The results of the present experiments indicate that that part of Bragg's argument applies with equal force to the case of the radiations which produce the photo-electric effect. Since the photo-electric effect can be produced with visible light in the case of sufficiently electro-positive metals, and since there is a continuous gradation between such cases and the effects here investigated, there seems to be no valid reason for supposing that the difference between the emergent and incident effect is not characteristic of both ordinary and ultra-violet light as well as the more penetrating radiations examined by Bragg. If it stood alone this investigation would be a strong argument in favour of the unitary theory of light. The objections to such theories on other and apparently more fundamental grounds are very serious, as Lorentz has recently shown. Under the circumstances it seems desirable to postpone further discussion pending the accumulation of more experimental evidence.

This subject and its method of investigation was suggested by Prof. O. W. Richardson and carried to its present stage under his direction. I wish to thank him here for his valuable assistance, advice, and encouragement throughout the course of this work.

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LXXXIV. *A Structural Theory of the Chemical Elements.*

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THIS paper gives a preliminary account of a structural theory of the chemical elements, which derives them as compounds, in a certain sense, of primary forms of matter. It is possible, on certain views, to accomplish this for the simpler elements, and to a greater degree, of course, for those which are more complex, the degree of complexity being measured by the atomic weight.

Calculations of the atomic weights of these hypothetical constructions, even in the simplest cases, can give results in sufficient and indeed unexpected accord with the best chemical determinations. The groupings of primary forms for the elements as arranged in the Periodic Table show curious systems which appear to shed light on the mutual relations of the elements. This is more especially the case

* Communicated by the Author, having been read at the meeting of the British Association at Portsmouth, 1911.

in the radioactive elements, and it will be seen that a consistent scheme for these transformations can be founded upon the views advocated in the paper—a scheme which readily removes many of the outstanding difficulties. It has not been possible, for reasons of space, to treat these elements at all completely in the paper; but sufficient indications of this point have been given, and the subject will be treated in greater detail later.

Elements which appear out of their places in the Periodic System always appear to need a characteristic construction of a somewhat different type from that of the class of elements with which they are associated, and with which the chemist is unable to find a clear connexion. It may be said that exactly in proportion as a set of elements do form a real chemical class, it has been found possible, as the result of an exhaustive examination, to endow the set with constitutions of a similar nature. Moreover, with elements for which the chemical determination of the atomic weight has been carried out to the second decimal place, it has been possible only in a few cases to find a choice of formulæ which would yield this value equally well.

It is perhaps necessary to point out at once to what extent the paper is speculative. This character must largely belong to it because the subject is treated only from the point of view of atomic weight. But the results are capable of verification in other ways, some of which are indicated. In particular, the actual existence of the primary substances has been verified by a mathematical investigation of their spectra, to be published independently, which shows that they are the origin of the unknown lines in the spectra of the nebulæ and of the solar corona.

The acceptance of these results involves secondary consequences of a far-reaching kind. In the first place, the nature of the positive electricity in the atom is determined, and found to be that supposed by Sir J. J. Thomson in his paper of 1904*. That is to say, positive electricity is regarded as existing in uniform volume distributions, whose volume is proportional to the positive charge. But in the conception of the structure of a simple atom there is a difference. Sir J. J. Thomson treated the electrons in the atom as revolving inside the positive sphere, which was of atomic size. On the view developed in this paper, positive electricity exists in units very small in radius compared even with the electrons, and is the source of nearly the whole mass of the atom. The revolving system is therefore a planetary

* Phil. Mag. March 1904.

one, and it is noteworthy that Rutherford *, in a recent paper, has concluded, from the evidence furnished by experiments on scattering, that the planetary system is the most probable. But although the size of the positive units is so different, Thomson's conception of the uniform volume distribution is essential to the calculations of the present theory.

In a complex atom, built up of simpler systems, the assemblage of positive charges is in many respects similar to the assemblage of electrons which revolve round them, and it is not unlikely that many of the positive charges would also revolve. But they are not all of the same size, although the difference in size is not great. Their mass is so great that a disturbance which could expel one of them from an atom would also expel many of the attendant electrons, and it would be impossible to isolate a positive charge. Evidence for the existence of such positive electrons should be furnished by certain experimental results; and this has recently been the case. In particular, a paper by Prof. R. W. Wood † may be mentioned.

The phenomena of radioactivity afford abundant evidence in the same direction. For example, the radium emanation has been shown, by the work of Ramsay and others, to belong without doubt to the argon group of inert gases, and to be a true element for which a vacant space has existed hitherto in the Periodic Table. Yet it gives off the simpler atom of helium. Unless the constituents of this atom already exist as a group, in unstable equilibrium with other groups, in the atom of the emanation, it is difficult to imagine by what means it can be detached as such when a really definite conception of the process is intended. Evidently the difficulty is extreme on Sir J. J. Thomson's view of the atom, which, it must be borne in mind, was only a provisional one adopted mainly for purposes of mathematical simplicity. It is none the less extreme on Rutherford's more recent view, a revival of the suggestion of Nagaoka, of a simple Saturnian system in the atom, involving only a single positive nucleus.

The mode of analysis adopted in this paper has nevertheless, by way of test, been applied to such a system; but it has been found impossible from such a conception to obtain atomic weights in good accord, or in some cases in any accord at all, with chemical determinations for the simpler elements. Similar application has been made to other conceptions of positive electricity—for example, surface distributions of uniform density,—and with the same lack of success. On

* Phil. Mag. May 1911. † Phil. Mag. Feb. 1908.

the whole, the investigation has established, with some thoroughness, that the atomic systems dealt with in this paper are, from the point of view of atomic weights, the only type which atoms can have on the basis of a purely electrical theory. We have indicated already some other considerations tending in the same direction.

Another consequence of the adoption of these views is the acceptance of the fact that all inertia is due to electric charges in motion. Much controversy has centred in this question, but, at present, the main trend of opinion is against the existence of any other kind of inertia. Larmor, in his theory of the æther, has adopted this view, and although attempts have been made to explain the results of Kaufmann on rapidly moving electrons by the help of Newtonian inertia, it is found that Bucherer's work gives the most satisfactory theory of these experiments. This work is based on the contraction formula for electrons in motion, and on the supposition that all inertia is of the electrical type. There is no necessity to give further references on this point.

The Primary Substances, or "Protyles."

The simple elements, from which, or rather from the constituents of which, we propose to construct all the others, consist of single rings of electrons rotating round small nuclei of positive electricity. These nuclei are small compared with the electron, and furnish nearly the whole mass of the atom. The number of these substances whose existence is declared is four; but only three are used in the following constructions. This number is fixed by no other consideration than that more than three are not necessary: as regards the fourth, more will be said later. Moreover, it is remarkable that if the next model simple atoms, in order of mathematical simplicity, are examined, they are found to be quite useless for all the elements of low atomic weight, which constitute the real test, and it is not possible, for example, to obtain the atomic weights of beryllium, boron, and carbon from any compound of protyles involving the next two from those considered in the paper.

The first of these primary substances is an atom containing a single ring of two electrons rotating round a positive nucleus. When this paper was communicated to the British Association, it was suggested that this element would be coronium, the unknown substance (or one of them) present in the solar corona. Subsequent work on its spectrum, which at that time was incomplete, has justified this supposition.

It has been shown by G. A. Schott that a system of rotating electrons would rapidly lose energy unless arranged in rings. From the point of view of the present paper, the actual arrangement does not require consideration ; but it is to be noted that the atoms with which we deal can be made to have the necessary permanence by this simple hypothesis. This can be seen intuitively, in fact ; for if n electrons are rotating at equal distances round the same circle, they each have an acceleration of the same amount towards the centre, and the vector sum of these accelerations is zero. This is Larmor's condition for the absence of radiation.

This condition cannot be fulfilled for a single electron ; so that the first primary substance must have two, as we have supposed, if an electrically neutral atom of the simplest kind is to be formed.

The second primary substance has three electrons, and a corresponding nucleus of a size, and with a charge therefore, sufficient to make the atom electrically neutral. This has been taken as hydrogen in the paper.

It is important at this point to preclude a misunderstanding; for it is not intended to state that a hydrogen atom contains three electrons. It certainly contains a very small number, whatever its constitution. In order to find a basis for the reckoning of atomic weights, we have subsequently taken such a unit of weight that the protyle with three electrons has a weight 1·008, the atomic weight of hydrogen, and the weights of the other elements are referred to this scale. Compounds are constructed with the weights usually given as atomic ; so that the elements, except perhaps hydrogen, all have the correct atomic weights relatively to one another. It remains to secure that they shall be correct relatively to that of hydrogen. If hydrogen is the substance with three electrons, this is secured automatically ; but if it is more complex, say equivalent to two atoms of this substance, all the groupings in the subsequent formulæ merely require multiplication by two. We definitely assume that hydrogen is either this substance or a polymer (not quite in the chemical sense), but nothing more definite until further examination has been made. But in order to work out a theory, it is convenient to suppose this substance to be hydrogen, with this reservation.

The third primary substance contains four electrons, with the corresponding positive charge in the nucleus. It is identified, with mathematical justification, as nebulium—the source of the principal lines in the spectra of nebulæ.

The fourth substance similarly contains five electrons, and is provisionally called protofluorine, mainly for lack of a better name. The name has been used before for a hypothetical element with an atomic weight nearly the same. No chemical similarity to fluorine is necessarily denoted. This element appears to be present strongly in the solar corona*.

The investigations of the spectra of these elements are to be communicated to the Royal Astronomical Society, and will probably be published in part before this paper.

The Nature of "Compounds."

When an element is said subsequently to be a "compound" of simpler elements, the statement does not relate to a compound as ordinarily known to chemists. Something of a more intimate nature is indicated. On the modern view of chemical affinity, valency is believed to be a capacity for taking up or giving off a certain number of electrons, so that when two elements, or ions, have opposite charges, they may be held together in a compound. The "residual" attraction of two molecules may also form an effective compound, as in Sir J. J. Thomson's discussion of the probable nature of chemical action †. But in all truly chemical compounds, the separate atoms of the elements concerned must be supposed to preserve their identity, though held together by chemical forces, that is to say, electrical forces of a particular kind.

This is illustrated from the fact that compound gases have a ratio of specific heats determinable from the number of atoms in the molecule. Now the radium emanation or niton belongs to a group of gases whose other members are monatomic, and this gas is capable of giving off helium—a fact which is difficult to explain if it be monatomic. The difficulty can be evaded by supposing that the atom of the gas contains all the components of the atom of helium, but not as a compound, in any ordinary sense, of the atom of helium with something else. In suitable circumstances, these components are excluded together as a helium atom; but while in the atom of niton they are more intimately related to the major part of the atom. Niton could therefore

* The strongest lines in the coronal spectrum are due to this substance, and it is therefore perhaps advisable to interchange the names coronium and protofluorine; but in this paper the names used when the paper was read have been retained in order to avoid confusion.

† *Vide* 'The Corpuscular Theory of Matter.'

behave as a monatomic gas, as there is every reason to suppose that it would if the experiment were possible.

Many suggestions could be made as to the probable nature of a compound of this kind. For example, if an element consisted of a compound of nebulium and protofluorine, it might have an atom made up of two coplanar rings of four and five electrons respectively, and two positive nuclei. The essential feature is that these two nuclei should not coalesce into one. The separate elements are there in a sense, but not in the chemical sense, in which the two elements would exist side by side as separate units, held together perhaps by the transfer of an electron from one to the other.

It is needless to dwell at any length upon the question of energy. The knowledge that an immense amount of energy is liberated in radioactive transformations, and that their rate of progress is apparently quite independent of external conditions, such as temperature, which influence ordinary chemical action, is sufficient to indicate the difference between the two types of "compound." When expressions like "compound" and "protyle" are used, it is on account of their convenience, and their limitations of meaning require emphasis.

Atomic Weight.

The weight of an atom, always determined from its inertia, may be regarded as the sum of the inertias of all its positive and negative charges. If the positive charges have a much smaller radius, their inertia will greatly overweigh that of the electrons, and we may neglect the latter for the present. The motions to which a nucleus is subject will always be slow in comparison with the velocity of light. Let a be its radius, and e the charge on an electron. If there are n electrons in a neutral atom of a primary simple substance, the positive charge is ne, and the inertia will be proportional to n^2e^2/a by the usual formula for slow motions.

If the positive electricity has a uniform volume density, its volume is proportional to ne, and therefore a to $n^{\frac{1}{3}}$.

Thus the inertia is proportional to $n^{\frac{5}{3}}$. That of a compound atom containing several nuclei associated with rings of electrons will be proportional to

$$\Sigma n^{\frac{5}{3}}.$$

Assuming that the hydrogen atom has three electrons, the relative weights of the atoms of the primary substances are

Coronium . . $n = 2$, $n^{\frac{5}{3}} = 3{\cdot}1748$,

Hydrogen . . $n = 3$, $n^{\frac{5}{3}} = 6{\cdot}2403$,

Nebulium . . $n = 4$, $n^{\frac{5}{3}} = 10{\cdot}079$,

Protofluorine . $n = 5$, $n^{\frac{5}{3}} = 14{\cdot}620$.

It is usual to take the atomic weight of oxygen as 16 ; so that hydrogen has an atomic weight 1·008. On this scale, we find :—

Atomic weight of Coronium = ·51282,

" " Hydrogen = 1·008,

" " Nebulium = 1·6281,

" " Protofluorine = 2·3615.

The atomic weight of coronium is approximately the value assigned by Mendeléef to a hypothetical element. Nebulium may be the element predicted with an atomic weight nearly equal to 2.

Compound Atoms.

Helium.—The terrestrial element succeeding hydrogen is helium, whose atomic weight, as given by the International Committee for the present year, is 3·99.

Again neglecting the weight of the electrons, we find by addition that the weight of an atom consisting of one atom of nebulium and one of protofluorine is 3·9896 or 3·99.

Helium can therefore be expressed as a simple type of compound atom. With the symbols Cn for coronium, Nu for nebulium, and Pf for protofluorine, we may write

$$\mathrm{He} = \mathrm{Nu}+\mathrm{Pf},$$

where the equation is not to be interpreted in the chemical sense.

Before considering other elements, we must take account of the inertia of the electrons. An estimate of its magnitude may be obtained by the supposition that they are moving slowly. It may be shown by a consideration of the spectral lines that the velocity of the electrons in an atom of nebulium is about ·004 C, where C is the velocity of light. The nature of the inertia-formula is such that this can be effectively treated as slow, in the computation of a small effect of this kind.

Now the mass of a slowly-moving electron is 6.10^{-28} gram, and the mass of a hydrogen atom is $1{\cdot}1.10^{-24}$ gram, according to the best estimates. The fraction of the weight of the atom due to its three electrons is therefore practically $1{\cdot}67 . 10^{-3}$, and therefore, if 1·008 be the atomic weight, the weight of the corresponding nucleus is only

$$(1{\cdot}008)(1-{\cdot}00167).$$

The revised weights of the nuclei of the other simple atoms become therefore

$$\mathrm{Cn} = {\cdot}51196, \quad \mathrm{Nu} = 1{\cdot}6254, \quad \mathrm{Pf} = 2{\cdot}3576.$$

Adding the weights of the electrons in each case, on the appropriate scale ·00056 for each electron, we have the following results :—

Atomic weight of		Coronium	=	·5131,
,,	,,	Hydrogen	=	1·008,
,,	,,	Nebulium	=	1·6277,
,,	,,	Protofluorine	=	2·3604,

the alterations affecting only the third decimal place slightly.

The atomic weight of helium now becomes 3·9881, or again 3·99.

It may be shown that this value persists even if the electrons move so fast as to double their inertia. This would approximately be the case if the velocity of an electron were 4/5 of that of light.

We proceed to the consideration of other simple cases before attempting to construct a general scheme. When the helium group enters, it is not implied that this group is always intended rather than its two component groups, which may be differently situated in the atom.

There is a fairly general suspicion that many of the elements may be composed of helium and hydrogen. This view receives some support from the following considerations.

In constructing the elements, coronium is not used. This reduces the number of primary substances to three. The possibility of fortuitous equalities of numbers is thereby greatly reduced. Coronium must be retained as a substance, but it does not seem to have a necessary function in the construction of others, being, like the possible primary substances with six and more electrons, rather a hindrance when the attempt is made to construct the simpler compound elements (with the exception of lithium, a doubtful case) by its combinations with others. It is possible that it is concerned in the composition of the very rare elements, such as cerium, neodymium, and praseodymium and their group, for these elements occur somewhat strongly in the sun, where coronium undoubtedly exists. If so, some light would be thrown on the apparent lack of places in the Periodic Table for these elements. The atom of coronium would be by no means so permanent as those of other substances, on account of its comparatively rapid radiation.

Argon.—The atomic weight of argon has been determined with greater accuracy than those of the other inert gases, and the International Committee now adopts the value 39·88. This is exactly ten times the value we have obtained for helium, and we may write

$$A = 10\mathrm{He}$$

as a provisional representation. The fact that small quantities of argon usually occur in mineral springs which are rich in helium is somewhat suspicious, and when helium is formed in radioactive processes, it is not unlikely that minute quantities of argon should accompany it, if the constituents of the argon atom are the same, in greater number, as in the case of helium. There is some reason to believe that all the inert gases are products of radioactive changes, and the question will be considered in greater detail later.

Beryllium.—The combination $3\mathrm{Pf}+2\mathrm{H}$ would have an atomic weight 9·097, or 9·10, the International value for beryllium.

Boron.—The International atomic weight of boron is 11·00. The combination $2\mathrm{He}+3\mathrm{H}$ gives this value exactly.

Carbon.—The value of the atomic weight of carbon is 12·00, although the best chemical determinations indicate a value slightly higher. The number 12·008, where the last figure may be smaller, may be obtained from the compound $2\mathrm{He}+4\mathrm{H}$.

Nitrogen.—$2\mathrm{He}+6\mathrm{H}$ gives a value 14·02. Values have been obtained by experiment ranging from 14·05 (Stas) to just below 14·01. At present this is the scheduled value, but it is not regarded as certain.

Oxygen.—$3\mathrm{He}+4\mathrm{H}$ gives 15·996, or 16·00, the value proper to the accepted one for hydrogen.

Fluorine.—The atomic weight of fluorine has not been determined recently. It is given as 19·0, the second decimal being small but uncertain. The combination $3\mathrm{He}+7\mathrm{H}$ gives 19·020.

Neon.—The scheduled atomic weight of neon is 20·2, Watson's recent determination giving 20·21. The combination $6(\mathrm{Pf\,H})$ gives 20·21, and will be taken subsequently as representing neon. Apparently the group $(Pf\,H)_8$ has considerable significance in atomic structure, according to the present theory.

Sodium.—The atomic weight of sodium is slightly greater than 23, but not so great as 23·01, according to current chemical opinion. The value 23·008 is given by the group 4He+7H.

Magnesium.—This is an element, like beryllium, which cannot be composed from the helium and hydrogen groups. Its atomic weight is 24·32, a value given exactly by 2H+5He+Pf.

Lithium.—We have considered all the known elements with atomic weights less than 25, with the exception of lithium, and the addition of argon. Lithium is the element which has presented the only difficulty, and it is possible that this difficulty is only apparent. Until very recently, the atomic weight of lithium was believed to be greater than 7. A recent determination with carefully prepared material, however, gave 6·94, at present the accepted value. It is not unlikely that the actual value may be even smaller.

The combination 3Nu+2H gives 6·90, and He+3H gives 7·01, the older value. The first combination gives the best result, and is used later. If it should be the case that the second protyle is not hydrogen, but in a sense half of it, so that all groupings should be doubled, this difficulty is removed on addition of the two groups. At present the question must be left open, but there is some reason to believe that the latter view is correct.

The Inert Gases.

After this preliminary sketch, we may proceed to a detailed theory of a definite group of elements in the Periodic System, and for this purpose we select the inert gases, including the radioactive emanations. They are a very fundamental type of matter, and the groupings which are found to be effective in representing them, from the point of view of atomic weight, have an important place in the suggested constitution of the other classes of elements. Too much stress must not be laid, in many cases, on the particular arrangements selected, which are purely speculative and provisional, but it seems probable that they may represent something in the structure of the atom, from the constant recurrence of those which are effective. It may be claimed that they introduce a system into the Periodic Table which does not appear to be fortuitous, at the same time enlarging the scope of the table. In the atom, they may be regarded as partially isolated from the rest, though not preserving their identity so completely as in an ordinary chemical compound. A rearrangement typical of radioactive change may be capable of rejecting a group, which may appear as an α particle. It is possible, as we shall see later, to give a speculative theory of some of the radioactive processes on this basis, which, however crude and incapable of verification in its present form, is certainly not in opposition to any of the phenomena known with certainty. Its capacity for verication is, however, in some respects very real, as will appear. The investigation also serves the purpose of indicating some lines on which valuable experiments might be made.

As an example of this, we may cite the generally accepted view that all α particles are positively charged atoms of helium. The value of e/m for these particles is not regarded as certainly accurate, and serves merely to indicate that they are of atomic size. The belief that they are helium rests entirely upon the spectroscopic investigations of Ramsay and others with regard to the products of disintegration of niton or radium emanation, and the more recent work of Rutherford and Royds referring only to a particular case *. These experiments prove that helium is one of these products, but they certainly do not prove that all the α particles from the radium or thorium series consist of helium. There is, in fact, strong reason to doubt this view, and it will be sufficient to mention only two facts in this connexion.

In the first place, not only was the helium spectrum obtained in these experiments, but three other lines, of wavelengths 6180, 5695, and 5455 which have never been identified. These results have been confirmed, and certainly seem to indicate a gas other than helium or any known terrestrial substance. The same spectrum is found for the gas liberated by solution of radium bromide.

The excess of hydrogen liberated in experiments with the emanation has also never been explained satisfactorily, and there is some doubt whether it is due entirely to moisture which has found its way into the apparatus. The writer feels compelled to express the belief that some α particles are not helium, but hydrogen and other substances, more especially nebulium, or more probably Nu_2, another elementary gas, and it is very desirable that more spectroscopic work

* A paper by Rutherford and Boltwood (Phil. Mag. October 1911), which has appeared since this was written, gives much more definite proof, but it again does not show that the helium may not be a modified α particle in many cases.

should be done in all possible cases. It seems not unlikely that some of the lines of the nebular and coronal spectra would be found, just as helium has been found.

Some calculations which may be made from the experimental results are very significant, and one or two may be cited as illustrations. In the first place, though the methods of finding e/m for the α rays from radium have been criticized, they have led to very concordant results. Rutherford's original investigation by the electric method gave $e/m = 6 \,.\, 10^3$. The photographic method of Des Coudres gave a value $6 \cdot 4 \,.\, 10^3$, and this was confirmed later by Rutherford by a combination of the magnetic deflexion and the heating effect, which gave $6 \cdot 5 \,.\, 10^3$. This agreement is remarkable, and certainly an indication that the results are probably correct. Now the value of e/m for a hydrogen atom with the electronic charge, as in electrolysis, is $9 \cdot 62 \,.\, 10^3$. Taking

$$e/m = 6 \cdot 4 \,.\, 10^3$$

for the α particle, its mass becomes therefore 1·5 times that of the hydrogen atom. If it has a double charge, this becomes 3 times that of the hydrogen atom. This does not point to helium as the α particle, but to the gas Nu_2, which we may call Dinebulium, with an atomic weight 3·25. This may be the origin of the three spectral lines already mentioned. There is evidence that the α particles from the emanation differ either in mass or velocity from those of radium. Rutherford has concluded that they have a smaller velocity. It is possible, however, that they have a larger mass, and really consist of helium.

One more calculation of considerable interest may be given. Becquerel has concluded that the amount of deviation, in a given magnetic field, is the same for the α rays of polonium and radium. This means that the momentum mV of the rays is the same. But the α rays from polonium are much more readily absorbed, and therefore apparently m is greater for these rays. In Rutherford's treatise * a comparative table of the absorptions is given. For a single thin layer of aluminium foil, the ratio of decrease is, for polonium, ·41, and for radium, ·48. Afterwards polonium rays cease to follow the exponential law. In a *single* thin layer, it cannot be very invalid to suppose the decrease proportional roughly to the velocity, or the time which it would take a ray to get through. If, then, the α ray from radium is really dinebulium, that from polonium has an atomic

* 'Radioactivity,' p. 162.

weight $3{\cdot}25 \times 48 \div 41$ or $3{\cdot}8$. This is consistent with the theory that the polonium α rays are actually helium.

This digression has been somewhat long, but it serves a useful purpose. Nebulium and protofluorine, even if not primary substances from which others are built up in this particular way, are not hypothetical, as a consideration of spectra shows.

We may now proceed further with the main argument. Of the inert gases, we have already considered helium, argon, and neon.

Krypton and Xenon.—The inert gases may be divided into the argon and neon groups, if the arrangement in double columns of the Periodic Table be adopted, that is to say, the arrangement which places potassium, rubidium, and cæsium in one subgroup, and sodium, copper, silver in another of the same column. In the argon subgroup, the sequence is argon, krypton, xenon, an unknown gas, and niton. The only other member of the parallel group at present known is neon, and it is followed by four vacant spaces. Sir William Ramsay has suggested that the vacant spaces should be occupied by emanations, possibly present in the atmosphere, but decomposed during the process of separation. We shall endeavour to fill these spaces, guided in our selection of formulæ by the groupings of primary atoms found effective for other elements.

We consider krypton and xenon in the first place. Argon has already been classified as He_{10}, and neon as $(PfH)_6$. It is preferable to write

$$A = 5He_2, \qquad Ne = 2(PfH)_3,$$

for the groups He_2 and $(PfH)_3$ appear to have some significance.

Consider now the groupings

$$5\{Nu_4(PfH)_3\}, \qquad 5\{He_4(PfH)_3\}$$

with an obvious relation to each other and to those of argon and neon. If they represent elements, the calculated atomic weights of these elements are respectively 83·08 and 130·28. The present International atomic weights of krypton and xenon are 82·9 and 130·2, which, allowing for errors of experiment, especially likely in the case of krypton, are in very close accord with these calculated numbers. Without further discussion, we shall consider these formulæ to represent the atoms of krypton and xenon.

Passing now to the neon group, the first vacancy occurs just before copper in the Periodic Table, and the hypothetical element has been predicted to have an atomic weight about equal to 63. The formula

$$X_1 = 2\{He_2(PfH)_3 \,.\, Nu_2(PfH)_3\}$$

which we select, in accordance with necessary selections for other elements, gives an atomic weight 62·88. The unknown gas is called X_1, and it is possible that the incomplete groupings involving He_2, Nu_2 are a criterion of instability. The possibility of a decomposition of this gas into the other inert gases with necessary stability is evident from the formula.

Returning to the argon group, we note that the gas preceding niton has a predicted atomic weight of about 176, by the usual method of the Periodic Table. This value has been mentioned, for example, by Sir William Ramsay. Calling it X_2, we may try a formula

$$X_2 = 5\{He_2(PfH)_3 \,.\, Nu_4(PfH)_3\},$$

giving the atomic weight 173·5. It contains a possibly unstable group, and may readily decompose into the inert gases of the atmosphere.

An alternative formula is

$$X_2 = 2\{2Nu_4(PfH)_3 \,.\, 3He_2(PfH)_3\}$$

with an atomic weight 175. The latter is preferable, but a real decision could only come with a knowledge of the gas. The second formula may illustrate a relation with niton, and it notably combines the double grouping of the neon series and the quintuple one of the argon series, besides giving a better value for the atomic weight.

It is worth the trouble to continue these speculations regarding unknown gases, though briefly, since one of them is generally believed to be the emanation from actinium.

The next vacancy in the neon group immediately precedes silver, and the corresponding gas should have an atomic weight of about 106. We suggest

$$X_3 = 2\{He_4(PfH)_3 \,.\, 2Nu_2(PfH)_3\}$$

or

$$X_3 = 2\{Nu_4(PfH)_3 \,.\, 2He_2(PfH)_3\}$$

with an atomic weight 105·6. These might be different elements, with the same groupings arranged differently. Examples of this are not unknown, and the case of uranium and uranium X may be cited.

These gases contain, throughout the series, a possibility of disintegration into the gases of the atmosphere.

Another vacancy precedes gold in the Table, the probable atomic weight concerned being 197. We suggest the gas

$$X_4 = 2\{He_4(PfH)_3 \,.\, 4He_2(PfH)_3\}$$

with an atomic weight 196·76, exhibiting both the double and quintuple groupings of the more primary groups.

We have passed over a vacancy on the horizontal row containing a series of the metals of the rare earths. There is a current view that samarium (150·4), europium (152·0), and gadolinium (157·3) form a triad in the last column of the table, like iron, nickel, and cobalt, or osmium, iridium, and platinum. Terbium (159·2) then appears in the column with copper, silver, and gold, and should be preceded by an inert gas of the neon group with an atomic weight nearly equal to 158. If this view be accepted, the only compound of the usual groupings which is available is, with atomic weight 157·6,

$$X_5 = 4\{He_4(PfH)_3 \,.\, Nu_2(PfH)_3\},$$

which is not quite in line with the general scheme.

But a consideration of the table appears to indicate that the true value should be nearly 153, if the successive differences are accounted in the usual way. The position of the rare earths is a baffling problem, and there is certainly no resemblance between terbium on the hand, and copper, silver, and gold on the other. In fact, the rare earths all resemble lanthanum, the first member of their series, in properties, and there is considerable justification for the proposal which has been made to extend the row to 16 instead of 8 members at this stage of the table. Quite apart from the present theory, it does not seem that terbium can retain its place, on purely chemical grounds, in the alkali column. We shall suppose, therefore, that 153, the value naturally suggested by the Periodic Table, is the proper approximate atomic weight of the gas now in question. We suggest therefore the formula

$$X_5 = 2\{2He_2(PfH)_3 \,.\, 3Nu_2(PfH)_3\}$$

with an atomic weight 152·49. There are other important considerations in favour of this formula, which cannot be discussed at present without undue digression. They will be dealt with to some extent later in the paper, and more specially afterwards. We may, however, state that there is considerable reason for the belief that this gas is the actinium emanation.

Thorium Emanation.—If the thorium emanation is derived from thorium by the expulsion of two α particles, both being helium atoms, the atomic weight of this emanation is about 224·4, or very close to the value for niton. The decimal in the atomic weight of thorium is not definitely settled, but it is evident that the atomic weights of the two emanations are within a few units of each other, and this fact renders it possible to take up a definite position with regard to them.

If the Periodic Table is to be accepted at all, it is evident that it contains no places for two inert gaseous elements so close together. Thorium emanation, though more unstable, is as much an element as niton. The suggestion may be made that the atomic weights of these emanations are *identical*, but that they consist of the same groupings in the atom arranged differently, in a more stable manner in the case of niton. Examples of elements with identical atomic weights are familiar in radioactive transformations. The case must occur whenever one element is derived from another by the expulsion of β particles and γ rays only. Two such emanations could break down in different ways.

This seems to be the only possible solution of the difficulty, and it is a matter which could perhaps be tested by spectroscopic work. For it involves the conclusion that the α particles from thorium and radium are not of the same character, if thorium is really the active constituent in its preparations.

Actinium Emanation.—A probable constitution of this emanation has been suggested, which leads to an atomic weight of 152·49. It is possible to obtain some degree of experimental verification of this value. Of the various attempts which have been made to find this atomic weight, that of Russ * appears to be the most satisfactory. The method of diffusion was used, and special precautions taken against unusual behaviour of small quantities of gas. Russ also performed experiments confirmatory of the method, and his final conclusion was that the thorium emanation is 1·42 times as heavy as that from actinium. The thorium emanation, in any case, has an atomic weight of about 222, and this leads to a value about 155 for actinium emanation.

This is sufficiently close to the value we have suggested, and decides the place of the emanation in the table. The atomic weight of actinium itself is therefore about 160. A

* Phil. Mag., March 1909.

precise value cannot be given until the nature of its α radiation is established. Without entering into a discussion at this point, the opinion may be expressed that these α rays consist perhaps of Nu_2, with atomic weight 3·25, which could easily be mistaken, except spectroscopically, for helium. There is some reason to believe that this gas may be responsible for the three spectral lines mentioned in an earlier section.

Radium Emanation or Niton.—In discussing a probable constitution of niton, we shall suppose that it is derived from radium by the expulsion of an atom of helium. On this point possible doubt has already been expressed, for reasons only partially indicated, though the indications given show that the α particles from radium and its products cannot all consist of helium. The value of the atomic weight of lead is another indication. The paper of Rutherford and Royds on the collection of the particles in a vessel may prove the matter in this special case. But if we adopt the usual view as a working hypothesis, the atomic weight of the emanation would be 222·4, if the atomic weight of radium is 226·4 as determined by Mme. Curie. The nearest value which can be obtained on the present scheme is given by

$$\text{Ra Em} = 2\{2Nu_4(PfH)_3 \,.\, 3He_4(PfH)_3\},$$

with an atomic weight 222·81. It can be arranged in other forms, one of which might be the thorium emanation, and is, in itself, quite consonant with the scheme, preserving the double and quintuple groupings. It still does so if arranged as

$$\text{Ra Em} = 2\{He_4(PfH)_3 \,.\, 4He_2Nu_2(PfH)_3\}.$$

Until further evidence concerning the α particle is available, this formula, in one form or another, will be adopted. If the atomic weight of helium be added, the atomic weight of radium becomes 226·80. This is very close to the value given by Thorpe's experiments, as described in a recent Bakerian Lecture. The formula is well in line with the scheme, but it does not exhibit radium as a transformation product of uranium if only helium is removed in the form of α particles.

If this value be correct, it reduces the discrepancy between the atomic weight difference of radium and lead, and the weight of the five helium atoms supposed to be ejected in a final transformation from radium to lead. The atomic weight of lead is given as 207·1, and with the value 226·80 for radium, the five α particles should weigh 19·70, which is very nearly the value for five helium atoms. The ordinary value for radium gives only 19·3. But this point must not be dwelt upon, as it seems probable that all the particles are not helium, and there may be more than five.

The results of this examination of the inert gases may be collected into the following table, as a representation of the first column of the Periodic Table. The practical value of the atomic weight, when one is generally accepted, is placed in brackets.

Group I.

Helium, He=Nu+Pf, 3·99 (3·99)	
	Neon, $2(PfH)_3$, 20·21 (20·2)
Argon, $5He_2$, 39·88 (39·88)	
	$X_1=2\{He_2(PfH)_3 . Nu_2(PfH)_3\}$, 62·88
Krypton, $5\{Nu_4(PfH)_3\}$, 83·08 (82·9)	
	$X_3=2\{He_4(PfH)_3 . 2Nu_2(PfH)_3\}$, 105·6
Xenon, $5\{He_4(PfH)_3\}$, 130·28 (130·2)	
	Ac Em $=2\{2He_2(PfH)_3 . 3Nu_2(PfH)_3\}$, 152·49
$X_2=2\{2Nu_4(PfH)_3 . 3He_2(PfH)_3\}$, 175·0	
	$X_4=2\{He_4(PfH)_3 . 4He_2(PfH)_3\}$, 196·76
Niton, $2\{2Nu_4(PfH)_3 . 3He_4(PfH)_3\}$, 222·8	

Other Groups of Elements.

After this sketch, necessarily somewhat brief, of the group of inert gases, we may proceed to consider other groups of elements with chemical similarity. Only those of accepted atomic weights are considered, and in particular, all the elements of the rare earths are ignored, since they are uncertain both in atomic weights and positions in the table. It must be stated that in many cases the suggested groupings are entirely provisional, and put forward partly to indicate the possibility of the process. Many considerations, atomic volume for example, would be necessary before anything of a final character could be attempted. But on the whole the system cannot be wholly fortuitous, and the results are suggestive in many ways.

Lithium, Potassium, Rubidium, Caesium.—For these elements the following formulæ may be suggested:—

Lithium, $H_2Nu_3 = 6{\cdot}90$ ($6{\cdot}94$),
Potassium, $2\{Nu_2 (PfH)_3\} H_2Nu_2Pf_3 = 39{\cdot}08$ ($39{\cdot}1$),
Rubidium, $4\{Nu_4 (PfH)_3\} He_4H_3 = 85{\cdot}44$ ($85{\cdot}45$),
Caesium, $4\{He_4 (PfH)_3\}\{Nu_4 (PfH)_3\} He_3 = 132{\cdot}81$ ($132{\cdot}81$).

The case of lithium has been discussed already. The formulæ present a definite scheme of development with atomic weight increasing, and their groupings have obvious relations with those of the inert gases. The relations among the metals themselves are of the kind which would be expected on the view that the elements are the representatives of definite positions of stability which have been reached in an evolution of matter from its simplest forms. The properties of these stable systems may be expected to recur at certain intervals, for example, alkaline properties and their chemical associates recur with the groups just written. Other groups of a similar kind might be written down with perhaps similar properties, but capable possibly of only a transitory existence, as in the case of radioactive products. The discovery of radioactivity has already led, as Sir William Ramsay pointed out in his Presidential Address to the British Association at Portsmouth, to the isolation of twenty-seven new "elements," many of which have been shown to possess definite chemical properties. The Periodic Table cannot take account of all unstable as well as stable elements, except on the view that the complete table should contain many times the present number of elements, in which the present set would be but isolated units, and such that the table should find places for whole groups at present unknown, or perhaps represented by a single member, as possibly, for example, in the case of sodium or manganese.

The real existence of a general scheme of this kind is an immediate deduction from the growing belief that all matter is to a certain extent radioactive. Campbell has detected the effect even in potassium, which perhaps gives a series of products for which the present table has no place. Radioactivity can easily be overlooked if the velocity of the expelled particles is below a certain value. It is a process of devolution of matter, and if the α particle were endowed with considerable mass it could not be detected. A gas like neon may be an α particle from certain kinds of matter, and it is probable that all the inert gases are waste products of this nature, which have accumulated in the atmosphere.

Their absence from the solar spectrum is significant, and perhaps an indication that in this case the process of devolution has not gone far. If they are radioactive products, the fact that their groups are so effective in the constructions for other elements has an important significance. If an atom of caesium, for example, gave off the group He_3, the remainder might disintegrate into krypton and xenon, without any possible detection by experiment.

Sodium, Copper, Silver, Gold.—These metals occupy the other sub-group in column 2 of the table, and are not closely related chemically, even in respect to valency. Sodium presents much more similarity to the alkali metals, but is devoid of some of their characteristic properties—it does not, for example, form alums. In the alkali group, lithium itself is somewhat exceptional, especially as regards its spectrum, as Hicks* has shown recently. The formula ascribed to it is not quite similar to those of the allied metals, as it only contains two of the primary substances.

Similar remarks apply to sodium in the present group. It is chemically unlike copper, silver, and gold, and it has been found impossible to obtain a formula quite in line with those of the other metals, nor conversely, to endow them with formulæ similar to that of sodium. It seems likely that sodium is the only stable representative of a whole group of elements. The formulæ suggested for the present elements are:—

$$\text{Sodium, } \{Nu_2\,(PfH)_3\}H_2Nu_2\,.\,PfH_2 = 23{\cdot}008\ (23{\cdot}0),$$

$$\text{Copper, } 2\{He_4\,(PfH)_3\}Pf_2\,.\,(PfH)_2 = 63{\cdot}57\ (63{\cdot}57),$$

$$\text{Silver, } 4\{Nu_4\,(PfH)_3\}2\{Nu_2\,(PfH)_3\}He_2\,.\,(PfH)_2 = 107{\cdot}89\ (107{\cdot}88),$$

$$\text{Gold, } 8\{He_2\,(PfH)_3\}2\{He_2Nu_2\,(PfH)_3\}Nu_2\,(PfH)_2 = 197{\cdot}3\ (197{\cdot}2),$$

where the formula for sodium has a pronounced similarity to that of potassium in the previous section.

Beryllium, Calcium, Strontium, Barium, Radium.—The spectrum of beryllium is abnormal in the same manner as that of lithium, and is not of the same type as those of its associated members of the table. This peculiarity has been pointed out to me by Prof. W. M. Hicks, who has not yet published his investigations of these series. We may expect to find a similar divergence in its formula, and this occurs.

* Phil. Trans. A. 1909.

The suggested formulæ are :—

Beryllium, Pf_3H_2 or $Pf(PfH)_2 = 9{\cdot}10$ (9·1),
Calcium, $2\{Nu_2(PfH)_3\}(PfH)_3Nu_2 = 40{\cdot}084$ (40·09),
Strontium, $4\{Nu_2(PfH)_3\}\{He_2Nu_2(PfH)_3\}Nu_3He_2 = 87{\cdot}64$ (87·63),
Barium, $4\{He_4(PfH)_3\}\{He_2(PfH)_3\}Pf_3He_2 = 137{\cdot}37$ (137·37),
Radium, $8\{He_2Nu_2(PfH)_3\}2\{He_2(PfH)_3\}He_5 = 226{\cdot}8$ (226·4).

Beryllium diverges very much in the same way as lithium, containing only two primary substances. It involves Pf_3H_2 in place of Nu_3H_2. That it should have a different valency from lithium may be seen. Even to protofluorine and nebulium themselves definite valencies can be ascribed on mathematical principles, but this question lies outside the range of the present preliminary exposition of the theory. The valency of an element will have no immediate relation to the valencies of other and simpler elements which could be formed by an arbitrary selection of some of its groups. Valency is, of course, not an idea which can be attached with any meaning to a group like, for example, He_3, unless the arrangement in this group be specified, and unless it be unaccompanied by other groups. Perhaps this remark is necessary to emphasise the distinction between compounds in the present sense and chemical compounds.

The formula for radium is obtained on the supposition that its α particle is helium.

Magnesium, Zinc, Cadmium, Mercury.—These metals occupy the other half of the column containing the calcium group, and possess a certain degree of similarity, especially zinc and cadmium. The suggested formulæ are :—

Magnesium, $NuHe_4(PfH)_2 = 24{\cdot}32$ (24·32),
Zinc, $2\{He_4(PfH)_3\}Nu_4(PfH)_2 = 65{\cdot}36$ (65·37),
Cadmium, $4\{He_2(PfH)_3\}He_6Pf_4(PfH)_2 = 112{\cdot}43$ (112·40),
Mercury, $8\{He_2(PfH)_3\}2\{Nu_2(PfH)_3\}H_6He_4(PfH)_2 = 200{\cdot}1$ (200).

The formula for magnesium is somewhat different from the others, but there is a corresponding chemical difference. Beryllium and magnesium have much in common, and the formula for beryllium may be written as $Pf(PfH)_2$, which is very similar to that of magnesium. The other three formulæ follow the usual line of development, with a corresponding gradation of chemical properties.

Nitrogen, Phosphorus, Arsenic, Antimony, Bismuth.—Columns 4 and 5 of the table do not contain many elements whose atomic weights have been determined with sufficient accuracy. They are accordingly passed over in the present sketch, and we proceed to column 6. In this column elements like vanadium and niobium will not be considered. They are classed with nitrogen, to which they have little resemblance, except perhaps in the formation of salts similar to the nitrates, and of oxychlorides. But phosphorus, arsenic, antimony, and bismuth form a series whose properties change continuously from non-metallic to metallic. Nitrogen is also, in some respects, a starting-point of this series. The suggested formulæ are :—

Nitrogen, $H_4 . He_2H_2 = 14{\cdot}02$ (14·01),
Phosphorus, $\{He_2 (PfH)_3\}He_3H = 31{\cdot}05$ (31·04),
Arsenic, $3\{He_2 (PfH)_3\}\{Nu_2 (PfH)_3\}Pf_2NuH = 74{\cdot}96$ (74·96),
Antimony, $3\{He_4 (PfH)_3\}2\{He_2 (PfH)_3\}Nu_3H = 120{\cdot}22$ (120·2),
Bismuth, $8\{He_2 (PfH)_3\}4\{Nu_2 (PfH)_3\}Nu_2 (PfH)_2 = 208{\cdot}08$ (208).

The formulæ for phosphorus, arsenic, and antimony have much in common, but that for bismuth is more reminiscent of some of the preceding metals, though at the same time not unlike the others of its group. The factor 3 in the inert gas groupings appears for the first time in arsenic and antimony, semi-metallic elements. It appears again in the next group of elements.

Oxygen, Sulphur, Selenium, Tellurium.—Of these four elements of column 7 of the table, the last three form a pronounced chemical series. Oxygen has little real relation to the others, and certainly none to chromium, molybdenum, and tungsten, which are its actual companions in the subgroup. It is probable that it ought to have a column of its own. But just in so far as nitrogen is, in some respects, allied to phosphorus, so is oxygen to sulphur. It is very easy, for example, to replace oxygen by sulphur in many classes of organic compounds. The formula might therefore be expected to show some relation to the other three. The following may be suggested :—

Oxygen, $\{Nu_2 (PfH)_3\}NuH = 16{\cdot}00$ (16·00),
Sulphur, $\{He_4 (PfH)_3\}HeH_2 = 32{\cdot}06$ (32·07),
Selenium, $3\{Nu_4 (PfH)_3\}2\{Nu_2 (PfH)_3\}NuH = 79{\cdot}20$ (79·20),
Tellurium, $4\{He_2Nu_2 (PfH)_3\}2\{He_2 (PfH)_3\}HeH_2 = 127{\cdot}5$ (127·5).

There is a curious similarity between the formulæ for selenium and arsenic, and in fact between the last two sets of formulæ. In each case it is accompanied by a gradual transition to the metallic state, selenium and tellurium having metallic varieties.

Fluorine, Chlorine, Bromine, Iodine.—Chlorine, bromine, and iodine form a well-defined chemical series, but fluorine is in some respects isolated, though quite fairly in accord with the others. But it has many exceptional properties, such as its extraordinary affinity for silicon. These elements are accompanied in the column by manganese, which cannot be regarded as related to them. The following may be suggested:—

Fluorine, $Nu\,(PfH)_3\,.\,H_2\,(NuH)_2 = 19{\cdot}02\ (19{\cdot}0)$,
Chlorine, $2\{Nu_2\,(PfH)_3\}H_2\,(PfH)_2 = 35{\cdot}47\ (35{\cdot}46)$,
Bromine, $4\{Nu_4\,(PfH)_3\}H_2Pf_2\,(PfH)_2 = 79{\cdot}93\ (79{\cdot}92)$,
Iodine, $4\{He_4\,(PfH)_3\}He_4\,(PfH)_2 = 126{\cdot}92\ (126{\cdot}92)$.

In the case of fluorine, the atomic weight is not known to the second decimal, so that the alternative

Fluorine, $\{Nu_2\,(PfH)_3\}Pf\,Nu_2 = 18{\cdot}98$,

is also worthy of consideration. These are the only two alternatives.

Chromium, Manganese, Iron, Nickel, Cobalt.—These metals occupy paradoxical positions in the table. Chromium appears as related to oxygen, and manganese to fluorine, while iron, nickel, and cobalt appear as a triad after the eighth column. It is significant that all appear consecutively in a row. Chromium is further associated, with some chemical correspondence, with molybdenum and tungsten. No analogue of manganese has been discovered, and it is followed only by vacant spaces.

There is a considerable similarity amongst these metals, for example in their capacity for forming salts such as the bichromates, permanganates, and ferrates. Moreover, iron, nickel, and cobalt are the magnetic metals. These considerations point to some factor in their constitution which has not occurred in the groups of elements already discussed, and it is noteworthy that an application of the usual groupings is not very successful. The best representations found are as follows:—

Chromium, $4He_2\{He_2\,(PfH)_3\}H_2 = 52{\cdot}00\ (52{\cdot}00)$,
Manganese, $6He_2\,.\,Pf_3 = 54{\cdot}938\ (54{\cdot}93)$,
Iron, $6He_2\,.\,He_2 = 55{\cdot}84\ (55{\cdot}85)$,
Nickel, $4He_2\{He_2\,(PfH)_3\}HePf_2 = 58{\cdot}69\ (58{\cdot}68)$,
Cobalt, $4He_2\{He_2\,(PfH)_3\}HHe_2 = 58{\cdot}97\ (58{\cdot}97)$.

These form a very definite system, with the pecularity that the usual groupings are replaced to a great extent by helium groups. When the suggested constitution of argon, $5He_2$, is considered, it is seen that they do not violate the usual relation to the inert gases.

Perhaps this preponderance of helium, that is to say, of the positive charges of only two types which may be the nuclei of the helium atom, may be responsible for the peculiar properties and isolated position of these elements. It is especially noteworthy that the formula for iron consists only of these.

Uranium.—Perhaps a suggestion with respect to the relation between uranium and actinium may be made at this point, though it is highly speculative. If the present atomic weight of uranium, recently determined carefully, be accepted it is in accordance with the constitution

$$\text{Uranium, } 8\{Nu_2\,(PfH)_3\}4\{He_2Nu_2\,(PfH)_3\}2\{He_2\,(PfH)_3\}=238{\cdot}50,$$

giving this accepted value exactly. This formula is a multiple of 3. Actinium is believed to be a branch product of the activity of uranium, and there is certainly a considerable gap between the atomic weights. An instability arising in an atom of uranium may in certain cases cause instability in a neighbouring atom, or the unstable atom may be projected into the stable one, so that they break up together. If this should happen three atoms or more of a new substance may be formed, presuming that the result is not a mixture of elements. If three atoms were formed the atomic weight of the substance would be $\frac{2}{3}$ of that of uranium, or 159·00. Its constitution might be arranged as

$$6\{Nu_2\,(PfH)_3\}4\{He_2\,(PfH)_3\}Nu_4,$$

derived directly from the formula for uranium. The escape of two α particles of constitution Nu_2 and atomic weight 3·25 would then leave the substance already indicated as the probable actinium emanation. If four α particles escaped each might be nebulium.

It is noteworthy that in the September number of the Philosophical Magazine Mr. G. N. Autonoff describes experiments which seem to indicate a branch product UrY derived in small quantity from uranium. This product appears to give off α rays, but not to the extent expected from the β radiation. If it be the parent of actinium, perhaps these α rays are not from UrY, but from one of its products.

At this point it is convenient to close the present paper. The views which have been advocated are capable in several ways of experimental test, more especially in connexion with spectroscopic work of the kind already done by Ramsay, Soddy, Rutherford, and others. They do not appear to be at variance with any established experimental result where comparison is possible, and they may serve to suggest useful directions of experimental inquiry, or the outlines of an interpretation of radioactive changes. It may be noted that, according to these views, the number of electrons in an atom is roughly proportional to the atomic weight. The ratio is generally about 2·5, rather smaller than Crowther's estimate.

LXXXV. *On Electrostriction*. *By* E. P. ADAMS, *Ph.D., Professor of Physics, Princeton University* *.

THE object of the present paper is the development of formulæ for some important cases of electrostriction, particularly those involving cylindrical condensers. M. P. Sacerdote † found the elongation per unit length of a charged cylindrical condenser to be

$$e=\left(\frac{1}{E}+k_1\right)\frac{K}{8\pi}\left(\frac{V}{d}\right)^2, \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where E is Young's modulus, K the dielectric constant, and d the small thickness of the dielectric, and k_1 a constant involving the dependence of K upon the state of stress in the dielectric. This expression was obtained by the energy method; when applied to a finite portion of an infinitely long cylinder there is some doubt as to the validity of this method. In the present paper this and other problems are solved by means of the general equations of equilibrium of elastic solids. An entirely different result is obtained for the elongation of a charged cylindrical condenser, and this has an important bearing upon the interpretation of the experiments of Prof. L. T. More ‡, who concluded that the whole elongation he obtained could be accounted for by the heat developed as a result of the high difference of potential it was necessary to employ; this conclusion is supported by the result of the present investigation.

It is well understood now that the system of stresses in dielectric media formulated by Maxwell is only approximate, no account being taken by him of the change in the dielectric

* Communicated by the Author.

† 'Recherches Théoriques sur les déformations électriques des diélectriques solides isotropes.' Paris, Theses No. 1012, 1899.

‡ Phil. Mag. [5] l. p. 198 (1900); [6] vi. p. 1 (1903); x. p. 676 (1905).