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AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

THE STORY OF THE CHEMICAL ELEMENTS[1]

TO-NIGHT I am to present to you a few sketches from the story of the chemical elements during the last three decades—a period during which that story has developed into an exciting drama.

Let me begin by briefly reviewing the state of our knowledge of the elements at the beginning of the century. Of the 89 elements now known about a dozen, including all the radioactive elements and several of the rare-earth elements, were still undiscovered. The chemical world had, only a few years previously, been excited by the discovery of two inert elementary gases—argon by Lord Rayleigh and Sir William Ramsay in 1894, and helium by the latter in 1895—two elements utterly different in their properties from any then known; and there had just been announced (in 1898) by Ramsay and Travers the isolation from the air of three more of these gases, neon, krypton and xenon, forming with argon a new very distinct group of the periodic system. The discoveries of argon and helium were especially striking; for argon had existed unknown through the centuries, though present to an extent of nearly one per cent. in the atmosphere; and helium had been detected in the sun by its spectrum long before it was found on the earth. Some of you will recall that Professor Ramsay exhibited in this country a few years later a minute bubble of helium and showed its spectrum—a substance that is now prepared in quantity large enough to fill huge dirigibles. And it is interesting to note that two other of these then rare gases, argon and neon, are now used for filling each year thousands of electric lamps. But of far greater importance was the bearing of the discovery of helium on the development of subatomic physics and chemistry, as we shall soon see.

Thirty years ago the periodic relations of the elements were commonly represented [in the way shown in Figure 1] by arranging the elements in the order of their atomic weights in periods of eight. This arrangement was fairly satisfactory for practical use; but it had many familiar defects—some of which suggested real theoretical difficulties.

[1] Address delivered at the New York meeting of the American Association for the Advancement of Science by its retiring president.

PERIODIC CLASSIFICATION OF THE ELEMENTS

	I		II		III		IV		V		VI		VII		VIII			O
1	1 H 1.008																	2 He 4.00
2	3 Li 6.94		4 Be 9.1		5 B 10.9		6 C 12.005		7 N 14.008		8 O 16.00		9 F 19.0					10 Ne 20.2
3	11 Na 23.00		12 Mg 24.32		13 Al 27.0		14 Si 28.1		15 P 31.04		16 S 32.06		17 Cl 35.46					18 A 39.9
4	19 K 39.10		20 Ca 40.07		21 Sc 45.1		22 Ti 48.1		23 V 51.0		24 Cr 52.0		25 Mn 54.93		26 Fe 55.84	27 Co 58.97	28 Ni 58.68	
		29 Cu 63.57		30 Zn 65.37		31 Ga 70.1		32 Ge 72.5		33 As 74.96		34 Se 79.2		35 Br 79.92				36 Kr 82.92
5	37 Rb 85.45		38 Sr 87.63		39 Yt 89.33		40 Zr 90.6		41 Cb 93.1		42 Mo 96.0		43		44 Ru 101.7	45 Rh 102.9	46 Pd 106.7	
		47 Ag 107.88		48 Cd 112.40		49 In 114.8		50 Sn 118.7		51 Sb 120.2		52 Te 127.5		53 I 126.92				54 Xe 130.2
6	55 Cs 132.81		56 Ba 137.37		Rare Earths				73 Ta 181.5		74 W 184.0		75		76 Os 190.9	77 Ir 193.1	78 Pt 195.2	
		79 Au 197.2		80 Hg 200.6		81 Tl 204.0		82 Pb 207.20		83 Bi 209.0		84		85				86
7	87		88		89		90 Th 232.15		91		92 U 238.2							

Fig. 1

(1) There were many gaps, assumed to represent undiscovered elements.

(2) Certain pairs of elements, potassium and argon, cobalt and nickel, tellurium and iodine, had to be placed in the reverse order of their atomic weights; for they would otherwise be out of place with respect to the sequence of properties.

(3) Hydrogen and helium were isolated elements, not related to the groups of eight.

(4) A large number of rare-earth elements had to be put in place of the single element lanthanum.

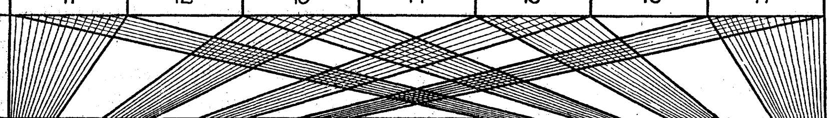
(5) Sets of three elements (iron, cobalt, nickel; ruthenium, rhodium, palladium; and osmium, iridium and platinum) were substituted for single ones in the eighth group.

(6) One had to cross the table to pass from the last of these three triplets to the next element, although the properties form a continuous sequence, as in the cases of nickel and copper or of platinum and gold.

(7) The grouping of elements was unnatural in many instances; thus, copper, silver and gold would appear from their position to be closely related to sodium and potassium; manganese to chlorine and bromine; and chromium, molybdenum and tungsten to sulfur and selenium.

Compare now this older periodic arrangement with one of the more recently published tables—for example, that of von Antropoff, shown in Figure 2. This conforms to the recent knowledge of the structure of atoms. It reverts, to be sure, to one of the arrangements of Mendeléeff, later revised by Thomson, with short periods of eight elements and long

O	I	II	III	IV	V	VI	VII
He 2	Li 3	Be 4	B 5	C 6	N 7	O 8	F 9
Ne 10	Na 11	Mg 12	Al 13	Si 14	P 15	S 16	Cl 17



O	Ia	IIa	IIIa	IVa	Va	VIa	VIIa	VIII			Ib	IIb	IIIb	IVb	Vb	VIb	VIIb
Ar 18	K 19	Ca 20	Sc 21	Ti 22	V 23	Cr 24	Mn 25	Fe 26	Co 27	Ni 28	Cu 29	Zn 30	Ga 31	Ge 32	As 33	Se 34	Br 35
Kr 36	Rb 37	Sr 38	Y 39	Zr 40	Nb 41	Mo 42	43	Ru 44	Rh 45	Pd 46	Ag 47	Cd 48	In 49	Sn 50	Sb 51	Te 52	I 53
X 54	Cs 55	Ba 56	La-Lu 57-71	Hf 72	Ta 73	W 74	Re 75	Os 76	Ir 77	Pt 78	Au 79	Hg 80	Tl 81	Pb 82	Bi 83	Po 84	85
Rn 86	87	Ra 88	Ac 89	Th 90	Pa 91	U 92											

Fig. 2

periods now with eighteen or thirty-two elements; but it is the work of Bohr and other investigators of atomic structure which has justified this arrangement and established it as most satisfactory.

This table, with its device of connecting zones, is probably as complete a representation of the relationships of the properties of the elements as can be afforded by any simple type of periodic table not directly representing the structure of the atoms. The table has the following advantages over the earlier one:

(1) All but three of the gaps have now been filled by the discoveries of new elements; most of which were made through studies of radioactivity and of the emission of X-rays.

(2) The inverted position of the elements argon and potassium, cobalt and nickel, tellurium and iodine, is fully justified now that atomic-structure studies have shown that it is not the atomic weight, but another characteristic, the atomic number, that determines nearly all the properties of the elements.

(3) Hydrogen and helium still form a pair by themselves; but this is clearly required by our knowledge of the structure of their atoms.

(4) The rare-earths still seem to be intruders; but this is only because the long period of 32 elements indicated by the structure of the atoms is, to avoid clumsiness, not shown in the table.

(5) The triplets now assume natural positions in the middle of the long periods; and form a continuous sequence with the next similar elements.

(6) There is now no break, but a progression, between these triplets and the succeeding elements, thus between nickel and copper, or platinum and gold.

(7) The relationships of the properties are much more fully indicated. Thus lithium and sodium are very closely connected with their nearest allies, potassium, rubidium and cesium; and they are also connected, but only remotely, with their distant relatives, silver, copper and gold. And the connecting zones lead directly from sulfur to selenium and tellurium, but only remotely to chromium, molybdenum and tungsten.

The periodic relations early impressed investigators with the conviction that the atoms of the various elements must have related structures, and must be built up progressively out of simpler units. Indeed, shortly after Dalton in 1803 developed the atomic theory, Prout proposed, purely as a speculation, without experimental basis, the hypothesis that all elements consist of hydrogen, and that therefore the weights of their atoms are exact multiples of the weight of the hydrogen atom. Prout's hypothesis was carefully tested during the next half century, as atomic-weight determinations became more accurate, by many careful investigators. It died hard, because of the indisputable facts—first, because some of the most important atomic weights (for example, those of helium, carbon, nitrogen, oxygen, fluorine, sodium and aluminum) are related to one another almost exactly as whole numbers, and second, because a far larger proportion of all the atomic weights have values within say 0.1 unit of a whole number than could happen by chance. Prout's hypothesis was, however, fully discredited as a general principle by the exact atomic-weight work of Stas in 1860–1865—but only to be revived again, as we shall see, by the development of subatomic considerations.

Let us now note the ideas about the atom itself that prevailed thirty years ago. Atoms were then regarded as ultimate entities, inscrutable with respect to their internal structure. It is true that the kinetic theory of gases, which postulated molecules as elastic spheres of definite dimensions, gave some insight into the size of molecules; and there were indications that the atoms within the molecules had diameters of the same general magnitude—of the order of a few hundred-millionths of a centimeter or of one hundred-millionth of an inch. Moreover, much was learned about the union of atoms to form molecules: indeed, upon this basis the great science of organic chemistry was created—probably the most extensive body of science and technology that was ever developed mainly through theoretical considerations. To each atom were assigned a certain number of bonds or valences; but there was no means of looking within the atom—of learning anything about its own structure or about the origin of these valences that are of such vital importance to the chemist.

Only two or three years, however, before the beginning of the period we are considering, three discoveries were made which were to lead during that period to the new sciences of electronic physics and subatomic chemistry. These were, first, the detection by J. J. Thomson and Kaufmann in 1897, in the long-known cathode rays, of the electron as an isolated electrified particle; second, the discovery of X-rays by Röntgen in 1895; and third, the discovery of radioactivity (in uranium) by Becquerel in 1896. And these discoveries were soon supplemented by the conception of energy-quanta by Planck (in 1900) and its extension by Einstein (in 1905) and by others.

It is obviously impossible in a single lecture even to outline the development of this vast field of research. I shall only attempt to sketch in a popular way a few of the well-established principles concerning the structure of atoms which bear upon the relations of the various elements to one another, not trying to describe their historical sequence or to explain their experimental basis.

First of all, as to the general nature of the atom. The theory proposed by Rutherford in 1911 has received through the years ever-increasing confirmation.

According to this theory the atom is a small-scale solar system: it consists, as is well known, of a very minute positively charged nucleus surrounded by mobile (negatively charged) electrons. In the case of hydrogen there is only one outer electron outside a nucleus having a unit-charge of positive electricity, which is equal and opposite to the negative charge on the electron. But with each succeeding element the number of outer electrons increases by one, and correspondingly the nucleus acquires one more positive unit-charge. Thus the neutral atom of helium has two outer electrons and a nucleus with two positive charges; that of oxygen has eight electrons and a nucleus with eight positive charges; that of uranium, the heaviest atom, 92 electrons and a nucleus with 92 positive charges. The charge on the nucleus, which increases steadily with the sequence of the elements, is often called the atomic number of the element.

Both the absolute mass and the charge of the electron are known within the surprisingly small error of 0.1–0.2 per cent. The mass or weight of the electron is only 1/1840 of that of the hydrogen atom; it is so light that it would take 10^{27} of them (1 followed by 27 ciphers) to weigh one gram.

The sizes of atoms and of their nuclei, as measured by the closest approach of other atoms or of other nuclei, are also approximately known. Thus the helium nucleus has a radius of about 10^{-12} cm, and the helium atom one 10,000 times larger or about 10^{-8} cm, a quantity which represents of course the distance of the electrons from the nucleus. To get a true picture of the atom one must visualize the relative values of these radii. Thus if the helium nucleus were magnified so as to be represented by a sphere of 1 cm radius, its two outer electrons would be located about 100 meters away: if the helium nucleus were a teed-up golf ball, the electrons would be on a green 200 yards away. An atom is therefore, like the solar system, "mostly hole," as Millikan has said.

Finally we now know, often with great accuracy, the energy which must be expended in order to remove many of the various electrons from the neighborhood of the nucleus. And upon the basis of this knowledge there can be constructed a chart [Figure 3] showing, in a way free from any uncertain hypothesis, the electronic structure of the atoms as a progressive and periodic property of the elements. This chart I presented and discussed at the Reno meeting of the Pacific Division of this association.[2] I call attention to it here mainly in order that, in our subsequent discussion of the nucleus, we may not forget the outer electrons and the extensive knowledge we have of them. The abscissas in the chart are the atomic numbers or nuclear charges, and the ordinates are the square-roots of the energies which must be added to the atom in order to remove the various electrons. The black circles represent the electrons, and their location shows their grouping and their energies of removal. The electron arrangements shown by the chart clearly account for the periodic relations of the elements. (This was briefly illustrated by the speaker.)

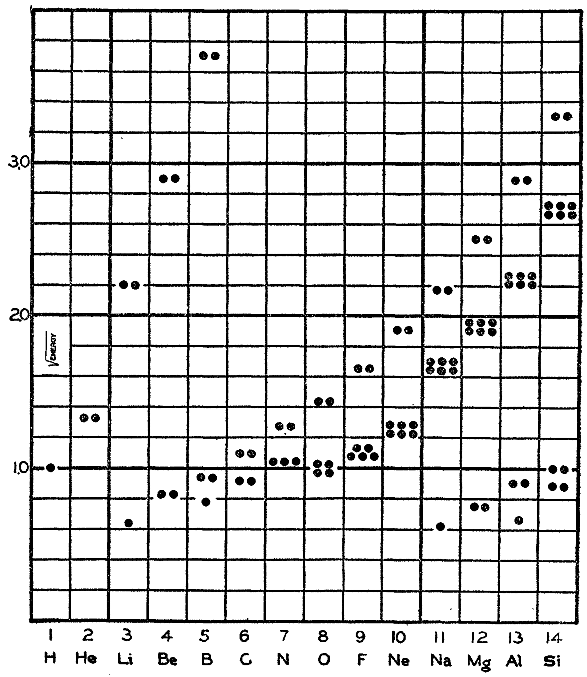


FIG. 3

Knowledge of the atom has evidently two distinct aspects—the nature of the nucleus and the relations of the outer electrons to it and to one another. This lecture is to be devoted mainly to the nucleus, and we must turn our attention to it without more delay. What is the structure of the nucleus? Whence arises its mass, and whence its positive charge, increasing progressively by one unit with each successive element? To these questions the investigations of the last twenty years have given fairly definite answers: they have demonstrated the composition of atom nuclei, though they have taught us very little about the dynamic relations involved. Namely, we are confident that the nuclei of the different atoms are built up through the association of various numbers of protons and electrons—a proton being the positive nucleus of the hydrogen atom, left after its electron is removed. Thus to account for the facts that the helium nucleus has a weight 4 and a positive charge 2, we assume that it consists of four protons and two electrons. The two electron-charges neutralize two

[2] See Noyes and Beckman, *Chemical Reviews*, 5, 85–107 (1928).

of the four proton-charges, giving a net positive charge of two units; but the electrons, since each has only 1/1840 of the mass of a proton, contribute scarcely anything to the mass or weight of the nucleus.

Let us play with these black and gray discs, and see what we can build out of them. The black discs represent protons or hydrogen nuclei: they are heavy, being made of metal. Consider that each has the weight of one proton, and that each black area facing you represents one unit of positive charge—one proton-charge. The gray discs are electrons: they are light (made of paper), each weighing 1/1840 of a proton, and each gray area facing you represents one unit of negative charge—one electron-charge. And here is a balance on which we can weigh our artificial atoms [shown in Figure 4].[3]

Let us now proceed to build. I put on the balance a proton—a hydrogen nucleus. Now I put on a second proton. This would be a nucleus with weight two and charge two, corresponding to an element of atomic weight 2 and atomic number 2. This does not exist—presumably because there is nothing to hold together the two protons, whose charges repel each other. Suppose now I add an electron, whose negative charge might bind the two positive charges together. This does not change the weight of the nucleus, which is still 2; but its net charge becomes 1, since one proton and one electron neutralize each other (as I may show by covering one proton-disc with the electron, when you see only *one* black area). This atom also does not exist, showing it is not a stable structure. The same is true of the combinations (built up by the speaker) of three protons with one electron and with two electrons. Only when we combine four protons and two electrons do we get an existing atom—that of the element helium. Its nucleus has a weight 4 and a charge 2. Let us compare this with the nucleus with three protons and one electron. The two models look alike to you in the audience, as they would look to the outer electrons, showing they have the same net charge; but the balance proves that they have different weights. Since the remote bodies the two nuclei would exert the same number, namely 2, outer electrons, and on these very remote bodies the two nuclei would exert the same electric force—cause them to arrange themselves and move in the same way; so that the two atoms might be expected to produce substances with the same chemical properties and also the same physical properties, except in the case of properties like density or diffusibility directly dependent on weight or mass.

[3] The speaker is greatly indebted to Dr. Arnold O. Beckman for his assistance in the devising of this demonstration of the structure of atom-nuclei, and to Professor Ira S. Bowen for many helpful suggestions.

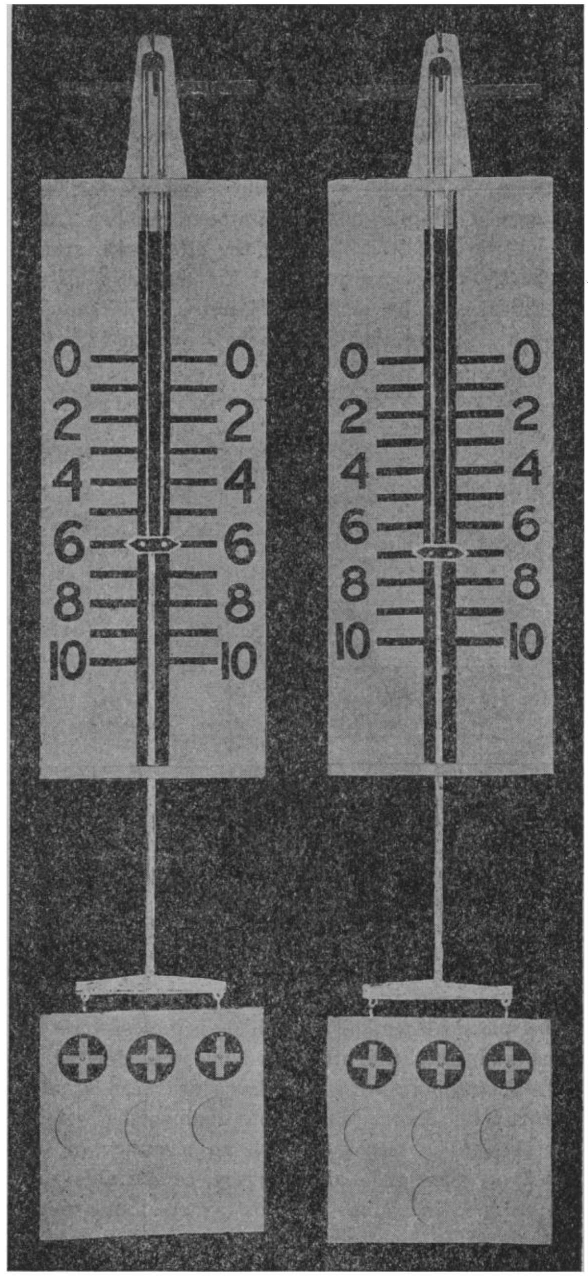


FIG. 4

Atoms of this type, having nuclei with the same charge but with different weights, as well as the almost identical elements which consist of such atoms, are called *isotopes*. Isotopes do not actually exist in the case of helium; but of the next atom, lithium, whose nucleus has three positive charges and whose atomic number is therefore 3, two isotopic forms of weights 6 and 7 have actually been discovered. Let us build up these nuclei by adding protons and electrons to our two helium nuclei in such a way as to give a nuclear charge of 3. We first get a nucleus with 4 protons and 1 electron, then one with 5 protons and 2 electrons—neither of which exists—probably because there are not enough electrons to bind the protons together. We next get a nucleus with 6 protons and 3 electrons, and one with 7 protons and 4 electrons, which are the two known isotopic forms of the element lithium, both with atomic number 3, but one with atomic weight 6 and the other with atomic weight 7 (often represented by Li^6 and Li^7). These are shown side by side in Figure 4. The possible isotopes of helium and lithium are shown in Figure 5.

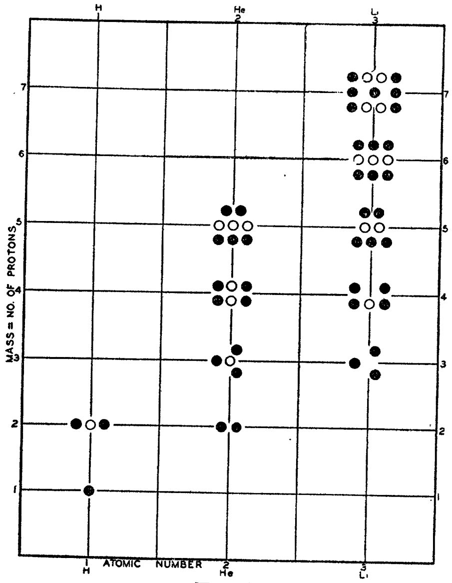


FIG. 5

The physical method by which isotopes were detected and their weights determined was devised by J. J. Thomson in 1913, and has since been steadily improved by Aston, till it now enables the weights of atoms to be measured with an accuracy of one part in a thousand—an accuracy comparable with that attained in all but the most exact atomic-weight determinations by chemical processes. This method can not be here described: its principle only can be briefly indicated. This principle (illustrated by Figure 6) is that a stream of the positive ions of an element, such as is produced in a discharge tube when the ionized atoms of the anode-material or gas shoot through a perforated cathode, on being passed through electric and magnetic fields is deflected from its path to a greater or less extent according as the ions have a smaller or greater mass. This deflection can be derived from the location of the spots produced when the streams of ions strike a photographic plate. The relative proportions of the two or more isotopes can also be estimated from the size and dark-

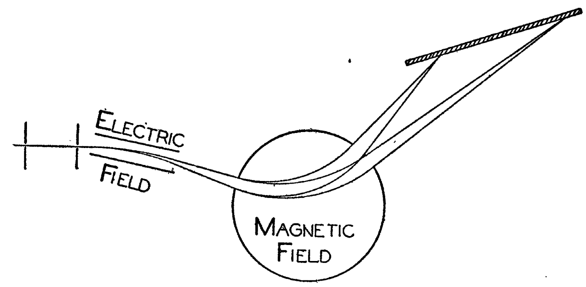


FIG. 6

ness of the spots. In this way lithium is found to give two streams arising from atoms of weights 6 and 7 present in the proportions of 6 and 94.

The results of Aston obtained with the elements up to calcium are shown in Figure 7, the relative pro-

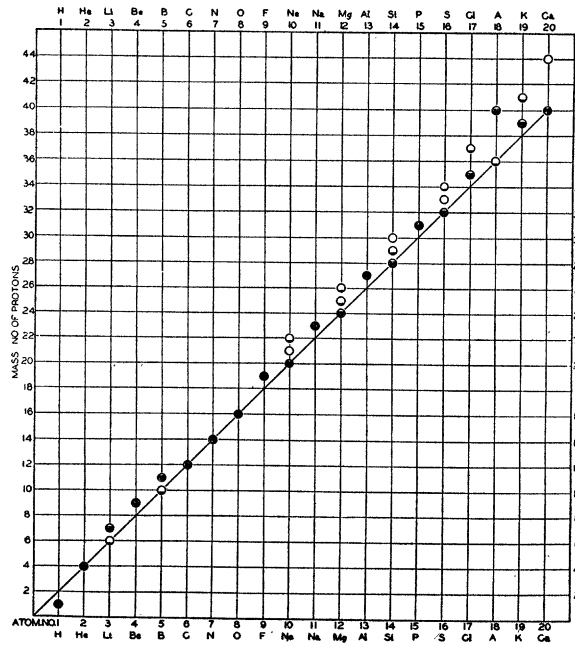


FIG. 7

portions in which two or more isotopes are present being shown by the shading of the circles. The figure shows that only three or four of the elements of the first two periods have isotopes, and that some of these have two and others three isotopes. Some of the higher elements have many more; thus element 34 (selenium) and element 36 (krypton) each have six, and element 50 (tin) has even eleven. On the oblique line crossing the chart any nucleus would be located which contained two protons for each electron. It will be seen that the nuclei of these lower elements mostly conform approximately to this condition.

Let us now consider the bearing of these results on Prout's hypothesis and on the structure of atoms. The accurate results of Aston are shown in Table I.

TABLE I

Atomic No.	Element	Atomic wt.	Isotopes No.	Isotopes At. wt.	Per cent.
1	H	1.0077	1	1.0078	100
2	He	4.00	1	4.0022	100
3	Li	6.94	2	6.012	7
				7.012	93
5	B	10.82	2	10.013	19
				11.011	81
6	C	12.00	1	12.004	100
7	N	14.01	1	14.008	100
8	O	16.00	1	16.000	100
9	F	19.00	1	19.00	100
10	Ne	20.18	2	20.000	91
				22.005	9
15	P	31.03	1	30.982	100
17	Cl	35.46	2	34.983	76
				36.980	24
18	A	39.94	2	35.976	1
				39.971	99
33	As	74.96	1	74.934	100
35	Br	79.92	2	78.929	50
				80.926	50

They prove that the atoms (except hydrogen—to which we will return) have weights that are almost exactly whole numbers when referred to that of oxygen as the whole number 16.00—just as would be predicted if they all were built up out of protons of weight unity and as would be required by Prout's hypothesis assuming the weight of the proton to be equal to that of the nucleus of the hydrogen atom. And the reason that chemically determined atomic weights often are not whole numbers is that many elements are mixtures of two or more isotopes. Thus the fact that chlorine has a "chemical" atomic weight of 35.46 is shown by Aston's results to arise from its being a mixture of about 76 per cent. of atoms of weight 35 and 24 per cent. of atoms of weight 37.

There is, however, apparently one striking discrepancy; the weight of the hydrogen nucleus is not 1.000, but 1.0078 (or ¾ per cent. greater), when referred to oxygen as 16.00. Why then should four protons uniting to form helium give an atom weighing only 4.00, not 4.03? This might have created a serious dilemma, had not Einstein's relativity theory come to the rescue just in time. It is one feature of that theory that energy, like matter, possesses mass, and that escape of energy in large quantity causes an appreciable decrease of mass. Now if a helium nucleus is formed by bringing the positive charges on four protons very closely together with the negative charges on two electrons we can imagine that there would be an enormous liberation of energy; and it may well be this decrease in energy which makes the mass of the helium nucleus three-quarters of a per cent. less than that of four hydrogen nuclei.

The recent very exact measurements of Aston show that a decrease in mass is also observed, though in less degree, in the formation of the higher elements; thus the mass of the oxygen atom is not just four times that of the helium atom, but 0.05 per cent. less than four times. The decreases in mass (expressed in terms of the mass of the hydrogen atom as 1000) derived from Aston's exact mass-spectra measurements are shown in Figure 8. The upper graph shows the

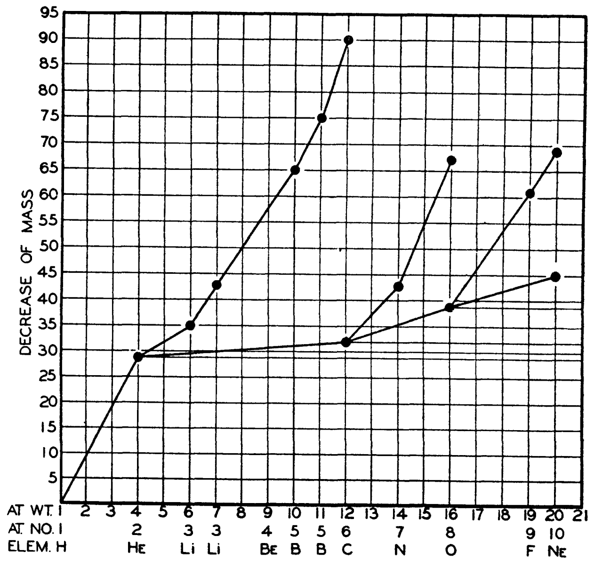


FIG. 8

decrease in mass when the nuclei are considered to be built up successively out of protons and electrons; the lower graphs show the mass-decrease when they are considered to be built up (so far as possible) out of helium nuclei already formed and of protons and electrons.

This decrease in mass is of extraordinary significance in another direction—with reference to the genesis of the elements. It shows that the formation of helium out of hydrogen nuclei and electrons would be attended with an enormous escape of energy. Now, since changes tend to take place in the direction in which energy is evolved, the large energy effects show that there is a great inherent tendency for this synthesis of helium and other atoms of moderate atomic weight to take place. The failure to form under ordinary conditions must be due to unknown dynamic conditions which prevent the nuclei approaching one another closely enough to bring into play the enormous attractive forces which potentially exist. From the view-point of cosmical development one of the most fundamental questions is, under what conditions, if any, can four hydrogen-nuclei unite with two electrons to form a helium nucleus? And it is this view-point that adds extraordinary interest to the recent conclusion of Millikan and Cameron that some of the cosmic rays have a frequency corresponding to the energy that would be set free in the synthesis of helium from hydrogen; for it indicates that it is now going on somewhere in the universe—a matter which unfortunately we have not time to follow further.

Helium nuclei are probably building stones in the construction of atoms. These nuclei, which are first formed out of protons (hydrogen nuclei) and electrons, unite with one another and with more protons and electrons to produce the more complex nuclei. According to this conception the atoms up to fluorine would be constructed as shown in Table II.

TABLE II

Element	Nuclear charge	Atomic weight	Structure
Li	3	6	$He^{++} + 2H^{+} + E^{-}$.
Li	3	7	$He^{++} + 3H^{+} + 2E^{-}$.
Be	4	9	$2He^{++} + 1H^{+} + 1E^{-}$.
B	5	10	$2He^{++} + 2H^{+} + 1E^{-}$.
B	5	11	$2He^{++} + 3H^{+} + 2E^{-}$.
C	6	12	$3He^{++}$.
N	7	14	$3He^{++} + 2H^{+} + 1E^{-}$.
O	8	16	$4He^{++}$.
F	9	19	$4He^{++} + 3H^{+} + 2E^{-}$.

There are two important lines of evidence that helium nuclei as such are really constituents of atoms. First, Rutherford has found that, when the helium nuclei emitted by radium at high velocity are caused to strike the atoms of certain elements they knock protons out of their atoms, but do not do so out of the atoms of other elements; and what is significant is that among the elements of low atomic weight only those atoms are disrupted which have weights that are not multiples of four; thus helium, carbon and oxygen are not decomposed, but protons are liberated from boron, nitrogen and fluorine; all of which contain protons in excess of those needed to form helium nuclei, as will be seen from Table II. Secondly, the radioactive elements of high atomic weight actually shoot off spontaneously helium nuclei, as we shall soon see.

We turn now to the last sketch in our story, one which must be presented very briefly in the form of a picture. This concerns the disintegration which some elements of high atomic weight are actually undergoing. This discovery opened a new domain of science, which in the first part of this century was developed, in spite of its complexity, with extraordinary rapidity and completeness. It was found that the atoms of certain long-known elements, especially of number 92 (uranium) and 90 (thorium), are shooting out from their nuclei in successive stages in perfectly definite sequence and in definite quantity helium nuclei He^{++} (commonly called alpha particles) as well as electrons (commonly called beta rays). The residual atom thereby progressively decreases in mass and changes in nuclear charge. Remarkably enough we never find that hydrogen nuclei escape.

Figure 9 gives in clear and tolerably complete form

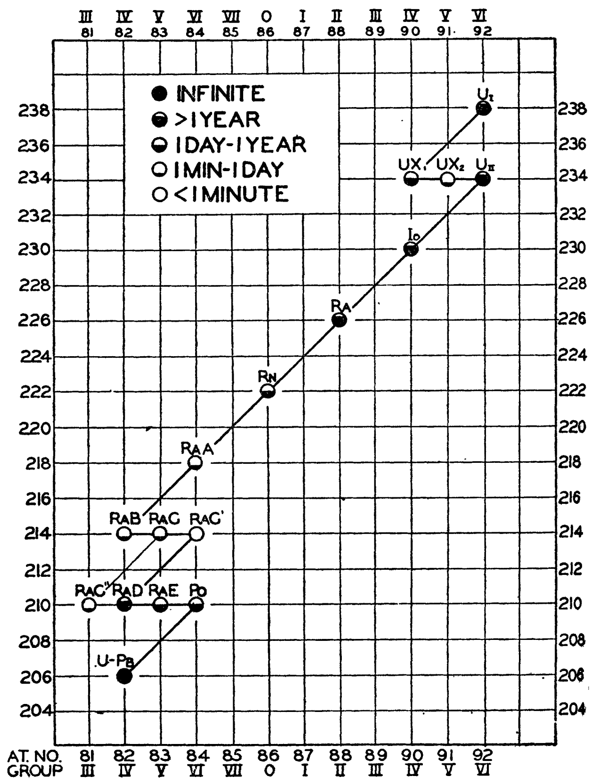


Fig. 9

a survey of the phenomena of radioactive disintegration for one of the three well-known series—the uranium-radium series. In this chart the ordinates represent the atomic weights of the elements, that is, the masses of the atoms; and the abscissas represent the atomic numbers, that is, the nuclear charges, which are equal to the number of the outer electrons and determine their arrangement, and therefore the chemical behavior and most of the physical properties of the elements. The lines indicate the nature of the successive disintegration processes that take place. The lines that run obliquely downward and to the left obviously show the escape of a helium ion (He^{++}); for this decreases the mass of the nucleus by four, and decreases its positive charge by two units. The lines that run horizontally to the right show the escape of an electron; for this does not change appreciably the mass of the nucleus, but increases its positive charge by one unit. The extent to which the atom is shaded also indicates its stability, which is the inverse of its rate of disintegration. This rate varies enormously: some kinds of atoms having a half-life of billions of years and others of a small fraction of a second, by the half-life being meant that period in which half of the atoms present at the beginning become disintegrated. The five degrees of shading indicate respectively (1) complete stability (no evidence of disintegration); (2) half-lives of more than one year; (3) between a year and a day; (4) between a day and a minute; and (5) less than a minute.

The direct evidence for the series of disintegrations is the nature and velocities of the particles emitted, the velocities being definite and characteristic for each process. But the conclusions are confirmed at several stages by the study of the residual elements. Thus radium was actually separated in a pure state from uranium minerals by the Curies and its atomic weight proved to be that predicted; radon, the immediate product of the disintegration of radium, was shown to be a gas as its position in the periodic system requires, and to be produced in a volume corresponding to the number of helium-ions emitted; and the final product has been isolated from uranium minerals and shown to be a form of lead with an atomic weight of 206, differing from that (207.2) of ordinary lead, which is doubtless a mixture of isotopes.

These radioactive phenomena exhibited by the higher elements thus confirm the conclusions drawn from the studies of the isotopes and of the artificial decomposition of the lower elements that atom-nuclei are built ultimately out of protons and electrons, but with the intermediate formation of helium nuclei, which themselves consist of four protons and two electrons.

This very inadequate survey of our knowledge of the phenomena of isotopes and of the artificial disruption and radioactive disintegration of nuclei in their bearing upon the structure of atoms must now be brought to a close. All that can be hoped is that it has served to give those of you who may be laymen in the field of modern physics some conception of the marvelous development of that science during the present century.

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THE RELATION OF SCIENCE TO INDUSTRY[1]

A WELL-KNOWN public speaker of fifty years ago once remarked ruefully after disastrous consequences had followed misplaced humor, as they often do, "I rose by my gravity and fell by my levity."

I use this incident as an introduction to my speech on "Science and Industry" for the sake of calling attention to the fact that what is absurd or ridiculous to-day was perfectly good science, or at least perfectly good philosophy, not more than 350 years ago—that the very existence of a "law of gravity" was discovered as late as 1650 A. D., and that "levity" and "levitation" have through all recorded history up to Newton been just as acceptable scientific ideas as gravity and gravitation—so recently have we begun to understand just a little bit about the nature of the world in which we live.

Nor do I need to go back 300 years to make my point as to the newness of our knowledge. It is within the memory of every man of sixty in this audience that in the great Empire State of New York the question could be seriously debated, and in the most intelligent of her communities, too, as to whether Archbishop Usher's chronology computed by adding Adam's 930 years to Enoch's 365 years to Methuselah's 969 years, etc., gave the correct date of the creation. Recent election returns from Arkansas indicate that the same debate is at this very moment going on there.

But what has this to do with "Science and Industry"? Everything! For mankind's fundamental beliefs about the nature of the world and his place in it are in the last analysis the great moving forces behind all his activities. Hence the enormous *practical* importance of correct understandings. It is his beliefs about the nature of his world that determine whether man in Africa spends his time and his energies in beating tomtoms to drive away the evil spirits, or in Phoenicia in building a great "burning fiery furnace" to Moloch into which to throw his children as sacrifices to his God, or in Attica in making war on his fellow Greeks because the Delphic Oracle, or the flight of birds, or the appearance of an animal's entrails bids him to do so, or in medieval Europe in preparing for the millennium to the neglect of all his normal activities and duties as he did to the extent of bringing on a world disaster in the year 1000, or whether he spent his energies in burning heretics in Flanders

[1] Address at the 160th annual banquet of the Chamber of Commerce of the State of New York, Waldorf-Astoria, New York City, November 15, 1928.