section B, physics, Ernest Merritt, Cornell University; section C, chemistry, James Lewis Howe, Washington and Lee University; section D, mechanical science and engineering, J. A. Brashear, of Pittsburg, Pa.; section E, geology and geography, J. F. Kemp, Columbia University; section F, zoology, C. B. Davenport, Harvard University; section G, botany, W. Trelease, Missouri Botanical Garden; section H, anthropology, A. W. Butler, of Indianapolis; section I, economic science and statistics, C. M. Woodward, Washington University.

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FREDERICK BEDELL,
General Secretary.

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*THE DEFINITION OF THE ELEMENT.**

IT is with hesitation that I enter upon so speculative a discussion as the nature of the elements, and yet there are reasons why it should prove of great profit to draw the attention of this representative gathering of the chemists of America to this subject. We have nearly reached the close of the first century in which these elements have been the subject of experimental research. The ingenuity and the patient labor of an army of workers have been directed at the solution of the many problems connected with these elementary substances, and the ultimate aim, the goal, of all their striving has been the discovery of the properties and the nature of the atom.

It is eminently fitting that, as we stand at the threshold of the new century, we glance back along the road we have already come and take some account of the progress we have made. The quicksands of mere speculation must be avoided, and yet the mental vision, the 'scientific imagination,' must be called into service in considering that which so far transcends our cruder actual vision as the incomparable atom itself. There is another reason for considering the nature of the elements. At several times during the century a wider vision has made it necessary to recast the definition of the elements to accord with increasing knowledge. It would seem as if another such period of change were approaching. There may be need of a truer definition, and how shall this be realized or the new definition properly fitted unless the knowledge gained be summed up and appreciated?

The conception of an element among the Greek philosophers and the earlier alchemists was very different from the modern idea. This conception sprang from the theories as to the formation of the material universe. The elements were the primal forms of matter seen only combined, impure, imperfect. They were the essences or principles out of which all things were evolved. In the four-element theory, which was so widely spread among the ancients, the fire, air, earth and water were not the ordinary substances known under these names, but the pure essences bestowing upon fire and water their peculiar properties. These essences were not thought of as actual substances capable of a separate material existence, and gradually the belief that a transmutation was possible between them sprang up. Thus they themselves might be derived from some one of

* Address of the Vice-President before Section C—Chemistry—of the American Association for the Advancement of Science, at the Columbus meeting, August, 1899.

them, as fire or water. The Thalesian theory deriving all things from water was especially popular and was not completely overthrown until the modern era.

When, later on, the alchemist conceived of all metals as composed of sulphur and mercury it was an essence or spirit of mercury that was meant. Certain common characteristics as luster, malleability, fusibility, combustibility, etc., naturally led them to think of the metals as belonging to the same order of substances containing the same principles, the relative proportions and purity of which determined the variations in the observed properties. Thus the properties of the metals depended upon the purity of the mercury and sulphur in them, the quantities of them and their degree of fixation. The more easily a metal was oxidized on being heated, the more sulphur it contained, and this sulphur also determined its changeability. The more malleable it was, the more mercury entered into its composition. If only something could be found which would remove the grossness from these essences, some unchanging, all-powerful essence, which, because of their search for it, gradually became known as the 'philosophers' stone,' then the baser metals might be transmuted into the noble gold when the sulphur and mercury were perfectly balanced and free from all distempers.

As has been said, these principles entering, all or some of them, into every known substance, were supposed to be not necessarily capable of individual existence themselves. This was the view held by the followers of Aristotle. With the reaction against the domination of the scholiasts, other views began to be held. It was Boyle who first gave voice to these changed views in his 'Sceptical Chemist' (1661). He defined elements as "certain primitive bodies, which, not being made of any other bodies, or of one another, are the ingredients of which all those called perfectly mixed bodies are immediately compounded, and into which they are ultimately resolved." He, however, did not believe himself warranted, from the knowledge then possessed, in claiming the positive existence of such elements.

But little attention was paid to the subject by the subsequent chemists. The phlogistics were too much occupied with their theory of combustion, and none could see the bearing of this question and its importance to exact science.

Macquer, in his 'Dictionary of Chemistry' (1777), words his definition as follows: "Those bodies are called elements which are so simple that they cannot by any known means be decomposed or even altered and which also enter as principles or constituent parts into the combination of other bodies." To this he adds: "The bodies in which this simplicity has been observed are fire, air and the purest earth." In all of this may be observed the resolution of observed forms of matter into primal principles following the dream of Lucretius and the early Epicurean philosophers, a dream abandoned by the atomic school following, though largely holding to the same definition.

It was only when chemists began to realize that mere observation of properties, chiefly physical, was not sufficient that the subject began to clear up and lose its vagueness. Black proved that certain substances were possessed of a constant and definite composition and fixed properties, unalterable and hence simple bodies or elements. Lavoisier finally cleared the way for the work of the nineteenth century by his definition that "an element is a substance from which no simpler body has yet been obtained; a body in which no change causes a diminution of weight. Every substance is to be regarded as an element until it is proved to be otherwise." With this clear definition to build upon, a rational system of chemistry became, for the first time, a possibility.

Thus the elements were recognized as simple bodies because there were no simpler. They were not complex or compound. The distinction was clearly drawn between bodies simple and bodies compound, and the name simple body has been frequently used as a synonym for element through a large part of this century. Naturally the question of simplicity was first settled by an appeal to that great arbiter of chemical questions, the balance. And, quite as naturally, many blunders were made and the list of bodies erroneously supposed to be simple was very large. All whose weight could not be reduced were considered elementary. When, however, from such a body, something of lesser weight could be produced, its supposed simplicity was, of course, disproved.

This test for the elemental character has been clung to persistently, and is perhaps still taught, although it was long ago recognized that many of the elements existed in different forms, a phenomenon to which Berzelius gave the name *allotropism*. One only of these could be simplest, and the others could be reduced to this one and rendered specifically lighter. With the discovery of this relation it should have been quite apparent that the old definition would no longer hold good. But many years passed before chemists were made to feel that a new definition was necessary, and adapted one to the newer knowledge.

The insight into what Lucretius would call 'the nature of things' was becoming clearer; the mental grasp upon these elusive atoms about which the old Epicurean reasoned so shrewdly was becoming firmer. Through what one must regard as the veil interposed by the earlier idea of the element, the chemist began to grope after the constituent particle or atom. It must be borne in mind that the definition of the element was largely formulated before the resuscitation of the atomic theory by Dalton, and the mental picture of the one has perhaps retarded the clearing up of the ideas concerning the other. From the atomic point of view the element was next defined as one in which the molecules or divisible parts were made up of similar indivisible particles. This afforded an easy explanation of allotropism as a change in the number of atoms in a molecule. As Remsen says: "An element is a substance made up of atoms of the same kind; a compound is a substance made up of elements of unlike kind."

Laying aside, then, all vaguely formulated ideas of essences, or principles, or simple bodies, or elemental forms, we found our present building upon the conception of the ultimate particle, be this molecule or atom.

As to this atom some clear conception is needed, and here we come to the *crux* of the modern theories. The chemist regards this atom as a particle of matter and is unwilling to accept the theory of Boscovich that it is infinitely small, and hence a mathematical point, nor can he admit that it is merely a resisting point, and hence that all matter is but a system of forces. And yet it seems as though some authorities would lead up to such a conclusion.

While we need not consider these atoms as mere centers of forces, we are compelled to study them by the operation of forces upon them. What are called their properties have been studied and recorded with great care. These properties are evinced in the action of the forces upon matter, and the exhibition of force without matter cannot be admitted. This study of the properties has been the especial occupation of the century now closing, and so the elemental atom has come to be regarded as a collection of properties. As Patterson-Muir puts it (Alchemical Essence and the

Chemical Elements, p. 31): "The name copper is used to distinguish a certain group of properties, that we always find associated together, from other groups of associated properties, and if we do not find the group of properties connoted by the term copper we do not find copper."

These properties are exhibited by the action of a small group of forces. Perhaps we do not know all of the forces; certain it is that we do not accurately know all of the properties, but, to quote Patterson-Muir again: "The discovery of new properties always associated with a group of properties we call copper would not invalidate the statement that copper is always copper."

The properties of an atom are either primary, inherent and as unchanging as the atom itself, or they are secondary and dependent upon the influence of the other atoms, or varying with the change of conditions. To the first class belong such properties as the atomic weight, atomic heat, specific gravity, etc.; to the second, chemical affinity, valence, etc. In all the study of the atom the distinction between these should be carefully maintained in order that there may be clear thinking.

There is no field of mental activity requiring more faith than that of the chemist. He is dealing with the 'evidences of things unseen.' He must not be content with the mere gathering of facts, but divine what he can of their deeper meaning. Few chemists have had such insight as Graham into the significance of even the simplest changes. He was not content with mere surface observation. Even the commonest observed phenomena were to him full of meaning as to the atoms and their 'eternal motion.' Thorpe (Essays in Historical Chemistry, p. 219) has drawn afresh the attention of the chemists to the thoughtful words of this great thinker. His mind was filled with the fascinating dream of the unity of matter. "In all his work," says Adam Smith, "we find him steadily thinking on the ultimate composition of bodies. He searches after it in following the molecules of gases when diffusing; these he watches as they flow into a vacuum or into other gases, and observes carefully as they pass through tubes, noting the effect of weight, of composition, upon them in transpiration. He follows them as they enter into liquids and pass out, and as they are absorbed or dissolved by colloid bodies; he attentively inquires if they are absorbed by metals in a similar manner, and finds remotest analogies which, by their boldness, compel one to stop reading and to think if they really be possible."

In his paper entitled 'Speculative Ideas respecting the Constitution of Matter,' published in the Proceedings of the Royal Society in 1863, which Thorpe calls his 'Confession of Faith,' he tells of his conception that these supposed elements of ours may possess one and the same ultimate or atomic molecule existing in different conditions of movement.

It is not possible for me, in the limits of this address, to array before you all of the various evidence which leads to the belief that our so-called elementary atoms are after all but compounds of an intimate, peculiar nature whose dissociation we have as yet been unable to accomplish. When properly marshalled, it gives a very staggering blow to the old faith. Thorpe speaks of the "old metaphysical quibble concerning the divisibility or indivisibility of the atom." To Graham "the atom meant something which is not divided, not something which cannot be divided." The original indivisible atom may be something far down in the make-up of the molecule.

How shall the question as to the composite nature of the elements be approached? The problem has been attacked from the experimental side several times during the last half century, but the work seems to have been carried on after a desultory fashion and was soon dropped, as if the workers were convinced of its uselessness. The results, being negative, simply serve to show that no method was hit upon for decomposing the elements upon which the experiments were performed. Thus, for instance, Despretz performed a number of experiments to combat Dumas' views as to the composite nature of the elements. Despretz made use of the well-known laboratory methods for the separation and purification of substances. Such were distillation, electrolysis, fractional precipitation, etc. Such work was quite inadequate to settle the question, as Dumas had pointed out that unusual methods must be used, or, he might have added, the old methods carried out to an unusual or exhaustive extent. Certainly, if a moderate application of the usual methods was sufficient for this decomposition, evidences of it would have been obtained long ago by the host of careful workers who have occupied themselves over these substances. Crookes has busied himself with the method of fractional precipitation (though not with special view to the testing of this question), and applied it most patiently and exhaustively to such substances as the rare earths, without obtaining results from which anything conclusive could be drawn. Victor Meyer seems to have believed that the decomposition could be effected by high temperatures, and was very hopeful of experiments which he had planned before his untimely death. Others have spasmodically given a little time to the problem, but no one has thought highly enough of it to attack it with all of his energy.

Let us stop a moment and ask ourselves what would be attained if any one should succeed in decomposing an element by one of the usual methods. Has not this been done repeatedly in the past and merely served to add to the list of the elements? Didymium has been made to yield praseo and neodymium. That which was first called yttrium has been divided into erbium, terbium and ytterbium, and according to Crookes may possibly be still further decomposed. But these and similar decompositions are not generally accepted as offering any evidence that elements can be decomposed. It is merely the discovery of one or more new substances which have remained hidden in constant association with known bodies which were supposed to be simple. It would be necessary to prove that a single individual element had, by the process adopted, been actually decomposed and not some pre-existing impurity discovered. This, of course, would be exceedingly difficult, and all such attempts as those mentioned can have little bearing upon the general question, and can hold out slight hope of reward beyond the fame springing from the discovery of a new element.

Successful decomposition should mean much more. It should mean the discovery of a method which will decompose not one, but many or indeed, all of the elements, and the decomposition of these must not yield a larger number of supposedly simple bodies, but a small group of one or two or three which are common constituents of all. It is quite idle to venture upon any prediction whether such a method will ever be discovered. Setting aside, then, the direct experimental proof of the composite nature of the elements as unattainable at present, let us next examine the indirect evidence. It would seem wisest for the present to introduce under that heading the spectroscopic work of Lockyer. The results, while highly interesting, are too indefinite as yet to speak of as having a direct bearing. Yet a careful study of the spectra of the elements leads us to a strong suspicion that the less plausible assumption is the one that the particles which give rise to such varied vibrations are simple and unitary in nature. Lockyer's most recent work, following up the line of his 'Working Hypothesis' of twenty years ago, is very suggestive and may lead to important results (Chemistry of the Hottest Stars, Roy. Soc. Proc., LXI., 148; On the Order of Appearance of Chemical Substances at Different Temperatures, *Chem. News*, 79, 145). Still too much must be assumed yet for such work to be very conclusive. He writes of 'proto-magnesium and proto-calcium,' and Pickering discusses a 'new hydrogen,' all with an assurance and confidence which proves at least how deeply these changes in the spectra have impressed some of those who have most deeply studied them.

But a more important method of indirectly testing the question is through a comparison of the properties of the atoms. Such a comparison has been made as to the atomic weights. In other words, the idea of the composite nature of the elements followed very close upon the adoption of a stricter definition of them as simple bodies. Dalton, Prout, Döbereiner, Dumas, Cooke and many others have aided in developing the idea, sometimes faultily and harmfully, at other times helpfully. Some fell into the common error of going too far, but all were struck by the fact that when these combining numbers, or atomic weights, were compared strange and interesting symmetries appeared. The times were not ripe for an explanation of their meaning, and such crude assumptions as that of Prout, that the elements were composed of hydrogen, or that of Low, that they were made up of carbon and hydrogen, were too baseless to command much genuine support or to withstand much careful analysis. The important feature of agreement between such theories was the belief that the elements were composite and had one or more common constituents.

From the comparison of one property, the atomic weights, the next step was to the comparison of all the properties. This comparison is brought out clearest and best for us in the Periodic System. Here all the properties are very carefully tabulated for us. The study of the system leads indisputably to the conviction that this is not an arbitrary, but a natural arrangement, exceedingly simple in its groundwork, but embodying most fascinating symmetries, which hint of great underlying laws. He who looks upon it as a mere table of atomic weights has lost its meaning. It tells, with no uncertain note, of the kinship of the elements and leads to a search after the secret of this interdependence and of their common factor or factors. There is so much which is made clearer if we assume a composite nature for the elements that many do not hesitate to make the assumption.

Still another indirect method of approaching that problem is by analogy with bodies whose nature and composition are known. A very striking symmetry is observed between the hydrocarbons, and these in the form of compound radicals show a strong resemblance to certain of the elements. This analogy need not be dwelt upon here. It has been recognized for a long time and tables of hydrocarbons have been constructed after the manner of the Periodic System. Now these bodies are simply built up of carbon and hydrogen in varying proportions, and in any one homologous series the increments are regular. We know that they are composite and that they have but two common factors, carbon and hydrogen.

Again, the fact that certain groups of associated atoms behave as one element and closely resemble known elements may be taken as a clue to the nature of the elements. Thus carbon and nitrogen, in the form of cyanogen, behave very much like the halogens; and nitrogen and hydrogen in the form of ammonia so closely resemble the group of elements known as the alkalies that this "volatile alkali" was classed with them before the era of our elements and the analogy lead to a vain search for an "alkalizing principle" and later to an equally futile pursuit of the metal ammonium.

A further clue to this nature is afforded in the remarkable changes of properties which can be brought about in some elements by ordinary means, and one might mention the equally remarkable veiling of properties induced by the combining of two or more atoms. Thus copper exists in a cuprous and a cupric condition, and the change from one to the other can be readily brought about. And this is true of many other elements.

This has doubtless been a tedious enumeration to you of well-known facts and arguments, but it has been necessary, for I wish to lead you to the summing-up of these arguments and to induce you to draw boldly the necessary deductions. It is high time for chemists to formulate their opinions in this matter. It would seem as if we were shut up to one or two conclusions. Either these imagined simple bodies are after all compounds, built up of two or more common constituents, or they are but varying forms of one and the same kind of matter subjected to different influences and conditions. The supposition that they are distinct and unrelated simple bodies is, of course, a third alternative, but to my mind this is no longer tenable.

The second hypothesis is the one put forth by Graham. It was his cherished vision of the gaseous particles about which he thought so deeply, and in many was so truly. Thorpe has written of this as follows (loc. cit. 222):

"He conceives that the various kinds of matter, now recognized as different elementary substances, may possess one and the same ultimate or atomic molecule existing in different conditions of movement. Graham traces the harmony of this hypothesis of the essential unity of matter with the equal action of gravity upon all bodies. He recognizes that the numerous and varying properties of the solid and liquid, no less than the few grand and simple features of the gas, may all be dependent upon atomic and molecular mobility. Let us imagine, he says, one kind of substance only to exist—ponderable matter; and, further, that matter is divisible into ultimate atoms, uniform in size and weight. We shall have one substance and a common atom. With the atom at rest the uniformity of matter would be perfect. But the atom possesses always more or less motion, due, it must be assumed, to a primordial impulse. This motion gives rise to volume. The more rapid the movement, the greater the space occupied by the atom, somewhat as the orbit of a planet widens with the degree of projectile velocity. Matter is thus made to differ only in being lighter or denser matter. The specific motion of an atom being inalienable, light matter is no longer convertible into heavy matter. In short, matter of different density forms different substances — different inconvertible elements, as they have been considered."

The hypothesis that the elements are built up of two or more common constituents has a larger number of supporters and would seem more plausible. Some have supposed one such primal element by the condensation or polymerization of which the others were formed. Thus we have the hydrogen theory of Prout, modified to the one-half atom by Dumas, and finally by Zängerle to the one-thousandth hydrogen atom. The suggestion of Crookes as to the genesis of the elements from the hypothetical protyle, under the influence of electricity, may also be mentioned here.

Others have adopted the supposition of two elements, Reynolds making one of these an element with a negative atomic weight, whatever that may mean. Low and others have fixed upon carbon and hydrogen as the two elements.

There are many practical difficulties in the way of these suppositions; the lack of uniformity in the differences between the atomic weights, the sudden change of electro-chemical character, and the impossibility, so far, of discovering any law underlying the gradation in the properties of the elements with the increase of atomic weights, are some of the difficulties. In comparing these two hypotheses that of Graham seems to me very improbable. I have thought of valence as dependent upon the character of the motion of the atom, but cannot well conceive of a similar dependence of atomic weight and all the other properties. There remains, then, the hypothesis of primal elements by the combination of which our elements have been formed. These molecules are probably distinguished from the ordinary molecules by the actual contact and absolute union of the component atoms without the intervention of ether.

Since these elemental molecules cannot as yet be divided, we may retain the name atom for them, but the idea of simplicity and homogeneity no longer belongs to them. The definition of an element as a body made up of similar atoms is equally lacking in fidelity to latest thought and belief, but chemists would scarcely consent to change it, and, indeed, it may well be retained, provided the modified meaning is given to the word atom. But, after all, an element is best defined by means of its properties. It is by close study of these that we decide upon its elemental nature, and through them it is tested. Complete reliance can no longer be placed upon the balance and the supposed atomic weight.

All elements are acted upon by gravity and chemical force and other physical forces, but within the last few years certain gaseous elements have been discovered which are not influenced by chemical force or affinity. According to some (Piccini, *Zeits. An. Chem.*, XIX, 295) this necessitates a division of the elements into two classes. Manifestly, since it is chiefly by the action of chemical force that we study the elements, the absence of such action cuts us off from our chief means of finding out anything about them, and it is equally clear that bodies so diverse cannot well be classified together. If all attempts at bringing about the chemical union of these gaseous elements with other bodies fail, I believe that we should insist upon the existence of two classes of elements and keep them distinct in all comparisons.

Of course, we are quite at a loss to say just what chemical force is, but it is believed to be determined by the electrical condition of the atom. Thus we have the elements which show the action of chemical affinity varying from strongly electro-positive to strongly negative. This electrical charge of the atom seems to be a primitive, inherent property, and so beyond our control or power to change. At least no change of the kind has ever been recognized and recorded. Sodium remains positive and chlorine negative in spite of all that may be done to them. We can, by uniting the two temporarily, cloak and neutralize their opposite natures, but the original condition returns on their release.

Is it not fair to assume that argon, helium and their companion gases, having no affinity, are without electrical charge—atoms from which the electrical charge has been withdrawn; the deadest forms of inanimate matter? Were they thus without electro-chemical properties and affinity from the beginning, or did they start out as ordinary atoms (if I may so call them), and somehow, somewhere lose these properties, and with them the power of entering into union of any kind, even of forming molecules, doomed to unending single existence? Can these be changed atoms of some of our well-known elements, a step nearer to the primal elements and with the electrical charge lost? Is it possible for us to bring about these changes? May we not unwittingly have done so at some time or other in the past? Is it possible to restore the electrical charge to such atoms, and so to place them once more on a footing of equality with elements of the conventional type? These and many other questions surge through the mind as one thinks of these wonderful gases. Perhaps the coming century will unfold the answers.

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University of North Carolina.

*ENGINEERING EDUCATION AS A PRELIMINARY TRAINING FOR SCIENTIFIC RESEARCH WORK.**

At first thought it might seem that the subject chosen for this address is of such a nature that it should have been made the basis of a paper before the Society for the Promotion of Engineering Education. I admit that it would not have been out of place there, but at the same time I am of the opinion that such an address also forms, as it were, a bridge from our special engineering section to the purposes of the general Association. It will show that the work and the attainments of the engineer form an important and integral part of the scientific work of to-day.

As you no doubt know, there has been for some time general and strong misgivings as to the future of this section of the Association, and many have expressed the opinion that engineers and professors of engineering ought not to belong to the American Association for the Advancement of Science, as the work of the engineer and the pure scientist are of such a very different nature. It must, of course, be granted that the work of most practicing engineers is only distantly related to the work of the members of this Association belonging to the various sections, with the exception of D. But, on the other hand, a great many of the practicing engineers and of the professors of engineering do truly scientific work, and, what is more, in the opinion of the speaker, the preliminary training of the engineer is perhaps the best yet found to educate a man for future scientific research work.

These facts have led the speaker to believe that a consideration of the subject announced might perhaps increase the interest in Section D, and possibly thereby help to prevent its disappearance, which, to many of us, has seemed both imminent and deplorable.

Presumably our friends, the pure scientists, will shake their heads significantly when they read the title of this address, and if any of them should happen to hear it, or later read it, they might perhaps even go so far as to bestow a smile of pity on us poor engineers, etc., who have such a high opinion of our own worth. But even if none of our scientific brethren should be converted, the speaker would feel satisfied with the results should he succeed in giving more confidence to the members of the engineering profession in its broad sense as possessing the necessary training for accurate and important scientific research work.

The proposition which I expect to defend in this address is that engineering education as furnished in the best technical schools of the world, together with the training obtained later in life as a practicing engineer, probably furnishes the best preliminary preparation for the successful prosecution of scientific research work. I am now speaking of the preliminary training; the special knowledge of the subject in which the research work is to be done

* Address of the Vice-President before the Section of Mechanical Science and Engineering, American Association for the Advancement of Science, 1899.