychology or economics. Elements in one subject matter or science are analogous to the elements in another because in each sphere they stand to everything else as the simple to the complex, the pure to the mixed, the parts to the whole. Thus the factors of price may be said to function as elements in economic analysis as do the parts of speech in grammatical analysis.

Another illustration comes from the theory of the four bodily humors in ancient physiology. In the traditional enumeration, which goes back to Hippocrates, they are blood, phlegm, yellow bile, and black bile, and they function analytically as do fire, water, air, and earth in ancient physics. They "make up the nature of the body of man," according to a Hippocratic treatise on the nature of man, "and through them he feels pain or enjoys health." Perfect health is enjoyed by a man "when these elements are duly proportioned to one another in respect of compounding, power, and bulk, and when they are perfectly mingled." Galen, in an analysis of temperaments, explains all varieties of temperament and all complexions of physique in terms of

these humors, either by their mixture or by the predominance of one or another. Thus the sanguine, phlegmatic, choleric, or melancholic temperament is accounted for by the excess of one and a deficiency of the other humors.

Still another physiological application of the notion of element is to be found in the ancient division of tissue into flesh and bone, or in the more elaborate modern analysis of the types of cells which comprise all living matter.

THESE ILLUSTRATIONS indicate that the irreducibility of elements to anything simpler than themselves does not necessarily mean that they are absolutely indivisible. Cells can be further divided into nucleus, protoplasm, and membrane without ceasing to be the elements of tissue. The parts of speech—nouns, verbs, adjectives—can be further divided into syllables and letters without ceasing to be the elements of significant utterance. Letters, treated as the elements of language, can be physically divided. The fact that terms are sometimes regarded as the logical elements out of which propositions and syllogisms are formed does not prevent a distinction from being made between simple and complex terms. Nicomachus calls the triangle elementary among all plane figures, "for everything else is resolved into it, but it into nothing else"; yet the triangle is divisible into the lines which compose it and these lines in turn are divisible into points.

When Nicomachus says that the triangle is the element of all other figures "and has itself no element," he does not mean that the triangle is absolutely indivisible, but only relatively so. Relative to the analysis of plane figures, there is no simpler figure out of which the triangle can be formed. Similarly, relative to the analysis of significant speech, there is no simpler part than the word. Relative to the analysis of melody, there is no simpler part than the tone. Musical tones may be physically, but they are not musically, complex.

THE DEFINITION OF element can also be approached by comparing its meaning with that of principle and cause. All three terms are brought together by Aristotle in the beginning of his *Physics*, when he declares that we attain

"scientific knowledge" through acquaintance with the "principles, causes, and elements" of things.

The word "principle" occurs almost as frequently as "element" in the titles of books which claim to be basic expositions or analyses. The two words are often used as synonyms. Lavoisier, for example, says that we can use "the term *elements*, or *principles of bodies*, to express our idea of the last point which analysis is capable of reaching."

To discover any difference in the meaning of "element" and "principle," it is necessary to specify their correlatives precisely. Out of elements, *compounds* or *mixtures* are formed. From principles, *consequences* are derived. In logic, for example, we say that terms are the elements of propositions (the proposition 'Socrates is a man' comprising the terms 'Socrates' and 'man'), but we say that axioms are the principles from which conclusions are derived. This does not prevent the same thing from being viewed in different connections as both element and principle—as an element because it is the simple part out of which a more complex whole is composed, and as a principle because it is the source from which something else is derived. The parts of speech in grammar are the elementary components of phrases and sentences; they are also the principles from which the rules of syntax are derived.

The third notion which belongs with element and principle is cause. Its correlative is *effect*. Again it can be said that that which is an element in one connection and a principle in another can be regarded as a cause from still a third point of view. In Aristotle's physical treatises, for example, matter is regarded in all three ways: it is an element of all bodies, for they are substances composed of matter and form; it is a principle of change, since from matter, form, and privation change is derived; it is a cause (*i.e.*, the material cause) of certain results.

But it must also be observed that everything which is any one of these three is not necessarily both of the others also. Since an element, according to Aristotle, is a "component immanent in a thing," anything that is an extrinsic principle or cause cannot be an element. Thus

the action of one body upon another is a cause and a principle, but not an element. Referring to these distinctions, Aquinas declares that "*principle* is a wider term than *cause*, just as *cause* is more common than *element*." The chapters on CAUSE and PRINCIPLE tend to substantiate this observation about the scope of these ideas in the tradition of western thought.

THE BASIC ISSUES concerning elements occur in the analysis of matter. Before Plato and Aristotle, the early Greek physicists had asked such questions as, From what do all things come? Of what are all things made? A number of answers were given, ranging from one kind of ultimate, such as earth or fire, through a small set of ultimate kinds, to an infinite variety. The classical theory of the four elements is the middle answer, avoiding the extremes of unity and infinity.

According to Galen, it was Hippocrates who "first took in hand to demonstrate that there are, in all, four mutually interacting qualities" and who provided "at least the beginnings of the proofs to which Aristotle later set his hand" in developing the theory of the four elements. Galen also indicates that it was a subject of controversy among the ancients whether the "substances as well as the qualities" of the four elements "undergo this intimate mingling" from which results "the genesis and destruction of all things that come into and pass out of being."

Aristotle, in his treatise "On Generation and Corruption," enumerates the various senses in which the physicist considers elements. "We have to recognize three 'originative sources' (or elements)," he writes: "firstly, that which is potentially perceptible body; secondly, the contraries (e.g., heat and cold); and thirdly, Fire, Water, and the like." The "potentially perceptible body" is identified with prime matter, and, since this "has no separate existence, but is always bound up with a contrariety," it can be ruled out from the usual notion of element. The elementary qualities, the "contraries" named secondly, are the hot and cold and dry and moist. The so-called elements, fire, air, water, and earth, are left to the last, and are mentioned "only thirdly," Aristotle says, because

they "change into one another . . . whereas the contraries do not change."

The elementary qualities "attach themselves" by couples to the "apparently 'simple' bodies." In consequence, Aristotle writes, "Fire is hot and dry, whereas Air is hot and moist . . . and Water is cold and moist, while Earth is cold and dry." Each of them, however, "is characterized *par excellence* by a single quality." In terms of these simple bodies and the elementary qualities all other material things can be explained.

In contrast to the elements stand the mixed, or compound, bodies, in the constitution of which two or more elements combine. There may be many kinds of mixed bodies, but none is irreducible in kind, as are the four elements; any mixed body can be divided into the different kinds of elementary bodies which compose it, whereas the elementary bodies cannot be divided into parts which are different in kind from themselves. A living body, for example, may contain parts of earth and water, but the parts of earth are earth, the parts of water, water.

It is precisely the mode of divisibility that Aristotle declares is "the fundamental question." In answering this question he opposes the theory of the four elements to another Greek account of the constitution of matter—the atomic theory, developed by Leucippus and Democritus, and expounded for us in Lucretius' poem *The Way Things Are*.

ACCORDING TO the Greek atomists, matter is not infinitely divisible. Lucretius writes,

..... if nature had not set a limit  
To fragmentation, by this time all matter  
Would have been so reduced by time's attrition  
That not one thing could move from a beginning  
To full, completed growth.

There must then be a "sure and certain limit" to the breaking of matter—a limit in physical division which ultimately reaches units of matter that are absolutely indivisible. Lucretius calls them "first beginnings" of "singleness/Solid, coherent, not compound, but strong/In its eternal singleness"—the "seeds of things," or atoms. The Greek word from which "atom" comes literally means *uncuttable*.

From this it is evident that Aristotle can deny the existence of atoms while at the same time he affirms the existence of elementary bodies. The elements, unlike the atoms, are not conceived as indivisible in quantity, but only as incapable of division into diverse kinds of matter.

In the Greek conception of atom and element, the difference between them lies in this distinction between quantitative and qualitative indivisibility. The atom is the least quantity of matter. It cannot be broken into quantitative parts. The elementary body is not atomic. It is always capable of division into *smaller* units, but all of these units must be of the same kind as the elementary body undergoing division.

The element is indivisible only in the sense that it cannot be decomposed into other *kinds* of matter, as a mixed body can be decomposed into its diverse elements. The atom cannot be divided in any way. Only compound bodies can be divided into their constituent atoms, all of which are alike in kind, differing only quantitatively—in size, shape, or weight. Different kinds of matter occur only on the level of compounds and as the result of diverse combinations of atoms.

This last point indicates another contrast between atoms and elements in ancient physical theory. The elements are defined, as we have seen, by their qualitative differences from one another; or, more strictly, according to combinations of elementary sensible qualities—hot and cold, moist and dry. By virtue of the qualities peculiar to them, the four elements stand in a certain order to one another. Water and air, according to Plato, are “in the mean between fire and earth” and have “the same proportion so far as possible; as fire is to air so is air to water, and as air is to water so is water to earth.” The quality which two of the elements have in common provides the mean. Thus fire and air are joined by the common quality of hot; air and water by moist; and water and earth by cold.

When their analysis reached its greatest refinement, the ancients recognized that the earth, air, fire, and water of common experience do not actually have the purity requi-

site for elements. They are “not simple, but blended,” Aristotle writes, and while the elements “are indeed similar in nature to them, [they] are not identical with them.” The element “corresponding to fire is ‘such-as-fire,’ not fire; that which corresponds to air is ‘such-as-air,’ and so on with the rest of them.” Thus the four elements are only analogous to, for they are purer than, ordinary earth, air, fire, and water; yet their names continued to be used as symbols for the true elements, a connotation which is still retained when we speak of men struggling against or battling with “the elements.”

Heisenberg's comment on Greek atomism is worth noting here. He writes: “In the philosophy of Democritus the atoms are eternal and indestructible units of matter, they can never be transformed into each other. With regard to this question modern physics takes a definite stand against the materialism of Democritus and for Plato and the Pythagoreans. The elementary particles are certainly not eternal and indestructible units of matter, they can actually be transformed into each other . . . But the resemblance of the modern views to those of Plato and the Pythagoreans can be carried somewhat further. The elementary particles in Plato's *Timaeus* are finally not substance but mathematical forms. ‘All things are numbers’ is a sentence attributed to Pythagoras. The only mathematical forms available at that time were such geometric forms as the regular solids or the triangles which form their surface. In modern quantum theory there can be no doubt that the elementary particles will finally also be mathematical.”

“IT WILL NO DOUBT be a matter of surprise,” Lavoisier writes in the Preface to his *Elements of Chemistry*, “that in a treatise upon the elements of chemistry, there should be no chapter on the constituent and elementary parts of matter; but I shall take occasion, in this place, to remark that the fondness for reducing all the bodies in nature to three or four elements, proceeds from a prejudice which has descended to us from the Greek philosophers. The notion of four elements, which, by the variety of their proportions, compose all the

known substances in nature, is a mere hypothesis, assumed long before the first principles of experimental philosophy or of chemistry had any existence."

This does not mean that Lavoisier entirely rejects the notion of elements in chemical analysis. On the contrary, he says that "we must admit, as elements, all the substances into which we are capable, by any means, to reduce bodies by decomposition." His quarrel with the ancients chiefly concerns two points. The first is on the number of the elements, which he thinks experiment has shown to be much greater than the four of classical theory. The second is on the simplicity of the experimentally discovered elements. They can be called atoms or simple bodies only if we do not thereby imply that we know them to be absolutely indivisible—either qualitatively or quantitatively. We are not entitled "to affirm that these substances we consider as simple may not be compounded of two, or even of a greater number of principles" merely because we have not yet discovered "the means of separating them."

In 20th-century physics and chemistry, element is used in the sense of chemical element. Two quantities of matter are said to belong to the same chemical element if their chemical reactions are identical. Elements are made up of atoms, each of which consists of a massive, positively charged nucleus surrounded by a cloud of light, negatively charged electrons.

The chemistry of an atom—or several atoms bound together as a molecule—is determined by the associated electrons. Hence all of the atoms of a given element have the same number of electrons. In the usual usage, the atoms of a given element need not all have identical masses. Their nuclei can differ by the number of electrically neutral, massive particles—neutrons. For example, the hydrogen nucleus has a single positively charged, massive particle, the proton, while the heavy hydrogen nucleus has a proton and a neutron: both isotopes—hydrogen and heavy hydrogen—have the same chemistry and, as the term is now usually employed, would belong to the same element.

According to the ancient meaning of the terms, the molecule would seem to be both a mixture and a compound—*mixed*, in that

it can be broken up into other *kinds* of matter; *compound*, in that it can be divided into *smaller* units of matter. The combination of the elements to form molecular compounds is determined by the proportion of their weights or valences rather than by a fusion of their qualities.

The most radical change in theory is not this, however; nor is it the increase in the number of the elements from four to more than one hundred; nor the ordering of the elements by reference to their atomic weights rather than by the contrariety of their qualities. It results from the discovery that an atom is not uncuttable and that new elements can be produced by atomic fission and fusion. Fission refers to the splitting of a heavy nucleus, such as that of uranium, into lighter ones, and fusion refers to the conjoining of lighter nuclei into heavier ones.

Faraday's experimental work in ionization and in electrochemical decomposition lies at the beginning of the physical researches which have penetrated the interior structure of the atom and isolated smaller units of matter. Even before atoms were experimentally exploded, analysis had pictured them as constituted by positive and negative charges.

As the result of his researches, Faraday, for example, conceives of atoms as "mere centres of forces or powers, not particles of matter, in which the powers themselves reside." The atom thus ceases to be "a little unchangeable, impenetrable piece of matter," and "consists of the powers" it exercises. What was ordinarily referred to "under the term *shape*" becomes the "disposition and relative intensity of the forces" that are observed.

With Faraday it is evident that the meaning of "atom" has departed far from the sense in which Lucretius speaks of "single solid unity" or Newton of "solid, massy, hard, impenetrable, movable particles . . . incomparably harder than any porous bodies compounded of them; even so very hard as never to wear or break in pieces; no ordinary power being able to divide what God himself made one in the first creation." With the conception of the elements as different kinds of atoms; then, with the discovery of radioactive elements undergoing

slow disintegration; finally, with the production of isotopes and new elements through atomic change; the meaning of "element" has moved equally far from its original sense.

DO THESE ALTERED meanings change the basic issues in the philosophy of nature? Are these issues resolved or rendered meaningless by experimental science?

The central point in the theory of elements is an irreducible qualitative diversity in kinds of matter. The elements of modern chemistry may no longer be *elementary* types of matter in the strict sense of the word; but the kind of difference which would be strictly elemental may be found in the distinction of the positive, the negative, and the neutral with respect to the electrical charge of subatomic particles.

Similarly, the central point in atomism as a philosophy of nature is the existence of absolutely indivisible units or quanta of matter; in other words, the denial that matter is infinitely divisible, that any particle, no matter how small, is capable of being broken into smaller parts. The strict conception of the atom is, therefore, not invalidated by the experimental discovery that the particles called "atoms" are not *atomic*, that they are themselves complex structures of moving particles, and that they can be physically divided.

It makes no difference to the philosophical atomist whether the particles which constitute molecules or the particles—the electrons and protons, the neutrons and mesons—which constitute "atoms," are *atomic*. Even if further experimental work should succeed in dividing these "subatomic" particles, the question could still be asked: Is matter infinitely divisible, regardless of our actual power to continue making divisions ad infinitum? Since the question, when thus formulated, cannot be put to experimental test, the issue concerning atoms would remain.

That issue would not refer to any particle of matter defined at a certain stage of physical analysis or experimental discovery. It would consist in the opposition of two views of the nature of matter and the constitution of the material universe: the affirmation, on the one hand, that truly atomic particles must exist;

and the denial, on the other, that no particle of matter can be atomic. The affirmative arguments of Lucretius and Newton make the constancy of nature and the indestructibility of matter depend on the absolute solidity and impenetrability of matter's ultimate parts. The negative arguments of Aristotle and Descartes proceed from the divisibility of whatever is continuous to the conclusion that any unit of matter must have parts.

The philosophical doctrine of atomism, in the form in which Lucretius adopts it from Epicurus, insists upon void as the other basic principle of the universe. "The nature of everything," he writes, "is dual—matter/And void; or particles and space, wherein/The former rest or move." Compound bodies are divisible because the atoms of which they are composed are not absolutely continuous with one another, but are separated by void or empty space. That is why they are not solid or impenetrable, as are the atomic particles which are composed of matter entirely without void. In Newton's language hardness must be "reckoned the property of all uncompounded matter," for if "compound bodies are so very hard as we find some of them to be, and yet are very porous," how much harder must be "simple particles which are void of pores."

The opponents of atomism tend to deny the existence not only of atoms, but of the void as well. Descartes, for example, denies that there can be "any atoms or parts of matter which are indivisible of their own nature . . . For however small the parts are supposed to be, yet because they are necessarily extended we are always able in thought to divide any one of them into two or more parts." For the same reason, he maintains, there cannot be "a space in which there is no substance . . . because the extension of space or internal place is not different from that of body." The physical world, on this view, is conceived as what the ancients called a plenum, continuously filled with matter. This controversy over void and plenum is elaborated in the chapter on SPACE.

Although he uses the language of the atomists, Faraday seems to agree with Descartes rather than with Newton. He pictures matter as "continuous throughout," with no distinc-

tion between "its atoms and any intervening space." Atoms, he thinks, instead of being absolutely hard, are "highly elastic," and they are all "mutually penetrable." He compares the combination and separation of two atoms with "the conjunction of two sea waves of different velocities into one, their perfect union for a time, and final separation into the constituent waves." Such a view of the constitution of matter, Faraday writes, leads to "the conclusion that matter fills all space, or at least all space to which gravitation extends."

The very continuity—the voidlessness or lack of pores—which the opponents of atomism insist is the source of matter's infinite divisibility, the atomists seem to give as the reason why the ultimate particles are without parts, hence simple, solid, and indivisible.

ON STILL OTHER POINTS, there is disagreement among the atomists themselves. Not all of them go to the extreme of denying existence or reality to anything immaterial; nor do all insist that whatever exists is either an atom or made up of atoms and void. In the tradition of the great books, the extreme doctrine is found in Lucretius alone. Though it is shared by Hobbes, and is reflected in the *Leviathan*, it is not expounded there. It is developed in his treatise *Concerning Body*.

For Lucretius, the atoms are eternal as well as indestructible. The "first beginnings" of all other things are themselves without beginning. "Atoms are moving," Lucretius writes, "in the same way now/As they have done forever, and will do/Forever," through an endless succession of worlds, each of which comes to be through a concourse of atoms, each in turn perishing as with decay that concourse is dissolved. Newton writes in what seems to be a contrary vein. "It seems probable to me," he says, "that God in the beginning formed matter in solid, massy, hard, impenetrable, movable particles." "All material things," he continues, "seem to have been composed of the hard and solid particles above mentioned, variously associated in the first Creation by the counsel of an intelligent Agent."

Nor does Newton appeal to the properties and motions of the ultimate particles except

to explain the characteristics and laws of the physical world. Unlike Lucretius and Hobbes, he does not—and there seems to be some evidence in the *Optics* that he would not—reduce the soul of man to a flow of extremely mobile atoms, or attempt to account for all psychological phenomena (thought as well as sensation and memory) in terms of atom buffeting atom.

The atomic theory of the cause of sensation is not limited to the materialists. Writers like Locke, who conceive man as having a spiritual nature as well as a body, adopt an atomistic view of the material world. "The different motions and figures, bulk and number of such particles," he writes, "affecting the several organs of our senses, produce in us those different sensations which we have from the colours and smells of bodies." Furthermore, the distinction which is here implicit—between primary and secondary sense qualities—is not peculiar to atomism. It can also be found in a critic of atomism like Descartes.

The atomistic account of sensation is, nevertheless, of critical significance in the controversy concerning this type of materialism. Critics of atomism have contended that the truth of atomism as a materialistic philosophy can be no greater than the measure of its success in explaining sensation—the source upon which the atomist himself relies for his knowledge of nature—in terms of the properties and motions of particles themselves imperceptible.

The issues involving atomism have taken a remarkable new turn since the 1960s with the discovery of the quark. As the 20th century neared an end, the quark was believed to be the ultimate constituent of nuclear particles such as protons and neutrons. However, the theory of quarks predicts that it is impossible to break up a proton and neutron into its quark constituents. This means that, as a matter of principle, these atomic constituents are in a certain sense undetectable as free particles. This is quite unlike the situation with atoms and their nuclei, which can be broken up into their detectable constituents.

THE ULTIMATE QUESTION is asked by Heisenberg: "Why do the physicists claim that

their elementary particles cannot be divided into smaller bits? The answer to this question clearly shows how much more abstract modern science is as compared to Greek philosophy. The argument runs like this: How could one divide an elementary particle? Certainly only by using extreme forces and very sharp tools. The only tools available are other elementary particles. Therefore, collisions between two elementary particles of extremely high energy would be the only processes by which the particles could eventually be divided. Actually they *can* be divided in such processes, sometimes into very many fragments; but the fragments are again elementary particles, not any smaller pieces of them, the masses of these fragments resulting from the very large kinetic energy of the two colliding particles. In other words, the transmutation of

energy into matter makes it possible that the fragments of elementary particles are again the same elementary particles."

Writing almost a half century earlier than Heisenberg, Planck contrasts the naïveté of the atomism that prevailed from the Greeks to the 19th century with the present scientific account of subatomic elementary particles. "In our own day," Planck writes, "scientific research, fructified by the theory of relativity and the quantum theory, stands at the threshold of a higher stage of development, ready to mould a new world picture for itself . . . From today's point of view, therefore, we must regard the . . . classical world picture as naive. But nobody can tell whether some day in the future the same words will not be used in referring to our modern world picture, too."