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SURFACE STRUCTURE AND ATOM BUILDING[1]

By Professor **W. D. HARKINS**
UNIVERSITY OF CHICAGO

I. INTRODUCTION

I WISH to express my great appreciation of the unexpected honor which is conferred upon me by the award of the Willard Gibbs medal, established through the generosity of William A. Converse, and bestowed by a jury chosen from the American Chemical Society. For many years Gibbs has been one of my heroes of science, and I am very proud to have my name associated with his in this way. As you know, he was the greatest of American chemists without being, in the technical sense, a chemist at all. The student of chemistry who shies at mathematics may well take this fact into account, for Gibbs at his desk discovered in a few years more concerning the relations of chemical phenomena than has been learned in the whole life work of dozens of other prominent chemists.

The number of facts which may be found in experimental work in any science is so great, and at the same time so limited in scope, that their discovery is seldom worth while unless they can be correlated with other facts to give general relations. The most general of these relations are often dignified by their designation as laws of nature. Thus scientists may be classified as those who discover facts and those who classify or correlate them, or as experimentalists and theorists. Usually the experimentalist needs to be, at least in a limited way, a good theorist, though it is not essential that the theorist be an adept in experiment. For this reason, Gibbs was able to become the greatest of theoretical chemists without the acquisition of any of the ordinary experimental technique of the science.

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[1] The Willard Gibbs lecture delivered in connection with the award of the Willard Gibbs gold medal by the Chicago Section of the American Chemical Society, May 25, 1928. Revised May 18, 1929.

Arrhenius, the first Gibbs medalist, established the precedent of describing his own work, and the factors which caused him to take up the specific topics of research which he had undertaken, and it has been requested that I should follow his lead, though it will be necessary to do so in a more limited way.

As an undergraduate, research appealed to me as one of life's greatest adventures, and I was attracted both to the very large, in astronomy, and to the extremely minute, in chemistry and physics. While the study of the atom and of radioactivity, then a new subject, had an extreme fascination, there were two subjects of investigation in physical chemistry which seemed to me of such minor importance that I took a firm resolution never to be enticed into working on either of them.

These two fields of work were surface tension and solubility. To illustrate, let us consider surface tension. I did not realize that the importance of the study of surfaces and surface energy arises from the fact that the surface lies outside every body, particle or cell. To get inside from outside or outside from inside, the surface must be traversed.

In 1909 I went to Germany to study with Haber, the chemist whose work on the synthesis of ammonia lengthened the World War by one or two years. On the first day of my stay in Karlsruhe, he invited me to lunch with him and his assistant at the leading hotel of the city.

Haber insisted that as a visiting professor—I was then professor of chemistry at the University of Montana—only a problem of extreme importance should be given to me. He and his assistant rose, drank my health, and Haber said, "He shall work on surface tension." Unfortunately, or fortunately, I knew hardly enough German to object, and when much later I found that many of the world's greatest scientists had been interested in surface phenomena, I was thankful for this lack of knowledge. Thus Gibbs himself, Laplace and Newman, Einstein, of relativity fame; Roentgen, the discoverer of X-rays; Sir William Ramsay, Lord Rayleigh, T. W. Richards, Bohr, Mendeleeff, van der Waals, Debye, Poincaré, the great mathematician, Walden, Guye and Maxwell—all these had an extreme interest in surface phenomena.

The idea of the problem suggested was that by the investigation of certain surface tension phenomena in extremely simple systems we might make more plausible the idea that the motion of the muscles is due to changes in surface tension of the fibrilles of the muscles, as related to practically simultaneous chemical and electrical changes. This idea seemed well supported by certain simple work done in Nernst's laboratory, but not by Nernst himself. My own experiments showed, however, that this work was altogether incorrect, and so the special point of view that such an extremely simple system could properly represent the mechanism lost its usefulness.

After the completion of the experimental work, I returned to America in order to work on physical chemistry with A. A. Noyes and G. N. Lewis, both of whom have been awarded the Gibbs medal. Here I met my second aversion, for A. A. Noyes stated that, under the grant from the Carnegie Institution which supported the work, it was expected that the general subject of research should be the theory of solutions, but the special subject solubility.

Now the greatest of solubility rules is "similia similibus solvuntur" or "like dissolves like." This rule suggested that the experiments on surface tension might have given results more in accord with the theory if more complicated molecules, such as those present in the muscles, had been used. It is advisable, however, in scientific work, to use as simple materials as will give the desired behavior, so substances like butyric acid were considered. Butyric acid is the substance which gives the disagreeable odor to rancid butter, and a molecule of this substance possesses the interesting characteristic that at one end it is like oil, and at the other like water.

Thus we may place a thick layer of oil on water and add butyric acid. The water-like ends of the molecules should be soluble in water, and the oil-like ends in the oil, but only at the interface between the two can both ends of the molecule be satisfied at the same time. From this point of view the butyric acid should be very much more soluble at the interface than in either oil or water, which is true. Furthermore, at the interface there should be a certain structure, since the molecules of butyric acid should, in general, be oriented with oil-like ends toward the oil, and water-like ends toward the water. (Orientation at a surface was here illustrated by throwing on the surface of water a large number of cylinders of wood, weighted at the red end, which represents a polar group, and white at the lighter or non-weighted end, which represents the non-polar groups.

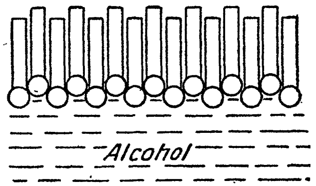

FIG. 1A. Orientation of the molecules at the surface of a liquid.

All these cylinders took on an upright position in the surface of the water, with the red ends down and the white ends up. The molecules differ in that they are in motion, so their orientation is not complete.)

A later careful search in the literature showed that Hardy, a noted English biologist, had just suggested (1912) that since a surface is extremely unsymmetrical with reference to the material on its two sides, the molecules in the surface should be oriented. Thus the theory of dissymmetry and that of solubility gave rise in two different minds to the same suggestion. Hardy suggested as an additional hypothesis that this molecular orientation should result in the attraction or repulsion of their surfaces according to the way in which the molecules are oriented. With this hypothesis, I was not so much in accord, and work was begun to show that the surfaces always attract, and that the variation in the magnitude of the attraction indicates that the molecules are oriented.

It was found that when alcohol, for example, is pulled apart it is separated at the weakest place in the liquid. That is, the final break seems to occur between the oil-like ends, and not between those that are water-like. Furthermore, when alcohol evaporates, the oil-like ends emerge first from the surface and the water-like ends escape last. Several years later this last idea led to the discovery of a new method of testing experimentally the symmetry of the molecules of a substance in the surface of a liquid.

It is of much interest to me that one of the speakers this evening, Dr. George L. Clark, while in my courses took excellent, but terse notes. In the notes from one of the lectures delivered in March, 1914, the following phrase, an extremely concise statement of the orientation theory, appears in connection with a discussion of interfacial energy and the spreading of oleic acid on water:

> COOH of acid down because both acid and water associated and polar.

Thus it was considered that when an organic substance spreads on water, a polar liquid, the active or polar group is oriented toward the water, and the inactive or hydrocarbon group toward the vapor phase.

These surface energy relations find their most important application in the field of colloids, particularly with reference to the structure and action of living organisms, but they are also of interest in connection with soaps and cleansing, paints and varnishes, milk and butter, food and medicinal substances.

In order to understand the action of surfaces, it appeared essential to learn as much as possible about the electrical structure of molecules and of atoms, so, in 1913, I began to study more intensively the current theories of atomic structure. In 1904, Nagaoka had suggested that an atom consists of a central sun or nucleus and a system of negative electrons as satellites. This theory was amplified by Rutherford, who showed that the positively charged atom nucleus appears to be extremely minute in comparison with the space occupied by the atom. For many years the phenomena of radioactivity had been extremely fascinating to me, and this was undoubtedly what caused my attention to be directed more specially to the nucleus, which determines the stability and even the existence of the atom as a whole.

The committee in charge of the arrangements for the Gibbs lectures has asked that a detailed discussion be presented concerning one of the general topics to which I have given particular attention, and I have chosen the subject "Atom Building," or modern alchemy, as the second topic in this series of two lectures.

II. ATOM BUILDING

1. *Ancient and Modern Alchemy*

One of the earliest experiences of a human being is that of becoming acquainted with the objects and the substances which make up his environment. Much later he may or may not learn that some substances are simpler than others, and that these, ninety-two in all, constitute the alphabet of nature from which all material things are made.

That some of these simple substances, or chemical elements, are more abundant than others is commonly taken as a matter of course, even although the relative abundance of the elements determines not only the environment but also the nature of life itself: in fact even its existence or non-existence. Thus arsenic and iodine are rare, and oxygen and iron abundant. How different life would be if the reverse were true!

The abundance of an element is determined by the stability of its atoms and the processes by which they are formed, and those by means of which one element (or more correctly atomic species) is converted into another.

For several thousand years the development of chemistry has been profoundly influenced by the idea that one element may be transmuted into another by an artificial process, although during the nineteenth century the alchemistic idea became discredited for a considerable period. It is natural that the greatest effort should have been placed upon attempts to change other elements, especially other metals, into gold, since this was the most beautiful, permanent and the most valuable of all known metals. Thus, one expression of the alchemistic idea is as follows:

> Since . . . the substance of the metals is *one*, and common to all, and since this substance is (either at once, or after laying aside in course of time the foreign and evil sulphur of the baser metals by a process of gradual

digestion) changed by the virtue of its own indwelling sulphur into *gold*, which is the goal of all the metals, and the true intention of nature—we are obliged to admit, and freely confess that in the mineral kingdom, as well as in the vegetable and animal kingdoms, nature seeks and demands a gradual attainment of perfection, and a gradual approximation to the highest standard of purity and excellence.[2]

The idea that all elements are formed from one primordial constituent is shown by this and other writings to be a very early one.

While ancient alchemy was so intimately associated and intermingled with mysticism that the two can not be disentangled, this is not true of the alchemy of the twentieth century. Nevertheless, one feature of the early work persists in almost all that is done at the present time: erroneous or incomplete observations, commonly with impure substances, are cited to show the change of one element or metal into another. In early alchemy, iron, in a stream which came from a deposit of copper ore, seemingly became converted into copper; impure mercury, when distilled, left a residue of gold. Is it at all strange that the alchemists adduced such phenomena as evidence for the transmutation of one element into another?

Within the last few years the belief in transmutation has become so intense that even able scientists, on finding gold in impure mercury, have believed it formed by an electronic change in the mercury itself, although the obvious explanation is that the gold was originally present and was sufficiently concentrated by the experimental process employed to be more easily detected in the final product. Not only gold, but also lead, helium and copper have been thought to be formed from certain metals by comparatively mild processes; that is, by those in which the intensity of the energy employed was very low. In no case is there a sufficient verification of the success of any attempt to change one chemical element into another by any artificial process whatsoever.

There are certain factors which are undoubtedly related to this failure of the modern alchemists: (1) It is probable that atomic transmutations are usually slow when small intensities of energy are applied, and are often slow with large intensities. (2) Many atomic transmutations do not take place with any measurable speed unless the intensity of the energy is extremely high.

Thus a part of the lack of success of artificial means is undoubtedly due to difficulty of obtaining and applying energy of the requisite high intensity, and may be due in some cases to the difficulty of detecting the minute amounts of the products of the transformation which are formed.

It is often assumed that the total energy applied, for example, several hundred thousand volts from an induction coil, is utilized in the atomic transmutation. However, if such a discharge is passed through air or oil to a mercury surface the total energy is distributed between so many atoms that the energy per atom is small.

While it seems certain that if an electron could be attached to the nucleus of an atom of mercury, the atom would become one of gold, and while it seems, from electrostatic considerations, that the positive nucleus of a gold atom should attract an electron, at distances not too large or too small, it is also probable that if the electron is to sufficiently penetrate the atom of mercury, a certain threshold energy must be exceeded—at least, that this must be true to insure a sufficient probability of penetration to give a yield large enough to be detected by chemical means. From this point of view, the bombardment of the mercury by electrons should occur in an X-ray tube, or more efficiently by means of a Coolidge electron tube. However, by the application of an X-ray tube with a mercury anticathode it was found that 145,000 volts per electron, or a velocity for the electron of 12,000 miles per second, is not a sufficient amount of energy to give in pure mercury a detectable amount of gold, even with the use of an extremely delicate test, so delicate that it was capable of detecting one part of gold in one hundred billion parts of mercury.[3]

Notwithstanding the failure thus far of all artificial means, it has been possible, by photographing the tracks of atoms in gases, to observe in the laboratory a *natural* process by means of which heavier atoms are produced by lighter ones. Thus the natural synthesis of atoms has been demonstrated. A description of the method used is given in section (9).

2. *The Natural Disintegration of Atoms*

The remarkable discovery of Becquerel (1896) and others that various "rays" are emitted by certain elements of high atomic weight gave a remarkable climax to nineteenth century chemistry. During this century the prevailing idea seemed to be that atoms are indivisible, and extremely hard and indestructible. That matter is built up of indestructible particles was suggested very early, and the idea was expressed in an interesting way by Newton:

> It seems probable to me, that God in the beginning formed matter in solid, massy hard, impenetrable, movable particles, of such sizes and figures, and with such other properties, and in such proportion to space, as most conduced to the end for which He formed them; and that these primitive particles, being solids, are incomparably

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[2] "The Golden Tract Concerning the Stone of the Philosophers" (see "The Hermetic Museum," vol. 1, p. 19).

[3] This test was developed by Haber for the purpose of determining the gold content of the water of the Rhine.

harder than any porous body, 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.

In contrast, the point of view at present is that we are very far as yet from the minuteness of scale which might permit the indivisibility of particles, and that even the conception of indivisibility at even the most minute magnitudes is very difficult of comprehension.

In radioactive processes the atoms emit gamma rays, which are extremely penetrating, but otherwise like X-rays. They also shoot out very fast particles, charged with either negative or positive electricity. The negative particles have been found to be negative electrons, with a mass when at rest about $\frac{1}{1{,}845}$ that of a hydrogen atom. The positive particles are doubly charged helium atoms (alpha particles). The electrons are found to possess varying speeds, with a maximum of the order of about 180,000 miles per second. The alpha particles have initial speeds as high as 20,000, or even more, miles per second. The initial speed is not continuously variable as for electrons, but is constant or nearly constant for any specific disintegration.

3. *The Composition of Atoms*

If the evidence of the radioactive disintegration of the heavy atoms is taken literally, the evident hypothesis is that atoms are composed of negative electrons and doubly charged helium atoms (He^{++} or α). However, the latter can not be the primary constituent of all matter, since it is heavier than the hydrogen atom. The lightest known positive particle is the hydrogen ion in a gas, and this is called the positive electron or *proton*.

According to the Nagaoka-Rutherford theory, an atom consists of a minute positive nucleus, which contains nearly all the mass of the atom (usually all but about $\frac{1}{3{,}700}$), surrounded by a diffuse system of negative electrons. Experiments made by shooting alpha particles through gold foil and through nitrogen indicate that the diameter of the nucleus is only about $\frac{1}{10{,}000}$ that usually ascribed to the atom. If this is actually the case, the nucleus has only one millionth of a millionth the volume of the atom, and a cubic centimeter of tightly packed nuclei would have a mass of about a million tons. This density of one thousand billion is extremely high even when compared with the density of 50,000 attributed by certain astronomers to the companion of Sirius, but the repulsion between such positively charged nuclei is presumably so high that no such density can be attained.

All ordinary matter which we know is very nearly electrically neutral, and is probably extremely close to exact neutrality. Since the proton and the electron have practically identical charges in magnitude, though opposite in sign, this indicates that the number of electrons in any atom is equal to the number of protons. Thus the oxygen atom is supposed to consist of 16 protons and 16 electrons. If the principles of electrostatics alone are considered, it is to be expected that protons attract electrons, but protons repel protons, and electrons repel electrons.

In the formation of an oxygen atom, and of most other atoms also, all the protons unite with exactly half the electrons to form an extremely stable group, the nucleus. The remaining half of the electrons are united in this by comparatively weak forces. In a much smaller number of atoms, the number of nuclear electrons is slightly in excess of half the number in the atom as a whole.

4. *The Problem of Atom Building*

The atom may be broken up with great ease into one or more electrons and a positive residue or core, but the central nucleus has an altogether different, higher order of stability. If the nucleus of an atom can be formed by any means whatever, it will pick up electrons from the surroundings and thus become converted into a complete atom. The problem of atom building is thus reduced to the building of atom nuclei.

It is self-evident that the nuclei of the heavier atoms are built either in one step or in several steps. While light atom nuclei, such as the alpha particle, may be formed in one step from protons and electrons, the probability that this may be true for heavy atoms, such as uranium, is exceedingly small.

Thus the nucleus of uranium I contains 238 protons and 146 electrons, and all these must meet in a volume, which, according to experiments on scattering, is of the order of 10^{-36} cc, or about one trillionth the volume of the atom. That all these should meet in such a small volume in one instant (or in say 10^{-12} seconds) would seem to be an event of almost infinitesimal rarity.

5. *The Periodic System of the Elements*

In the decade between 1860 and 1870, a classification of the elements was made in such a way as to later throw great light on what is now termed technically the structure of the atom. Newlands found that when arranged in order of their atomic weights the elements fall into octaves or periods of eight with respect to the variation of their chemical and physical properties. Mendeleeff developed this idea into what is called the periodic system of the elements. He arranged the elements according to an element number, misnamed the atomic number, which was later found to be identical, when all the elements are included, with the magnitude (in electron units) of the positive charge on the nuclei of the atoms of the element. The length of the periods of this system are 2, 8, 8, 18, 18 and 32 elements, or 2×1^2, 2×2^2, 2×2^2, 2×3^2, 2×3^2 and 2×4^2, though in the periods of 18 and 32 certain secondary periods of 8 are to be found.

It is now believed that this periodic variation in chemical and physical properties gives an index to the structure of the system of electrons outside the nucleus, or of the non-nuclear part of the atom. Thus lithium, sodium and potassium are much alike in physical and chemical properties, although sodium contains 8 more non-nuclear electrons than lithium, and potassium 8 more than sodium. This likeness of properties is supposed to be due to the occurrence of one loosely attached (or outer?) electron in each of these atoms. If seven more non-nuclear electrons are present than in lithium, the seven go into the same set as the one already present, and the element is neon. The atoms of neon are inactive and have little attraction for themselves or other atoms. Thus sets of light electrons are supposed to form a *complete* set of firmly bound electrons.

6. *The Periodic System of the Atomic Species (The New Periodic System)*

Since the loosely bound (non-nuclear) electrons give definite periods of variation to the chemical and physical properties of the elements, it seems natural to suppose that the tightly bound (nuclear) electrons and protons may also exhibit some sort of periodic variations. The difficulty arises that the nuclei of atoms do not directly affect the ordinary physical or chemical properties of the elements.

In 1914, an attempt was made to find some characteristic of atomic nuclei already observed which would serve as a basis of a new classification. The characteristic chosen was that of atomic stability. Since the stability of the atom is that of its nucleus, this involved a study of nuclear stability.

The only atoms whose stabilities were known at that time were those of the radioactive or heavy elements. Each of these elements consists of several atomic species; that is, of several types of atoms of different stability. Thus the ten radioactive elements were known to consist of more than forty atomic species. If several species belong to one element, if the nuclei of their atoms have the same positive charge, they are called isotopes.[4]

It was noticed that if one negative electron is emitted from the nucleus, a second follows, and that the presence of a single or odd electron is accompanied by nuclear instability.

The radioactive elements alone, however, did not give enough data for the development of the desired relations. Since the stabilities of the ordinary elements were totally unknown at that time, it was necessary to establish a hypothesis as the basis of further work.

It was therefore assumed that: *The abundance of an atomic species*[5] *is related to the stability of its atoms, and in general the most abundant species represent the most stable atoms.*

It was not assumed that the stability of an atom is the only factor which influences its abundance. Thus, the rate at which any species of atoms is formed may depend on still other factors than stability. For example, the most abundant species known is oxygen, while carbon is a comparatively rare element. Now if an atom of carbon of mass 12 is converted into an atom of oxygen of mass 16 by the addition of a helium nucleus (α-particle) of mass 4, then the amount of carbon in existence depends not only upon the stability of the carbon nucleus but also upon the extent to which it has been converted into oxygen.

However, notwithstanding this difficulty, the use of the above principle has been justified by the discoveries of the past decade.

The variation of the stability of atoms with the composition of their nuclei is expressed by a number of relations listed below.

(1) *First periodic relation: high stability and abundance for species of even electronic number.* The most important and general of the periodic relations which concern nuclear stability relates to the number of negative electrons in the nucleus (electronic number).

In general atoms of even electronic number are extremely more abundant and stable than those of odd number, and the number of species of atoms is also much larger.[6]

The remarkable emphasis which nature has put upon this relation is only feebly expressed by Fig. 1, which gives the abundance of the atomic species on earth. The contrast in abundance between even and odd electronic numbers is very great. Thus, if be-

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[4] The term isotope is often used in an entirely improper sense. Isotope in no case signifies the species of more than one element. Thus, about two hundred atomic species are known, but not more than eleven isotopes.

[5] The term *atomic species* was not used in the first papers but was devised later to express the meaning of the above principle. According to earlier use the term element might refer to a single isotope of a radioactive element or to the whole chemical element.

[6] *J. Am. Chem. Soc.*, 39: 858 (1917), Table II; *Physical Review*, 15: 73–94 (1920); *J. Am. Chem. Soc.*, 42: 1956–97 (1920).

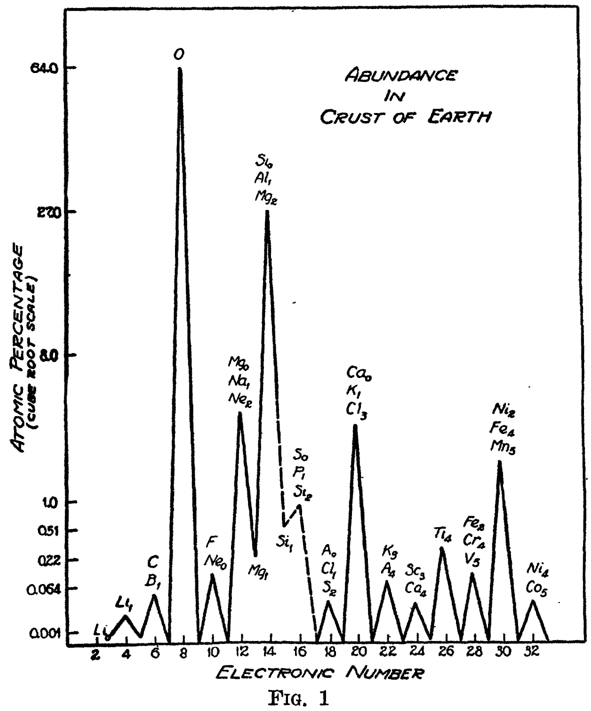

FIG. 1

tween numbers 0 and 12 the highest abundance for the species of any odd number is represented by a height of one eighth inch, as it is in the figure, then on the same scale the peaks for species of even number would rise as high as 700 feet. Furthermore, the species of odd electronic number are so rare that, with only four exceptions, they have not even been discovered. Also, for each even number the species are more abundant than for either of the two adjacent odd numbers. Fig. 2 shows that the general relations for the material of the meteorites are exactly the same.

Not only do the species for each even electronic number exhibit a higher abundance, but in addition the number of species is relatively large (Fig. 3). The fact shown by this figure is extremely remarkable in that the average number of known species is twenty-three times higher for an even than for an odd electronic number.

The above relations may be expressed more concisely by the statement: *The number of electrons in the nucleus is even for almost all atoms and for almost all species of atoms.*

Among the radioactive elements all the most stable species are those of even electronic number, for example, the half-life of uranium is five billion years; for uranium 2, it is two billion years; of ionium, two hundred thousand years, and of radium, 1,730 years. In contrast the longest half-life for a species of odd electronic number is only five days. Also, among the ordinary elements, the most abundant isotope of every element thus far investigated has an even electronic number, with only two exceptions: nitrogen and xenon.

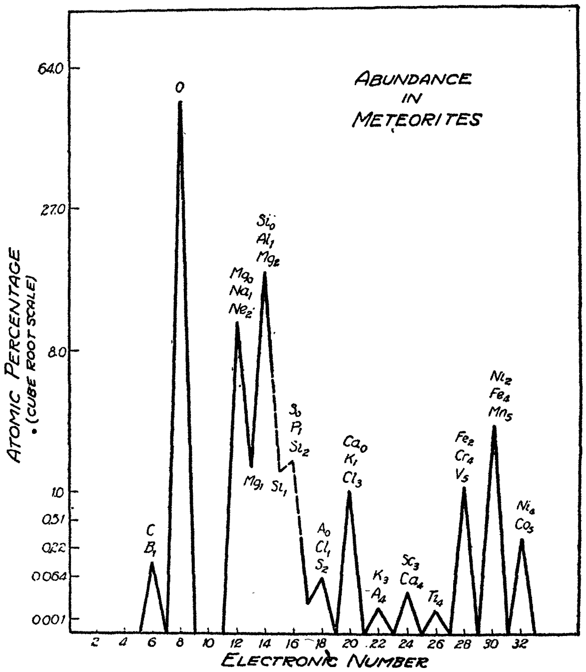

FIG. 2

In a paper which considered the nucleus of the atom to be built up from groups of protons and electrons, one of the tables[7] lists in elements 2 to 27 a total number of 202 groups, each of which contains a pair of electrons, and in addition eight extra pairs of electrons, while in the same set of elements there are only two odd or single electrons.

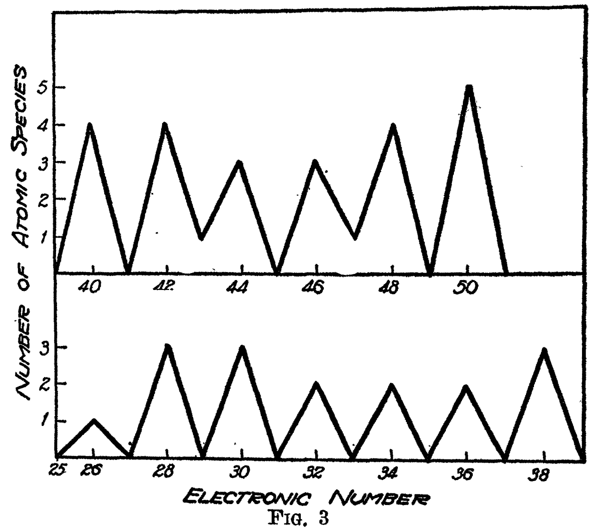

FIG. 3

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[7] Table II, "The Evolution and Stability of Complex Atoms," *J. Am. Chem. Soc.*, 1917.

Whether or not the groups specified in this table exist as such, it seems probable that: The negative electrons in the nuclei of atoms are largely associated in pairs.

At the present state of development of quantum mechanics this suggests that the electron spin may be involved. However, in general, one pair of electrons (binding electrons) seems to bind two pairs of protons, so a proton spin may also occur. The analogy with the pairs of electrons of the outer atom is not of necessity at all close on account of the complication introduced by the presence of the proton.[8]

Certain pairs of electrons (cementing electrons) may be emitted as beta particles from very heavy atoms, or serve to make the nucleus relatively more negative in lighter ones. The two electrons of a pair are not ejected simultaneously, but consecutively. That there is a relation between them is indicated by the fact that the energy of emission of the second electron is much higher in each case than that of the first. In some instances, one electron is emitted, then an alpha particle, and quickly the second electron; or the pair of electrons seems to be related to the holding of an alpha particle.

(2) *Second periodic relation: high stability and abundance for atoms of even atomic number (even nuclear charge).* While the first periodic relation was discovered by mapping the electronic and protonic composition of atom nuclei, the second was predicted from a theoretical basis. This theory was that the nuclei of atoms other than hydrogen are built up almost entirely from alpha (helium) particles; but that, if they are not actually built up by the addition of alpha particles, the stability of the nucleus becomes relatively high whenever its composition is that of a whole number of alpha particles, or a whole number of alpha particles plus one or more pairs of cementing electrons.

From this point of view, the stability, and therefore the abundance, should be high for atoms of even atomic number, that is, for elements of even number. Thus the positive charge on the nucleus of the helium atom (alpha particle) is 2, and therefore only atoms of even nuclear charge can be built up from, or have the composition of, a whole number of alpha particles. Since the numerical value of the nuclear charge gives the atomic number, this means the atoms belong to elements of even number.

Fig. 4 shows that in the meteorites *each element of even atomic number is very much more abundant than the adjacent elements of odd number.* Furthermore, every one of the five most abundant elements, oxygen, silicon, iron, magnesium and sulphur, has an even number. Of the material of the meteorites 98.8 per cent. consists of even, and only 1.2 per cent. of odd numbered elements.

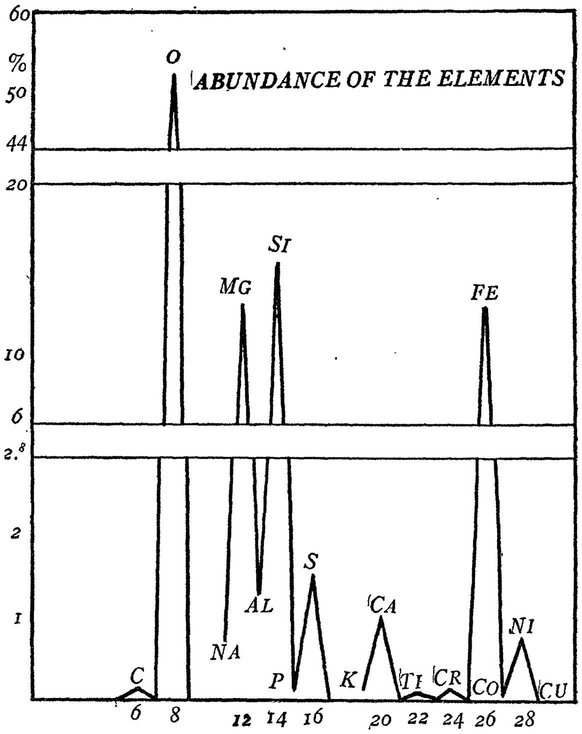

Fig. 4

In the meteorites there are 70 atoms of even to 1 of odd nuclear charge, while in the earth's crust the ratio is 9 to 1 (hydrogen excluded, since it is considered as the fundamental element). The crust of the earth does not properly represent the composition of the earth as a whole, since there has been much segregation of material. In order, therefore, to determine to what extent in the earth the elements of even number are more abundant, the data used should refer to elements such as the rare earths whose relative abundance has not been greatly affected by processes of segregation. Twelve years ago the writer showed that each rare earth of even number is much more abundant than the two adjacent elements of odd number. Later experimental work by Goldschmidt and Thomassen, as represented by Fig. 5, gives further evidence which exhibits the great contrast between even and odd.

Additional evidence for the idea that elements of even number have the more stable atoms is shown by the fact that they are not so easily disintegrated by bombardment with alpha particles (Rutherford) and by the fact that for very light atoms the packing effect (loss of mass) involved in their formation from

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[8] Thus the statement which sometimes appears in papers on the new quantum mechanics that the "pairing of the electrons in the nucleus is the result of the Pauli principle" is peculiarly enigmatic, since the Pauli principle was deduced from systems in which no protons are present, and also long after the pairing in the nucleus was postulated.

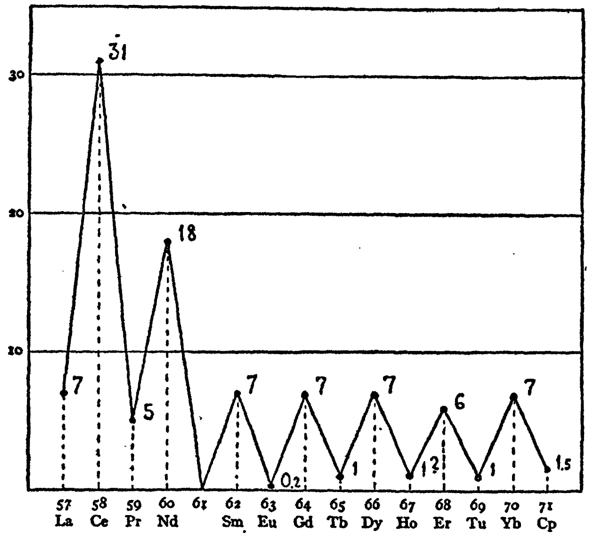

FIG. 5. Periodicity of two in the abundance of the rare earths as a function of the atomic number, as determined by Goldschmidt and Thomassen. The height of each point represents the abundance of the rare earth element in minerals on the surface of the earth. Obviously each element of even number (number given below) is very much more abundant than either adjacent element of odd number. This accords exactly with the predictions of the hydrogen-helium theory of atom building developed eight years before the work represented above was done by Goldschmidt and Thomassen.

hydrogen is much less than for elements of odd number (Costa and Aston).

If the atoms of the elements of even number are more stable in general than those of odd number, then there should be not only more atoms but also more kinds of atoms of even number. Fig. 6 shows that the number of species per element (isotopes) is much larger for even than for odd atomic numbers. The mean number of isotopes per element as shown in the figure is 5.4 for even and 1.6 for odd, while for the radioactive elements values are 4.5 and 1.8, respectively.

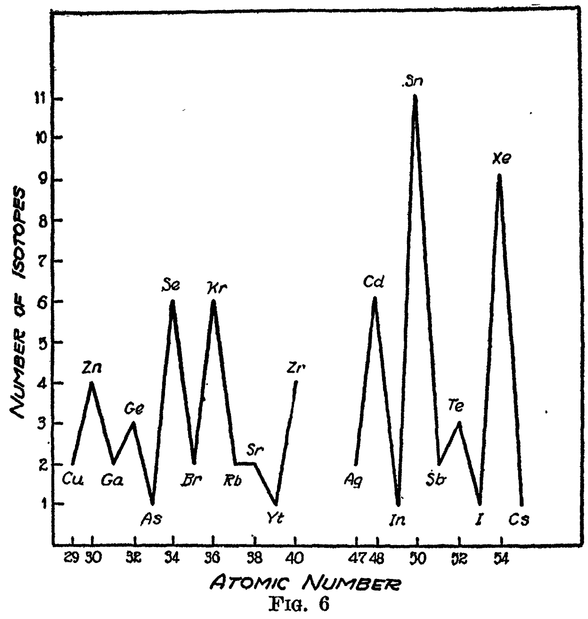

FIG. 6

In general, also, the most stable isotope for each radioactive element has an enormously longer life than the adjacent elements of odd number.

It is of interest in connection with this relation to note that the only two undiscovered elements are in the radioactive region, and that both have odd atomic numbers. Possibly these are so unstable that they do not exist on earth in detectable quantities.

(3) *Primary and secondary factors which determine the abundance of the elements.* It is evident from the preceding discussion that there is a direct relation between the abundance of the elements and the atomic number, and that there is no very marked relation to the periodic system of Mendeleeff. This indicates that the abundance of the elements is determined in a primary sense by the stability relations of the complex atoms themselves, and also by the stability of any electron-proton groups, such as the alpha particle, from which they may be built. However, it is obvious, *even if in the formation of the elements there*

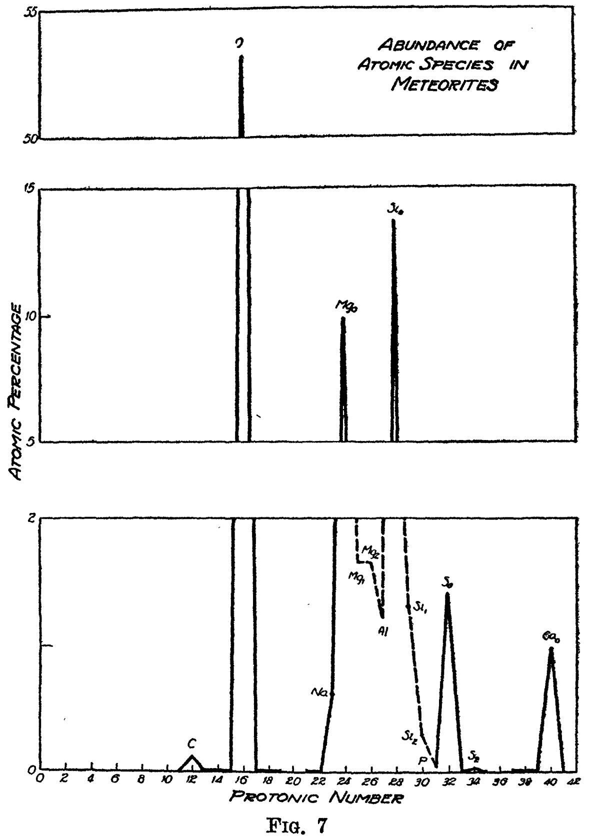

FIG. 7

is no relationship to the ordinary periodic system, that in all the differentiative processes which occur after the original formation, the chemical and physical properties would play their part, so that if any special material is taken for consideration, relationships to that system would appear more and more as the process of differentiation takes place.

The fact that in the meteorites the elements of even atomic number are in all cases more abundant than the adjacent elements of odd number seems to indicate that in such bodies the process of differentiation has not proceeded to such an extent as to cause the chemical and physical properties to have an influence sufficient to obscure in any marked degree the most general of the abundance relations due to nuclear stability, but it does not show that there has been an entire absence of differentiation. The composition of the earth's surface, as compared with that of the meteorites, shows a less rigid, but very marked adherence to the odd and even system, but certain groups of elements related in chemical and physical properties are relatively more abundant. Thus the alkali metals, sodium and potassium, the halogens and aluminum are present in much larger quantities. In the meteorites calcium is much less abundant than magnesium, while on earth both elements are of the same order of plentifulness.

The evidence shows that segregative processes of a physical or chemical nature have proceeded much farther on earth than in the meteorites.

(4) *Third periodic relation: high stability and abundance for atoms whose protonic number is divisible by 4, with a secondary periodicity of 2.* Fig. 7 shows that the abundance of the light atoms is highest for atomic weights (or number of protons in the nucleus) divisible by 4. For the heavier and less abundant species the abundance is high for atomic weights divisible by 2.

(To be continued)

THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

THE REGULAR FALL MEETING OF THE EXECUTIVE COMMITTEE

THE regular fall meeting of the executive committee of the American Association occurred at the Cosmos Club, in Washington, on Sunday, October 20, one session being held in the forenoon and one in the afternoon. The members present were Cattell, Compton, Curtiss, Kellogg, Livingston, Ward and Wilson. Absentees were Lillie, Millikan and Moulton. The following paragraphs present items of business transacted:

1. The minutes of the last meeting were reported as approved by mail.

2. The permanent secretary presented the auditor's reports on the treasurer's statement and on the permanent secretary's financial statement for 1927–28, which were accepted.

3. The treasurer's report and the permanent secretary's financial report for 1928–29, of September 30, 1929, were presented, and it was ordered that they be audited and then presented to the council at Des Moines.

4. The committee appropriated $1,000 from the treasurer's available funds for the use of the committee of one hundred on research for the association year 1929–30.

5. The committee recommended to the council that $3,000 of the treasurer's available funds be appropriated for allotment for 1930 by the committee on grants for research.

6. The permanent secretary reported the publication, on October 15, of the volume of Summarized Proceedings for 1925–29 and the report was accepted. The edition is of 4,250 copies, of which 3,877 have been disposed of; 3,637 copies were sold, 125 copies were sent free to section and society secretaries and secretaries of special committees of the association and 115 copies were sent free to foreign organizations and institutions. No free copies are to be sent to organizations and institutions in the United States and Canada unless by special action of the association council. The volume is for sale by the permanent secretary's office, at $3 each to members of the association, $4 to others. Cloth-bound copies may be had, as long as the supply lasts, at $4 each to members and $5 to others.

7. The permanent secretary reported that membership in the association has increased very satisfactorily during the year that closed September 30. The total enrolment on September 30 was 18,462, and the net increase for the year is 2,134.

8. The permanent secretary reported that the special committee on symbols and abbreviations (Dr. A. E. Kennelly) had approved for the association the following sets of symbols presented by the American Standards Association, of which the American Association is one of the sponsor organizations:

Symbols for photometry and illumination (May 13).
Navigational and topographical symbols (May 15).
Graphical symbols for telephony and telegraphy (July 26).
Symbols for hydraulics (July 26).