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THE PROBLEM OF RADIOACTIVE LEAD[1]

WE meet to-day with happiness which six months ago would have seemed beyond the bounds of reasonable hope. After anxious months, the confidently awaited victory, which last spring still seemed far away, has crowned the cause of justice, truth and liberty. We in America rejoice that this cause is our cause, and that at the most critical time we were able to render effective help to the staunch and brave allied forces which had fought so long and so nobly.

The object of this address is not, however, to appraise the military issues of the great war so fortunately ending, nor to deal with the weighty international problems now faced by the world, but rather to bring before you other considerations, having to do with the advancement of science.

The particular subject chosen, namely, the problem of radioactive lead, is one of peculiar and extraordinary interest, because it involves a readjustment and enlargement of many rather firmly fixed ideas concerning the chemical elements and their mutual relations, as well as the nature of atoms.

Within the last twenty years the definition of these two words, "elements" and "atoms," has been rendered somewhat uncertain, and bids fair to suffer even further change. Both of them are ancient words, and both even a century since had acquired meanings different from those of long ago. Thales thought of but one element, and Aristotle's elements—earth, air, fire, water and the quintessence, derived perhaps from yet more ancient philosophy—were not plentiful enough to account for all the manifold phenomena of nature. Democritus's old idea of the atom was asso-

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[1] Address of the President of the American Association for the Advancement of Science, Baltimore, December, 1918.

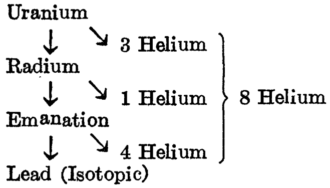
ciated rather with the philosophical conception of indivisibility than with the idea of chemical combination in definite proportions. To-day many chemists and physicists think that the chemical atoms of the last century are no longer to be considered as indivisible. In that case, the old Greek name "atom" is no longer fitting, because it denotes indivisibility. Some one has even facetiously suggested that the word "tom"—indicating divisibility—would be more appropriate! Moreover, if our so-called atoms are really divisible, we can not but be somewhat doubtful as to our definition of the ultimate elements of the universe. The reason for this new turn of thought is due, as you all know, to the discovery of the unexpected and startling phenomena of radioactivity.

To-night we have to deal with a substance directly concerned with the iconoclastic radioactive changes—with the very phenomena which cause us to stop and think about our definitions of atoms and elements. For the lead obtained from radioactive minerals appears to have resulted, together with helium, from the radioactive decomposition of elements of higher atomic weight. Skeptical at first, the whole chemical world has now come to acknowledge that the well-defined element, helium (discovered by Sir William Ramsey twenty-three years ago), is one of the decomposition products of radium. Radium itself is a substance which, in many respects, acts as an element, with 226 as its atomic weight, and must be considered as the heaviest member of the well-known calcium family; but its atoms appear to be so big and so complex as to disintegrate because of lack of stability. The disintegration is slow, and not to be hastened or retarded by any agency known to man; 1,670 years are demanded for the decomposition of half of any given portion of radium, according to the exact measurements of Professors Boltwood and Ellen Gleditsch. Moreover, we have reason to believe that this decomposition proceeds in a series of stages, successive atoms of helium (five in all) being evolved with different degrees of ease by any given atom of radium [illegible] the end most, indeed probably all, of the residual part of the radium appears to have been converted into the peculiar kind of metallic lead with which we are concerned to-night. The nature of the end-product was first suggested by Boltwood, who pointed out the invariable presence of lead in radium minerals. Thus we must accept a kind of limited transmutation of the elements, although not of the immediately profitable type sought by the ancient alchemists.

Interesting and significant as all of this is, nevertheless the whole story has not yet been told. Radium itself appears to come from the exceedingly slow decomposition of uranium, an inference drawn from the fact that radium is found only in conjunction with the uranium, which even after careful purification soon becomes radioactive and gives every indication of suffering slow disintegration. Moreover, uranium is not the only other heavy element which appears to be capable of decomposing and yielding elements of lower atomic weight. Another, thorium, has a like propensity, although the steps in this case are perhaps not so fully interpreted, nor so generally accepted. In the process of disintegration all these heavy atoms yield strange radiations, some of them akin to, or identical with X-rays, which bear away that part of the colossal energy of disintegration not made manifest as heat. These facts have been proved beyond doubt by the brilliant work of Madame Curie, Sir Ernest Rutherford, and others.

The nature of the rays, and of the highly interesting evanescent transition products and their relation to one another is too complex for discussion now. We are concerned rather with the nature of the more permanent of the substances concerned—especially with the starting point, uranium (possessing the heaviest of all atoms), radium, and the lead which seems to result from their disintegration. Omitting the less stable transition products, the most essential outcomes are roughly indicated by a sort of genealogical tree herewith shown:

HYPOTHESIS CONCERNING THE DISINTEGRATION OF URANIUM



Thus each atom of uranium is supposed to be converted into radium by losing three atoms of helium, and each atom of radium is supposed to be converted into a kind of lead by losing five more, as already stated.

If uranium can thus disintegrate, should we call it an element? and should we call its smallest particles atoms? The answers depend upon our definition of these two words. If the word "element" is supposed to designate a substance incapable of disintegration, apparently it should not be applied to uranium; neither should the word "atom" be applied to the smallest conceivable particles of this substance. But no one would now maintain that any element is really incapable of disintegration. A method of still retaining the terms in this and analogous cases is to define an element as "a substance which has not yet been decomposed artificially," that is to say, by the hand of man—and an atom as "the smallest particle of such a substance, inferred from physicochemical behavior." The atom, then, is not to be considered as wholly indivisible, but only as indivisible (or at least, as not yet divided) by artificial means. For, as in the case of radium, the disintegration of uranium can not be hastened or retarded by any known earthly agency. So long as it stays intact, the atom of uranium behaves quantitatively in the same fashion as any other atom: Dalton's laws of definite and multiple combining proportions apply without exception to its compounds. In this connection one should remember that the atomic theory, as a whole, including Dalton's and Avogadro's generalizations, is not in the least invalidated by the new discoveries of radioactivity. On the contrary, the atomic theory is entrenched to-day more firmly than ever before in its history.

Interesting speculations by Drs. Russell, Fleck, Soddy and Fajans and others have interpreted in extremely ingenious and plausible fashion the several transitory steps of the changes, and indicate the reasons why the end-products of the decomposition both of uranium and thorium should be very similar to lead, if not identical with it. Therefore a careful study of the properties of lead of indubitably radioactive origin became a matter of great interest, as a step toward confirming these speculations, especially in comparison with the properties of ordinary lead. Such investigations should throw light on the nature of radium and uranium and the extraordinary changes which those metals suffer. Moreover, by analogy, the resulting conclusions might be more or less applicable to the relations of other elements to each other; and the comparison of this new kind of lead with ordinary lead might afford important information as to the essential attributes of elementary substances in general, in case any differences between the two kinds should be found.

Before the subject had been taken up at Harvard University, chemists had already recognized the fact that the so-called uranium-lead is indeed qualitatively very like ordinary lead. It yields a black sulphide, a yellow chromate, and a white sulphate, all very sparingly soluble in water, just as ordinary lead does. Continued fractional crystallization or precipitation had been shown by Professor Soddy and others to separate no foreign substance. Hence great similarity was proved; but this does not signify identity. Identity is to be established only by quantitative researches. Plato recognized, long ago, in an often-quoted epigram, that when weights and measures are left out, little remains of any art. Modern science echoes this dictum in its insistence on quantitative data; science becomes more scientific as it becomes more exactly quantitative.

One of the most striking and significant of the quantitative properties of an element is its atomic weight—a number computed from the proportion by weight in which it combines with some other element, taken as a standard. There is no need, before this distinguished audience, of emphasizing the importance of the familiar table of atomic weights; but a few parenthetical words about their character is perhaps not out of place. As has been more than once said, the atomic weights of the relatively permanent elements, which constitute almost all of the crust of the earth, seem to be concerned with the ultimate nature of things, and must have been fixed at the very beginning of the universe, if indeed the universe ever had any beginning. They are silent, apparently unchanging witnesses of the transition from the imagined chaos of old philosophy to the existing cosmos. The crystal of quartz in a newly hewn piece of granite seems, and probably is, as compact and perfect as it was just after it was formed, eons ago. We can not imagine that any of its properties have essentially changed during its protracted imprisonment; and, so far as we can guess, the silicon and oxygen of which it was made may have existed for previous eons, first as gas, and then as liquid. The relative weights in which these two elements combine must date at least from the inconceivably distant time when the earth "was without form and void."

Although, apparently, these numbers were thus determined at the birth of our universe, they are, philosophically speaking, in a different class from the purely mathematical constants such as the relation of circumference to the diameter of a circle. 3.14159 . . . is a geometrical magnitude entirely independent of any kind of material, and it therefore belongs in the more general class of numbers, together with simple numerical relations, logarithmic and trigonometric quantities, and other mathematical functions. On the other hand, the atomic weights of the primeval elements, although less general than these, are much more general and fundamental than the constants of astronomy, such as the so-called constant of gravity, the length of the day and year, the proper motion of the sun, and all the other incommensurable magnitudes which have been more or less accidentally ordained in the cosmic system. The physicochemical constants, such as the atomic weights, lie in a group between the mathematical constants and the astronomical "constants," and their values have a significance only less important than the former.

In the lead from uranium, we have a comparatively youthful elementary substance, which seems to have been formed since the rocks in which it occurs had crystallized. Is the atomic weight of this youthful lead identical with that of the far more ancient common lead, which seems to be more nearly contemporary as to its origin with the silicon and oxygen of quartz?

The idea that different specimens of a given element might have different atomic weights is by no means new—it far antedates the discovery of radioactivity.

Ever since the discovery of the definite combining proportions of the elements and the ascription of these proportions to the relative weights of the atoms, the complete constancy of the atomic weights has occasionally been questioned. More than once in the past investigators have found apparent differences in the weights of atoms of a single kind, but until very recently all these irregularities have been proved to be due to inaccurate experimentation. Nevertheless, even thirty years ago the question seemed to me not definitively answered, and careful experiments were made with copper, silver and sodium, obtained from widely different sources, in the hope of finding differences in the atomic weights, according to the source of the material. No such differences whatever were found. More recently Professor Baxter, of Harvard, compared the atomic weights of iron and nickel in meteorites (from an unknown, perhaps inconceivably distant source) and the same terrestrial metals. In these cases also the results were negative. Thus copper, silver, sodium, iron and nickel all appeared to be perfectly definite in nature, and their atoms, each after its own kind, all alike.

The general question remained, nevertheless, one of profound interest to the theoretical chemist, because it involved the very nature of the elements themselves; and in its relation to the possible discovery of a difference between uranium lead and ordinary lead, it became a very crucial question.

Early in 1913, when the hypothesis of radioactive disintegration had assumed definite shape, Dr. Fajans's assistant, Max Lembert, journeyed to Cambridge, bringing a large quantity of lead from Bohemian radioactive sources, in order that its atomic weight might be determined by Harvard methods, with the precision attainable there. The Carnegie Institution of Washington gave generous pecuniary assistance toward providing the necessary apparatus, in this and subsequent investigations.

The most important precautions to be taken in such work are worthy of brief notice, because the value of the results inevitably depends upon them. The operation consists in weighing specimens of a salt of the element in question, and then precipitating one of the constituents in each specimen, determining the weight of the precipitate, and thus the composition of the salt. In the first place, each portion of substance to be weighed must be free from the suspicion of containing unheeded impurities, otherwise its weight will mean little. This is an end not easily attained, for liquids often attack their containing vessels and absorb gases, crystals include and occlude solvents, precipitates carry down polluting impurities, dried substances cling to water, and solids, even at high temperatures, often fail to discharge their imprisoned contaminations. Especial care was taken that each specimen was as pure as it could be made, for impurity in one would vitiate the whole comparison.

In the next place, after an analysis has once begun, every trace of each substance to be weighed must be collected and find its way in due course to the scale pan. The trouble here lies in the difficulty in estimating, or even detecting, minute traces of substances remaining in solution, or minute losses by evaporation at high temperatures.

In brief, "the whole truth and nothing but the truth" is the aim. The chemical side of the question is far more intricate and uncertain than the physical operation of weighing. The real difficulties precede the introduction of the substance into the balance case. Every substance must be assumed to be impure, every reaction must be assumed to be incomplete, every measurement must be assumed to contain error, until proof to the contrary can be obtained. Only by means of the utmost care, applied with ever-watchful judgment, may the unexpected snares which always lurk in complicated processes be detected and rendered powerless for evil.

After all these digressions, made in order that the problems concerned should be clearly recognized, let us turn to the main object of our quest. In the present case, each form of lead was first weighed as pure chloride, and the chlorine in this salt after solution was precipitated as silver chloride, the weight of which was determined. Precautions too numerous to mention were observed. Thus the weight of chlorine in the salt was found, and by difference the weight of the lead. From the ratio of weights, the atomic weight of lead was easily calculated.

The outcome of the first Harvard trials, published in July, 1914, brought convincing evidence that the atomic weight of the specimen of uranium-lead from Bohemia is really less than that of ordinary lead, the value found being 206.6, instead of 207.2—a difference of 0.3 per cent., far beyond the probable error of experiment. Almost simultaneously preliminary figures were made public by Drs. Hönigschmid and St. Horovitz and Maurice Curie, pointing toward the same verdict.

This result, interesting and convincing as it was, was only a beginning. Other experimenters abroad have since confirmed it, especially Professor Hönigschmid, who had studied at Harvard and understood the necessary refinements of analysis; and many new determinations have been made at the Wolcott Gibbs Memorial Laboratory, with the assistance of Dr. Charles Wadsworth, 3d, and Dr. Norris F. Hall, upon various samples of lead from radioactive sources in widely separated parts of the world. Messrs. E. R. Bubb and S. Radcliff, of the Radium Hill Company, of New South Wales, kindly sent a large quantity of lead from their radium mines, and a particularly valuable specimen prepared from selected crystals of pure mineral was put at our disposal by Professor Gleditsch—not to mention other important contributions from others, including Professor Boltwood and Sir William Ramsay. Each of these samples gave a different atomic weight for the lead obtained from them, and the conclusion was highly probable that they contained varying admixtures of ordinary lead in the uranium-radium-lead. This was verified by the knowledge that in at least some cases the uranium ore actually had been contaminated with lead ore. The purest Norwegian specimen thus acquired especial importance and significance, because it was only very slightly, if at all, vitiated in this way. As a matter of fact, it gave 206.08 for the atomic weight in question—the lowest of all. Here are typical results, showing the outcome; many more of similar tenor were obtained.

ATOMIC WEIGHTS

Common lead	207.20 207.19	....207.19
Australian Radioactive Lead containing probably 25 per cent. ordinary lead	206.32 206.36 206.33 206.36	....206.34
Purest Uranic-lead	206.08 206.09	....206.08

Hönigschmid, from similar pure material, had found figures (206.05) agreeing almost exactly with the last value. One can not help believing that this last specimen of lead is a definite substance, probably in a state almost pure, because of the unmixed quality of the carefully selected mineral from which it was obtained.

A further question now arises: is it a *permanent* substance—really an end-product of the disintegration? Soddy's hypothesis assumes that it is. The only important fact militating against this view is the observation that uranium-lead is always radioactive, and hence might be suspected of being unstable. In various impure specimens, however, the radioactivity is not proportional to the change in the atomic weight; hence the radioactivity is probably, at least in part, to be referred not to the lead itself, but rather to contamination with minute, unweighable amounts of intensely radioactive impurities—other more transitory products of disintegration.[2] If weighable, such impurities would almost certainly *increase*, not *diminish*, the atomic weight; hence their presence could not account for the low value.

Let us compare the actual result for the atomic weight of this kind of lead with the theory of Soddy and Fajans. If this theory is sound, the simple subtraction of eight times the atomic weight of helium from that of uranium, or five times the atomic weight of helium from that of radium, should give the atomic weight of the lead resulting from the disintegration, as follows:

HYPOTHETICAL CALCULATION OF ATOMIC WEIGHT OF URANIUM-LEAD

Atomic weight of uranium..	= 238.18		
8 × atomic weight of helium	= 32.00		
Residue (lead?)	206.18	=	206.18
Atomic weight of radium...	= 225.96		
5 × atomic weight of helium	= 20.00		
Residue (lead?)	205.96	=	205.96
Average hypothetical value for lead		=	206.07
Observed value for uranium-lead[3]..		—	206.08
Difference			0.01

The agreement is remarkably good. Each of the individual calculated values shows less than 0.05 per cent. deviation from the average, and the average itself shows essential identity with fact—a striking confirmation of the theory. This is perhaps the most successful

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[2] For this reason the term "radio-active lead" although it describes the fact, is perhaps not from a theoretical point of view the best designation of either uranium or thorium lead; but the term is convenient because it distinguishes between these two forms and common lead.

[3] This is the Harvard result. If Hönigschmid's value is given equal weight, the average observed value would be 206.07, exactly identical with the hypothetical value.

attempt on record to compute an atomic weight from hypothetical assumptions. Usually we are wholly at a loss as to the theory underlying the precise relationships, and must determine our values by careful experiment alone.

The value 206.08 for the atomic weight of lead has further support in the fact that it is more nearly half way between thallium, 204, and bismuth, 208, the two neighboring elements in the periodic system, than is the atomic weight 207.2 possessed by ordinary lead.

It appears, then, that 206, the value pertaining to uranium-lead, is a very reasonable value.

But, as has been repeatedly pointed out, ordinary lead, constituting the vast bulk of the lead in the world, has without doubt a much higher atomic weight, 207.2, not to be expected from either of the lines of reasoning just given. In order to test the uniformity of this circumstance, Professor Baxter, of Harvard, with the help of one of his assistants, investigated ordinary lead from non-uraniferous ores from many parts of the world, and discovered that the constancy of its quantitative behavior is as striking as that of copper or silver. His figures agreed very closely, within the limit of error of experimentation, with those obtained as a part of the present comparison of the two kinds of lead, so that there could be no question as to lack of identity of methods or precautions.

Before leaving the subject of the relative atomic weights of these two types of lead, it is not without interest to note the exact absolute weights of the atoms. If, as we have excellent reason for believing on the basis of the brilliant work of Professor R. A. Millikan, a so-called gram-atom (the atomic weight in grams) contains 606.2 sextillion actual atoms, the weights of the atoms of the two kinds of lead must be respectively 342 and 340 septillionth of a gram. Their extreme smallness, as regards bulk, may perhaps best be inferred from the consideration that the smallest object visible as a point in the common microscope has a diameter probably about one thousand times as great as an atom of lead.[4]

Evidently, on the basis of the quantitative results just exhibited, we must admit that there is at least one real difference between radioactive lead and the common metal. Are there other differences?

A question as to the density of each substance, and therefore as to the bulk occupied by the respective atoms, at once arises. Since the atom of uranium-lead weighs less than the other, it must occupy less space, supposing that it has the same density; or else it must have less density, supposing that it should occupy the same space. The identity of the chemical behavior of the two types of lead suggests the probability of the latter alternative, and this was therefore assumed by Soddy; but experimental proof was evidently desirable. Therefore an extended investigation of the density of the various kinds of lead was carried out likewise in the Gibbs Memorial Laboratory. As a matter of fact, the densities of the several specimens were found to be very nearly proportional to their atomic weights; that is to say, the bulk of the atom of radioactive lead is almost exactly the same as the bulk of the atom of ordinary lead, although the weights of these atoms are so markedly different.

DENSITIES AND ATOMIC VOLUMES

	Automatic Weight	Density	Atomic Volume
Pure uranio-lead	206.08	11.273	18.281
Australian mixture	206.34	11.289	18.278
Pure common lead	207.19	11.337	18.277

A distinctive property of elementary substances, which has always been supposed to be concerned more or less definitely with the atomic weight, is the spectrum, depending upon the wave-lengths of light emitted by the vapor. But, surprisingly enough, the spectrum lines produced by these two sorts of lead, when heated to the high temperature of the electric arc, are so precisely alike, both as to

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[4] If the smallest object visible in a microscope could be enlarged to the width of this printed page, the atoms in it would appear about the size of the dots on the letters i, or the periods, in the type above.

their wave-lengths and their intensities, that no ordinary spectrum analysis shows any difference whatever. This has been proved by careful experiments at Harvard and elsewhere, and is made obvious by the photographs now thrown on the screen. A and B were from two different specimens of radioactive lead, C from ordinary lead, all very carefully purified. The range covered is about from 3,000 to 2,000 wave-length—far in the ultra-violet. Very recently Professor W. D. Harkins, of Chicago, and two assistants, have detected, with a very extended grating spectrum, an exceedingly minute shift (0.0001 per cent. of the wave length—an amount far too small to be shown by the spectra exhibited) of one of the lines. The wonder is, not that there should be a difference, but rather that they should be so very nearly identical. Evidently the very considerable difference in the atomic weight produces only a barely perceptible effect on the wave-lengths of light emitted by the several isotopic forms of a given element, although a less difference in atomic weight between two different elements (for example, cobalt and nickel) is concomitant with utterly divergent spectra.

Another very interesting question, involving the relations of substance both to light and to weight (or rather density) is its refractive index. All the formulæ relating to molecular refraction involve the *density* of the substance concerned. In the case under consideration, do the differing weights of the atoms, and therefore the differing densities of the same compounds of the two kinds of lead, affect the refractive indices of the salts? It the refractive index of a given salt of radio lead identical with that of the same salt of ordinary lead? Evidence on this point would go far to decide whether density or atomic volume is the more important thing in determining refractive index. A very careful study carried out with the help of Dr. W. C. Schumb at Harvard has within the past few months shown that as a matter of fact the refractive index or ordinary lead nitrate is identical with that of the nitrate of radiolead within one part in nearly twenty thousand, a result which shows that density is a less important factor in deterining refractive index than had been previously assumed.

Both of these conclusions concerning light—that drawn from the spectra and that drawn form the refractive indices—have a yet more far reaching interest, for they give us a further clue as regards the innermost nature of the atom. That part of the atom which determines its weight seems to have, at least in these cases, very little effect on that part of the atom which determines its behavior toward light.

Immediately connected with the question of density of the solid salts is the question as to the densities of their saturated solutions, as well as to the extent of saturation. Fajans and Lembert had recently obtained results probably indicating that the molecular solubility of each kind of lead is the same, and that the densities of the solutions are different, the density of the radiolead solution being less to an extent consistent with its smaller molecular weight. These results, however, left much to be desired in the way of accuracy, and needed verification. Therefore a very careful investigation, begun at Harvard with the assistance of Schumb, before the appearance of Fajan's publication, furnished valuable knowledge on this point.

SOLUBILITY OF TWO KINDS OF LEAD NITRATE*

	Common Lead	Uranium Lead
Per cent. salt in saturated solution (25.00°)	37.342	37.280
Grams lead per 100 grams water	37.28	37.130
Molecular solubility per 1,000 grams water	1.7993	1.7989

Here, again, differences in weight alone are manifest, and these are proportional to the differences in the atomic weights; the molecular behavior is essentially identical in the two sorts.

The identity in solubility might also be inferred from the impossibility of separating the

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* The uranium lead used in these determinations was a specimen from Australia having the atomic weight 206.41, not quite like the earlier sample, but not different in important degree.

two kinds of lead from each other by fractional crystallization. This was predicted by Soddy, and tested by him and by others. Various vain attempts have been made to separate the different kinds of lead from one another, but apparently when once they are mixed, no chemical method can separate them, since the properties of the different kinds are so nearly alike. The latest attempt at the Gibbs Memorial Laboratory involved one thousand fractional crystallizations of the Australian lead nitrate, which is believed to contain both ordinary and uranium-radium-lead. The extreme fraction of the crystals (representing the least soluble portion, if any difference in solubility might exist) gave within the limit of error the same atomic weight as the extreme fraction of the mother liquor (representing the most soluble portion), thus confirming the work of others in this direction.

When wires constructed of two different metals are joined, and the junction heated, an electrical potential or electromotive force is produced at the junction. This property seemed, then, to be a highly interesting one to test, in order to find out how great may be the similarity of the two kinds of lead. In fact, wires made of radioactive lead and ordinary lead tested in the Gibbs Laboratory gave no measurable thermoelectric effect, the wires acting as if they were made of the same identical substance, although the atomic weights and densities were different. No other known case of this sort is known, so far as I am aware. The melting points of the two kinds of lead were likewise found, with the assistance of N. F. Hall, to be identified within the probable accuracy of the experiment.

Let us bring all these results together into one table, so that we may better grasp their combined significance.

Summed up in a few words, the situation appears to be this: At least two kinds of lead exist: one, the ordinary metal disseminated throughout the world, in non-uraniferous ores; another, a form of lead apparently produced by the decomposition of uranium, radium being one of the intermediate products. If we leave out of consideration the probably inessential difference in radioactivity, the two kinds are very closely if not exactly alike in every respect, excepting atomic weight, density and immediately related properties involving weight, such as solubility. Thorium lead appears to be a third variety, with similar relations. Shall we call these substances different elements, or the same? The best answer is that proposed by Soddy who invented a new name, and called them "isotopes" of the same element.

COMPARISON OF PROPERTIES OF DIFFERENT KINDS OF LEAD[5]

	Common Lead	Mixture (Australian)	Uranio-Lead	Percentage Difference	
	A	B	C	A–B	A–C
Atomic weight..	207.19	206.34	206.08	0.42	0.54
Density........	11.337	11.289	11.273	0.42	0.56
Atomic volume..	18.277	18.278	18.281	0.01	0.02
Melting point (absolute)....	600.53	600.59	—	0.01	—
Solubility (metal as nitrate)....	37.281	37.130	—	0.41	—
Refractive index of nitrate	1.7815	1.7814	—	0.01	—
Thermoelectric effect	—	—	—	0.00	—
Spectrum wave length	—	—	—	0.00	0.00

Since every new fact concerning the behavior of the elements gives a new possible means of discovering something about their nature, and since these facts are of especially significant kind, the anomaly is of more than passing interest, and may be said to constitute one of the most interesting and puzzling situations now presented to the chemist who looks for the deeper meanings of things.

Many new queries arise in one's mind from a study of the data. Among them is a question as to the nature of ordinary lead, which possesses a less reasonable atomic weight than the radioactive variety. Why should this state of things exist?

Ordinary lead may be either a pure substance, or else a mixture of uranium-lead with lead of yet higher atomic weight, perhaps 208. The latter substance might be formed, as

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[5] For the sake of better comparison, all the results given are those obtained at Harvard. No results of experiments elsewhere are inconsistent with these.

Soddy points out, if thorium (over 232) lost six atoms of helium, and he and Hönigschmid have found quantitative evidence of its existence in thorium minerals.

After reviewing all the data, Professor F. W. Clarke has brought forward an interesting and reasonable hypothesis explaining the difference between the several kinds of lead. He points out that whereas we have every reason to believe that uranium and thorium lead are the results of disintegration of heavier atoms, ordinary lead may be imagined to be the product of a far earlier synthesis or evolution from smaller atoms. The hypothesis might be supported by the analogy of the synthesis and decomposition of organic substances, which by no means always follow similar paths; it seems to be consistent with most, if not all, of the facts now known.

On the other hand, may not the uniformity of ordinary lead and its difference from either of the radioactive leads be almost equally capable of interpretation in quite a different fashion? Whenever, in the inconceivably distant past, the element lead was evolved, it is hardly to be supposed that uranium-lead and thorium-lead could have been entirely absent. The conditions must have been chaotic and favorable to mixture. When the two or more forms were mixed, none of the processes of nature would separate them. Therefore they must appear eons afterwards in an equably mixed state on earth, constituting our ordinary lead. There may have been more than two forms of lead; but two forms, one possessing an atomic weight 206 and the other, an atomic weight over 208, would account for all the facts. The identity in nature of all the common lead on earth might indicate merely that one time all the matter now constituting the earth was liquid or gaseous in violent agitation, so that all the kinds of lead were thoroughly commingled before solidification. This explanation, if it could be confirmed, would furnish important evidence concerning the early history of planets. So far afield may a difference in weight amounting to two units in the twenty-fourth decimal place, between two kinds of atoms so small as to be far beyond the possible range of our most piercing means of actual observation, carry the inquiring investigator!

The true answers to these questions are not to be found by speculation, such as that just detailed, however suggestive such speculation may be. They are to be found by careful observation. For example, the doubt as to the nature of ordinary lead can only be decided by discovering whether or not it may be separated into two constituents. Since weight (or mass) is the quality distinguishing between the several isotopes or kinds of lead, weight (or mass) must be made the basis of separation. Hence the only hope of separating isotopes of lead lies in the method of fractional diffusion, as has been already suggested by many other experimenters on this subject. Promising preliminary experiments preparatory to such an undertaking have already been begun at Harvard, and before long more light may be obtained.

The idea that other elementary substances also may be mixtures of two or more isotopes has been advanced by several chemists. Especially if ordinary lead should really be found to be thus complicated, many, if not all, other elements should be tested in the same way. The outcome, while not in the least affecting our table of atomic weights as far as practical purposes are concerned, might lead to highly interesting theoretical conclusions.

How can such remote scientific knowledge, even if it satisfies our ever-insistent intellectual curiosity, be of any practical use? Who can tell? It must be admitted that the relationship is apparently slight as regards any immediate application, but one can never know how soon any new knowledge concerning the nature of things may bear unexpected fruit. Faraday had no conception of the electric locomotive or the power-plants of Niagara when he performed those crucial experiments with magnets and wires that laid the basis for the dynamo. Nearly fifty years elapsed before his experiments on electric induction in moving wires bore fruit in a practical electric lighting system; and yet more years before the trolley car, depending equally upon the principles discovered by Faraday, became an everyday occurrence. At the time of discovery, even if the wide bearing and extraordinary usefulness of his experiments could have been foreseen by him, they were certainly hidden from the world at large.

The laws of nature can not be intelligently applied until they are understood, and in order to understand them, many experiments bearing upon the fundamental nature of things must be made, in order that all may be combined in a far-reaching generalization impossible without the detailed knowledge upon which it rests. When mankind discovers the fundamental laws underlying any set of phenomena,these phenomena come in much larger measure than before his control, and are applicable for his service. Until we understand the laws, all depends upon chance. Hence, merely from the practical point of view, concerning the material progress of humanity, the exact understanding of the laws of nature is one of the most important of all the problems presented to man; and the unknown laws underlying the nature of the elements are obviously among the most fundamental of these laws of nature.

Such gain in knowledge brings with it augmented responsibilities. Science gives human beings vastly increased power. This power has immeasurably beneficent possibilities, but it may be used for ill as well as for good. Science has recently been blamed by superficial critics, but she is not at fault if her great potentialities are sometimes perverted to serve malignant ends. Is not such atrocious perversion due rather to the fact that the ethical enlightenment of a part of the human race has not kept pace with the progress of science? May mankind be generous and high-minded enough to use the bountiful resources of nature, not for evil, but for good, in the days to come!

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PROCEEDINGS OF THE BALTIMORE MEETING OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

THE seventy-first meeting of the American Association for the Advancement of Science was held at Baltimore from December 23 to 28, and in view of the unusual conditions it has been a decided success. It will be remembered that the meeting place was changed from Boston to Baltimore, partly because war conditions had brought together at Washington scientific men from all over the country, and it was planned to have a brief compact program devoted to war issues and topics more intimately pertinent to the immediate welfare of the country. While it was not feasible to have the meetings in Washington, it was thought that members in Washington might be able to attend meetings at Baltimore, but a short distance away.

With the sudden termination of hostilities the problems confronting the scientific workers have to a large extent either suddenly changed their nature altogether or have been considerably modified and, although but a short time has intervened since the signing of the armistice, the nature of the contributions and discussions in the various meetings shows a quick recognition and adjustment to these changed conditions.

The rapid release of men by demobilization and the prevalent less congested conditions as to university buildings and hotel accommodations have apparently been partly responsible for the surprisingly large enrollment. The opening meeting at McCoy Hall on the evening of December 26 had an attendance of about four hundred people, and the total registration for the week was seven hundred and twenty-eight, which did not include some of the members of the various affiliated societies. At the opening meeting Dr. Edward L. Nichols announced that the address of the retiring president of the association, Dr. Theodore W. Richards, on "The Problems of Radioactive Lead" would not be given, Dr. Richards being