relation, is needed in all fields if we are to be able properly to relate ourselves to the realities in the midst of which we live. Scientific research is no narrow thing. The scientific motive and the scientific method properly apply in all phases of human thought and action. The field is a vast one and its intricacies increase in geometrical ratio as our knowledge grows and our vision widens. Perhaps the phrase "productive scholarship" or "creative scholarship" would be less liable to misunderstanding than the word "research." I would use the three as almost synonyms.

In closing may I be allowed a word of caution against misinterpretation of the attempt to emphasize scientific research in college? This does not at all mean, as so many seem to think, emphasis upon the so-called utilities. So-called practical motives are a poor inspiration and an unsafe guide in research. Let me quote a paragraph from a former discussion of this theme:

> The motives to research may be as varied as are the characters and interests of the men engaged in the pursuit. But the urge which seems the most productive of the highest grade work is that of the fun of the game, the pleasure in the research itself, the love of truth and its pursuit. Ulterior motives of personal profit or even the desire to promote the progress of civilization and the well-being of society, all have an element of danger. They are likely to persuade the student, perhaps unconsciously, to control the direction of his search, turning it into so-called profitable channels. But no man can know where lie the great undiscovered truths. Truth itself is a safer guide into the unknown than is any man's guess as to the probable best line of approach to worth-while knowledge. The student who humbly follows where the subject itself seems to lead him, eager to follow whatever turn the investigation naturally takes, is the one most likely to find the richest deposits for his mining. Truth is too manifold, too unexpected, too great, oftentimes too profoundly simple, for any man's successful anticipating. From the most unexpected sources come discoveries that open great vistas far beyond the previous imagining of any man. The humble following of the subject itself and the suggestions that develop in the research is the method usually that brings to the largest results. Interest in the subject itself, the desire to know the truth, the pleasure, the uplift of soul, that comes with the gaining of some new vision into a hitherto unexplored field of reality, these are the safest guides, leading one to results in value far beyond fame or financial profit or some invention that shall increase the perhaps already too great complexity of human life. The instinct for truth, the love of understanding for its own sake is ingrained in the human soul.

And to it may safely be made the strongest appeal in inducing students to enter upon the life of research. The fun of the game, the worth of the game for its own sake, makes a keener appeal to men of the finest type than does the thought of possible dollars to accrue or possible fame to be attained.[2]

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ATOMIC NUMBERS VERSUS ATOMIC WEIGHTS

IN the first report of the International Commission on the Chemical Elements the following statements

[2] Several persons who have heard or read this paper in manuscript have referred to the college described as Utopian. It is really not so far removed from realization as one might think. In Oberlin College since 1836 the faculty have had complete control over educational policy and methods, over budget, over appointment of teachers and other members of the staff, and in reality, though not in legal form, have had as much determining influence as the trustees in choice of president. Oberlin's president functions not as an autocrat, but as chairman of faculty and trustees. Oberlin has a ''Presidential Committee'' composed largely of faculty members which is empowered to act for the trustees when the latter are not in session. Many colleges limit the number of their students. Five years ago when Oberlin received a gift of several million dollars the faculty voted that it should be the policy of the college to have more full professors than associate professors and more associate professors than instructors. She now has 51 full professors, 40 associate and assistant professors, 18 instructors (including gymnasium floor directors) and 7 laboratory and other teaching assistants. Numerous colleges encourage individual work for honors, mostly by seniors. Oberlin now has a committee considering increase of such individual work in the college. Swarthmore has no regular classroom work for honors students in the junior and senior years. Professor Hilton, of Pomona College, puts a good many of his first course students onto an original problem for about one quarter of their time and continues this method with more advanced students and with such success that the heads of the zoological departments of two universities have said to me that their best trained graduate students come from Pomona. For a good many years Goucher College never allowed her students to know anything about grades until after their graduation, though the registrar's records were kept in the form of grades. I am under the impression that no student ever made inquiry after graduation as to her grades. At least two colleges now keep for each student cards not only giving grades but annotated also somewhat as suggested in this paper. During the first 20 years of Goucher's work just 20 per cent. of her graduates went on to graduate study in universities requiring college graduation for admission. Half time teaching and half time for research is found, I think, only in a few collegiate departments of universities and in no independent colleges. The college pictured in this paper is a composite of features from a number of institutions but embodies no new feature except the combination itself.

occur: "A *chemical element* is defined by its *atomic number*." This statement serves as an example of the tendency among physical chemists to regard the order of arrangement of the elements as more important than the atomic masses which are so arranged. Their justification for this procedure is twofold. First, the atomic numbers are supposed to represent the number of electrons belonging to each elementary atom, and, secondly, the net electric charges carried by the atomic nuclei. Neither of these assumptions is absolutely proved, and much experimental work must be done in order to establish their verity. The atomic numbers may be changed by the discovery of new elements, or by the definite placing in the scale of atomic weights of such spectral elements as nebulium and coronium, which are now known only from their spectra in nebulae or in the sun. There is evidence to show that nebulium falls between hydrogen and helium, and that coronium is lighter than hydrogen; so that the placing of these elements would involve the renumbering of all the others. I cite here only one of the uncertainties that are connected with the atomic numbers; for present purposes I need not follow this line of discussion any further.

Now the value of any theory is best determined by its utility. Does it bring all lines of evidence into convergence? Does it assist in the solution of related problems? Does it point the way to new discoveries? All this has been done by the atomic theory, and in great part through the practical uses of the atomic weights. These are the fundamental data of chemical arithmetic. When we fix the chemical formula of a new compound, or from a formula we compute the quantitative composition of the substance that it represents, we use atomic weights. If we write the equation for a chemical reaction, no matter how complicated it may be, we still use atomic weights or symbols representing them. The atomic numbers do not help us, for they have no bearing upon these very common problems. For the atomic weights of the elements *and* their numerical order the periodic law was developed, but the weights came first. The physical properties of the elements were then found to be functions of the atomic weights, but the functions were often, if not always, periodic, and not determined by or directly related to the quantities which we now call the atomic numbers. In the Lothar Meyer curve of atomic volumes this periodicity is clearly shown, and the elements fall into natural groups regardless of their atomic numbers. The atomic volumes represent the ratios between the specific gravities of the elements and their atomic weights. The similar curves of melting points and of compressibilities also represent ratios in which the atomic numbers do not appear. The superior utility of the atomic weights is evident. Even the atomic numbers and the physical quantities that are directly related to them may be interpreted as functions of the atomic masses. If so much be admitted, then a chemical element should be defined by the aggregate of all its properties.

So far the argument is strongly in favor of atomic weights, but are they definite constants? Or are they merely "statistical averages" of nearly related but not identical quantities? The problem is complicated by the existence of isotopes, and their true nature is as yet incompletely determined. Are they all to be classed together, or do they fall into two or more different classes? The time is not yet ripe for a complete answer to these questions, but some evidence bearing upon them is even now available. In the study of radioactivity it has been found that two elements, uranium and thorium, are spontaneously but slowly decomposing and probably have been doing so for many millions of years. This process of decay ends, so far as we now know, with the production of two varieties of lead, one from uranium as its ancestor, the other from thorium. The atomic weight of uranium lead is approximately 206; that of thorium lead is about two units higher. These atomic weights have been directly determined with material derived from ores of uranium and thorium. Between these varieties of lead and their ancestral elements, four other decomposition products have been identified with hypothetical atomic weights ranging from 210 to 214, and all six of these products are given the same atomic number with ordinary or normal lead, and are regarded as isotopic with it. That is, they are assumed to be chemically identical with normal lead, and not separable from it or from one another by any purely chemical process. That they have not been so separated is true, but to say that such separation is impossible is to go beyond the evidence. The history of science contains many instances of impossibilities that have become possible. Ordinary lead, which I believe to be the normal or stable product of elemental evolution, has an atomic weight of 207.2, as determined by Baxter and Grover with samples derived from four different ores, and from localities as widely separated as Missouri and Australia. This value is definite, and is the one which, rounded off to 207, is used in chemical calculations. It is hard to believe that so constant a figure can be a mere statistical average of values ranging from 206 to 214, or even from 206 to 208.

Now these isotopes of lead, with numerous other products of radioactivity, are assigned atomic weights and numbers which are largely hypothetical. For uranium lead and thorium lead the atomic weights have been actually determined, and the same is true for radium, and less exactly for its emanation. Ionium is known to have a lower atomic weight than thorium, but the other "elements" of this group have had their constants fixed by reference to those of their ancestors. The atomic weight of uranium as we know it is that of an element which is slowly decomposing, and has been doing so for millions of years. The atomic weight of normal uranium, as the element was before it began to decay, is unknown. Conditions of which we know nothing favored its evolution; when they passed the element became unstable and decomposition began. Our existing uranium is not the same as it was at the beginning; it is a mixture of undecomposed atoms with some products of decomposition, among which may be substances that are not giving off radiations and are not likely to be detected easily. This, I admit, is speculation, which may or may not be sustained by future discoveries. The essential fact is this: that the radioactive elements are products of decomposition, and their atomic weights and numbers as derived from those of uranium and thorium, two partially decayed elements, can not be exact. The derived "elements" are themselves decaying, some slowly and others rapidly, some of them with life periods of many years, some with their existence limited to fractions of a second. They are matter in transit from one form to another; and how far they are entitled to be called elements is yet to be decided. They can not be defined by indefinite atomic numbers.

So much for the radioactive elements and their isotopic relations. It is not necessary for present purposes to consider them in greater detail. What, however, can be said of the elements below lead in the scale of atomic weights? Here the study of "mass-spectra" by Aston is extremely suggestive. These spectra, as recorded on carefully calibrated photographic plates, may be divided into two classes: first, those giving single lines, and, secondly, those in which the record is multiple. By the relative position of these lines upon the plates the atomic weights of the elements giving them are approximately determined, and all are found to be near whole numbers when $0 = 16$ is taken as the standard of comparison. That standard, however, was originally adopted by chemists as a matter of convenience, and has no philosophic background.

The elements giving single line spectra are defined by Aston as "simple" or pure elements, not complicated by the presence of isotopes. Their atomic weights, therefore, are definite quantities, and not statistical averages. Those giving double or multiple spectra are supposed to be mixtures of isotopes. Up to the time of writing, or rather of the latest published report seen by me, 23 elements have been defined as simple, or about half of those that have been investigated. What is the meaning of the others? The isotopes revealed by radioactivity are, as we have seen, decomposition products; are those of the mass-spectra of the same character? Or are the mass-spectra due to impurities too small in amount to be detected by other means? Or do the multiple spectra represent clusters of similar, but slightly different atoms which reveal their differences on the photographic plates? That is, as Aston maintains, are the elements giving these spectra mixtures of isotopes?

In the report of the International Commission, pp. 9 and 11, is given a table of isotopes that is extremely suggestive. The simple or pure elements, so far as they have been identified, are, with few exceptions, all below atomic number 40. Eight of them do not appear in the table, for they were discovered by Aston since it was published. Iodine and caesium are also simple elements; but, as we ascend in the scale of atomic weights, the isotopes tend to become more common and more numerous. I speak of a tendency, not of a definite rule. Although doublets and triplets appear in the lower part of the scale, that is, among the elements of structural simplicity, we can say that the more complex an element is, the probability of the appearance of multiple mass-spectra becomes greater. Not until all the elements have been studied by Aston's method can any definite rule as to isotopes be formulated. Among the radioactive elements or pseudo-elements isotopy seems to be the rule. "Simple" elements have not been found among them. In this region isotopy is definitely associated with atomic instability. Is it not, therefore, legitimate to suppose that some of the multiple mass-spectra may indicate elemental decomposition? Along this line of thought, however, we must not go too far. Two elements, chlorine and mercury, need separate consideration, and there may be others like them.

Consider first the two elements as we know them, that is, as they occur in nature. The atomic weight of chlorine is very constant, and the value assigned to it is 35.46 within 1 part in 10,000. That of mercury is very close to 200.6, and its definiteness is also fixed by determinations of its density. Brönsted and Hevesy determined the specific gravity of mercury from ten different sources, and only found differences corresponding to differences in atomic weight of from 0.0004 to 0.0012. The ten samples were identical within the limits of experimental uncertainty. The same chemists, however, by a process of fractional evaporation, succeeded in partially separating mercury into two fractions which differed in density and also in atomic weight. The atomic weight determinations were made on the original fractions by Hönigschmid and Birckenbach, who found for the heavier fraction $Hg = 200.628$; and for the lighter one $Hg = 200.562$ to 200.568. These figures are conclusive; and although the fractional separation was not absolutely complete, they prove the composite character of mercury. Similar results, by a similar method, have been obtained by Harkins and his colaborers in Chicago. According to Aston, the mass spectrum of mercury shows two lines at 202 and 204, with four others of uncertain significance between 197 and 200. These figures, it seems to me, are questionable, for 197 is the atomic weight of gold, and 204 that of thallium. Did the mercury studied by Aston contain as impurities minute traces of gold and thallium?

By prolonged fractionation Harkins has divided hydrochloric acid into two portions which differ in atomic weight and density, thus showing that chlorine, like mercury, is composite. But for neither element has the separation of its components been complete. That one component is more massive than the other is clear, but the definite atomic weights of the two elements show a constancy of composition which calls for explanation. We are not dealing with indefinite variable mixtures.

I now venture to offer a hypothesis which is at least fairly plausible. In the evolution of the elements some of them were generated as doublets in which the components are loosely held together, but which in their chemical relation act as units. We can conceive of such doublets as analogous to double stars, those pairs of suns which move and act together, notwithstanding their differences in mass. Whether this analogy can be extended to the elements that give multiple mass-spectra remains to be seen. About half of the known elements are yet to be studied by Aston's methods, and the work is being carried forward energetically. When it is finished we may hope to know much more as to the relative significance of atomic weights and atomic numbers, and as to the real nature of the chemical elements.

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MATHEMATICS AND GEOPHYSICS[1]

GEOPHYSICS is physics applied to the study of terrestrial phenomena. To make the statement more definite it may be of interest to enumerate the subdivisions of this science as formulated by the National Research Council in organizing the American Geophysical Union. That union includes sections of: (1) Geodesy, (2) oceanography, (3) meteorology, (4) seismology, (5) terrestrial magnetism, (6) volcanology and (7) geophysical chemistry.

To the student of geophysics, as to the student of physics in the narrower sense, there are open three ways for discovering truth: (1) Observation of phenomena under controlled conditions, in short, laboratory experiments; (2) observation of phenomena as they are presented to us by nature; and finally (3) logical deduction from assumptions suggested by observation and experiment and comparison of the conclusions reached with the observed facts. The most satisfactory method of deriving our conclusions is by mathematical reasoning, since this method alone gives quantitative results.

From the nature of the case the methods of laboratory experiment have been of less use in geophysics than in physics in the narrower sense. The experimenter can reach only a few miles into the upper air with his pipes and balloons carrying their recording apparatus and must himself remain on a still lower level. Our deepest borings penetrate but a few thousand feet into the outer skin of the earth[2] and the interior of the earth still remains, as has been well said, the playground of the imagination, almost as much so as when Dante peopled it with the spirits of the departed.

It would, however, be unfair to insist on this thesis of the comparative inapplicability of laboratory methods to geophysical problems without mentioning the work of the Geophysical Laboratory, a department of the Carnegie Institution, which is in fact applying laboratory methods to these problems and applying them with marked success. Still, with every allowance of this sort made, in geophysics the methods of the physical laboratory can do little for us in comparison with what is possible in other sciences.

Therefore, in geophysics we must depend all the more on the observation of those phenomena directly presented to us by nature and on mathematical reasoning. A striking example of this method or combination of methods is found in recent progress in our knowledge of that still mysterious region just referred to, the interior of the earth. Important advances have been made which I shall not attempt to set forth by combining the observations at earthquake stations all over the globe and applying to these observations mathematical methods of rather recent development, the theory of integral equations.

Now it would be impossible for any one person to discuss satisfactorily all the problems in geodesy, seismology, oceanography, etc., in which mathematics has given aid, or which still await the hand of him who shall apply existing mathematical methods to them, or who, if need be, shall devise new methods.

1 Read at the summer meeting of the Mathematical Association of America at Poughkeepsie, N. Y., September 5, 1923.

2 The greatest authenticated height reached by a sounding balloon bearing instruments is 35 kilometers. A pilot balloon without instruments is reported to have reached the height of 39 kilometers, but this record is open to doubt (information supplied by U. S. Weather Bureau). The deepest boring in the world is at Fairmont, West Virginia. The depth is 2310 meters (7579 feet) (information supplied by U. S. Geological Survey).