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THE ALCHEMIST[1]

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BUREAU OF STANDARDS

THE volumes on alchemy in our large libraries may be counted by the hundreds. Innumerable tracts and treatises filled with the most incomprehensible nonsense ever written have appeared in Spanish, Italian, German, Dutch, English, Arabic, Persian and Latin. The name alchemy is probably of Arabic origin, dating from the eighth century, the prefix "al" being Arabic for "the" and "chema," meaning to hide. Alchemy accordingly denotes "the hidden science." The prefix *al* occurs in many of our scientific words; alcohol, *the* burning liquid; alkali, *the* acrid substance; algebra, *the* reunion, and many others.

The scope of alchemy is a disputed question. According to the transcendental theory, it did not purport to be a science at all, but rather was concerned with man's soul. Its object was the perfection, not of material substances, but of man in the spiritual sense, a branch of mysticism in which transmutation was symbolical of the salvation of humanity.

However, most of the alchemists themselves were of the opinion that the primary object of their endeavors should be confined to the production of gold. These were the real alchemists in which we are now interested. Of such there were naturally two types. There was the knavish, corrupt alchemist, who, as Rodwell[2] says, had brains enough to perceive that his search was futile and utilized his wits to dupe more credulous people, wheedling their fortunes out of them on pretense of returning it tenfold. Modernized, these men are our successful oil-stock promoters. They abounded during the Middle Ages and became immensely wealthy by such shallow tricks as the secretion of a piece of real gold in the crucible in which the pretended transformation was taking place.

Then there were the alchemists proper, ardent, persevering

[1] Published by permission of the Director of the Bureau of Standards, Department of Commerce.

[2] Rodwell—"The Birth of Chemistry," MacMillan, 1874. This book and Redgrove's "Ancient and Modern Alchemy," Rider and Son, 1911 and 1923, contain excellent historical summaries. Several of the alchemical illustrations in the present paper were taken from these two books rather than from the original sources. Rodwell's work is especially interesting because it was written nearly fifty years ago when the atom was considered the ultimate unit; when the subject of alchemy stood in extreme disrepute.

FIG. 1. HERMES, FROM THE TEMPLE OF PSELCIS

The alchemical writers of the middle ages claimed every great man and deity of antiquity as of their number, although alchemy was practically unknown prior to the eighth century. We derive our expression "hermetically sealed" from the alchemical use of the name Hermes.

workers, who believed heart and soul that gold could be made and that by long search or diligent study of the unintelligible works of their predecessors they could discover the philosopher's stone. Poor misguided wretches—they have now become chemists, for the science, or rather art, of chemistry owes its origin to the labors of these honest men.

Honest?—only in the relativity sense, however! One needs merely to read a dozen volumes or so of their testimonials to realize that the world is growing better. For example, Magnus, of the thirteenth century, could instantly transform a winter's day into glowing summer, an accomplishment fully described by many writ-

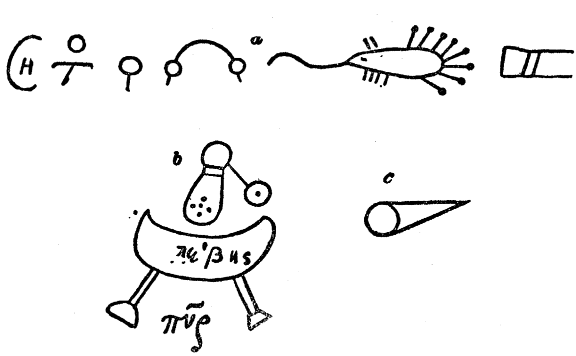
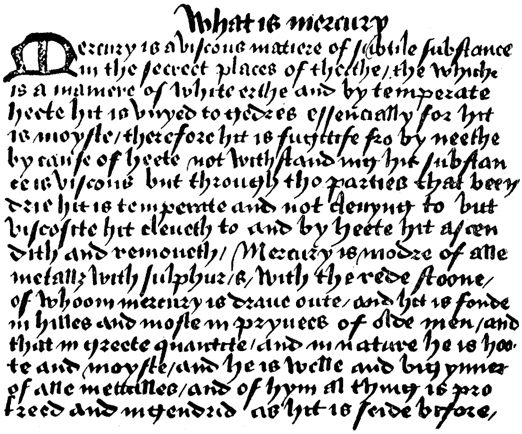


FIG. 2. AN ALEMBIC AND SYMBOLS FROM A GREEK MANUSCRIPT ON ALCHEMY



What is mercury

Mercury is a viscous matiere of subtile substance in the secreet places of therthe, the whiche is a maniere of white erthe and by temperate heete hit is brought to degrees essencially for hit is moyste, therefore hit is fugitife fro by neethe by cause of heete not withstandyng hit substance is viscous but through tho parties that been dire hit is temperate and not cleuyng to but viscosite hit cleueth to and by heete hit ascendith and remoueth, Mercury is modre of alle metallz with sulphur is, with the rede stoone of whoom mercury is drawe oute, and hit is founde in hilles and moste in pryuees of olde men, and that in greete quantite, and in nature he is hoote and moyste, and he is welle and bigynner of alle metalles, and of hym al thing is procreed and engendred as hit is seide before,

Fig. 3. English Manuscript on Alchemy dating from the Fifteenth Century

ers and witnesses. His pupil, Thomas Aquinas, constructed a bronze statue which Magnus animated with his elixir of life. This statue was useful as a domestic servant, but was very noisy and talkative. Finally, Aquinas was forced to punish it severely with a hammer in order to continue his studies in quiet. Lulli, a contemporary, converted 50,000 pounds of base metal into the purest of gold and was employed by one of the Kings Edward to replenish the exchequer. This he did to the extent of 30 millions of dollars in synthetic gold bullion. Henry VI granted patents to alchemists on the processes involved in the manufacture of philosopher's stones. In 1404 the making of gold and silver was forbidden by

Fig. 4. An Alchemist Hermetically sealing a Flask containing the Elixir of Life

Note the symbol for the sun, representing gold.

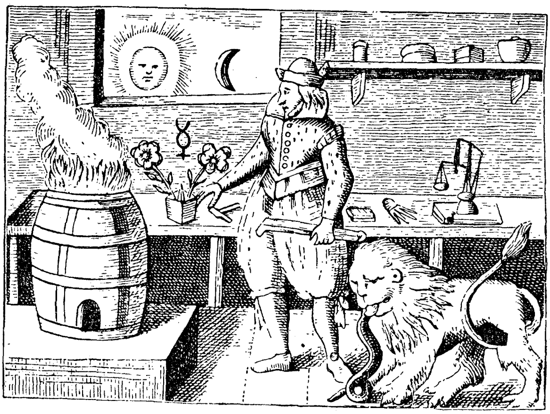


FIG. 5. AN ALCHEMIST'S METHOD FOR EXPLAINING CHEMICAL REACTIONS

Note the symbols for gold (sun), silver (moon) and mercury. The lion devouring the snake represents an acid dissolving a salt.

Act of Parliament. To such dangerous proportions had the industry developed that the welfare of the state was threatened.

There is no doubt that the true alchemists, like the modern scientist, were much overworked individuals. Paracelsus affirms that "they diligently follow their labors, sweating whole days and nights by their furnaces. They do not spend their time abroad for recreation but take delight in their laboratory. They wear leather garments with a pouch, and an apron wherewith they wipe their hands. They put their fingers amongst coals, into clay and filth, not into gold rings. They are sooty and black like smiths and colliers and do not pride themselves upon clean and beautiful faces."

Let us peep into the laboratory—"a gloomy dimly lighted place full of strange vessels and furnaces, melting pots, spheres and portions of skeletons hanging from the ceiling; the floor littered with stone bottles, alembics, great parchment books covered with hieroglyphics; the bellows with its motto Spira Spera (breathe and hope); the hour glass, the astrolabe, and over all cobwebs, dust and ashes. The walls are covered with various aphorisms of the brotherhood; legends and memorials in many tongues. Look at Faust as depicted by Rembrandt for a truly alchemical interior."

Alchemy as practiced during the middle ages was the logical outgrowth of accepted philosophical thinking, which dated from the fifteenth century B. C. and was given new impulse by Aristotle in the fourth century B. C. This theory postulated four elements, earth, fire, air and water. Gradually, the terms assumed a broader meaning. All incandescent objects, lightning, electrical sparks, were represented as fire. Smoke, steam, vapors and gases were called air. Water included all liquids, blood, milk, and later solutions and acids, terminology now surviving in aqua fortis, aqua regia, eau de vie. Any solid was an earth, and to-day we have the *earth metals* and the *rare earths* as a result of this early usage. The general idea of four elements was not disproven until a century and a half ago, when air was found to be a mixture of two (later several) gases, fire the result of intense chemical action and earth a mixture of many elementary materials.

With these hypotheses, transmutation was experimentally demonstrable. Fire converts water into steam or air. The alchemists therefore reasoned, plausibly enough, if water can become air why may not one metal, which was supposed to be compounded of these elements in certain proportions, be changed into another metal compounded of the same elements in a different proportion. Admitting the possibility of the process, it is not strange that men attempted to produce gold. Gold has been valued since the earliest antiquity on account of its peculiar color, its luster, its unalterability in air, and especially its rarity as compared with other commodities. For its procurement, the lives of millions of men have been sacrificed in battle, in the forever distant past, praise Heaven!

It is useless to describe the methods which the alchemist employed in carrying out his prolonged attempts at transmutation. The intricate processes were subdivided into twelve groups technically known as calcination, dissolution, separation, conjunction, putrefaction, congelation, cibation, sublimation, fermentation, exaltation, multiplication and projection. A misstep at any stage in the development was fatal to the process and all the fruit of months of toil was lost in a single moment. The modern chemist or physi-

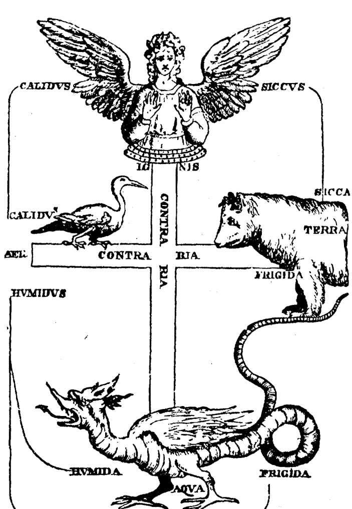


FIG. 6. AN ALCHEMICAL REPRESENTATION OF TRANSMUTATION

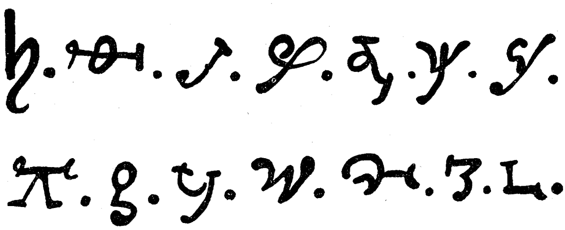


FIG. 7. SYMBOLS FOR LEAD FROM AN ITALIAN MANUSCRIPT OF THE SEVENTEENTH CENTURY

cist carries through no more elaborate experiments than those of the early alchemists.

The mystical language which these savants adopted was intended to prevent the vulgar from acquiring the results of their long-continued labors. This obscurity led to multiplication of symbols which were nearly as voluminous as those employed in astrology. In a single Italian manuscript the element mercury is represented by 22 different symbols and by 33 different names.

To illustrate how utterly nonsensical and unintelligible alchemical language could be and generally was, we quote from Paracelsus, one of the greatest alchemists of the sixteenth century:

> The life of metals is a secret fatness; . . . of salts, the spirit of aquafortis; . . . of pearls, their splendor; of marcasites and antimony, a tinging metalline spirit; . . . of arsenics, a mineral and coagulated poison. The life of all men is nothing else but an astral balsam, a balsamic impression, and a celestial invisible fire, an included air and a tinging spirit of salt. I can not name it more plainly although it is set out by many names.[3]

Figs. 1 to 7 show several typical illustrations from the early alchemical literature. The interpretation of these fanciful drawings is difficult and has proven a matter of some discussion and variance of opinion. Figs. 5 and 6 are more directly related to the transcendental or mystic aspect of the art of alchemy. Ancient books on alchemy are literally filled with allegorical pictures of this character, many of which are in color and artistically decorated.

MODERN ALCHEMY

Let us pass over a period of two hundred years and consider the subject of modern alchemy. The new developments are due to the great strides made during the past twenty years in our knowledge of atomic structure. Fig. 8 shows a photomicrograph of a copper ingot magnified 250 times. This beautiful structure is also characteristic of gold. Such photomicrographs enable the metallurgist

[3] Paracelsus, De Natura Rerum.

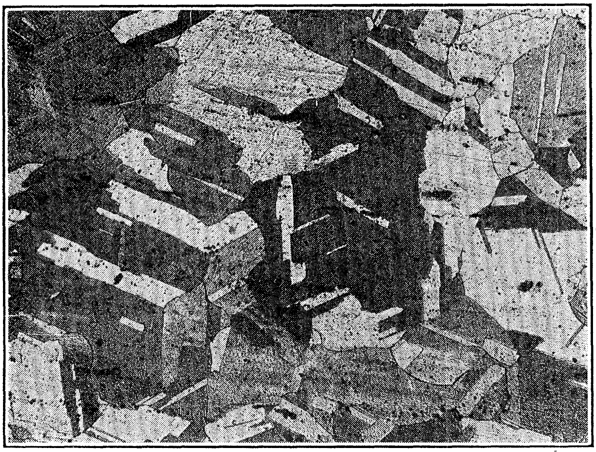


FIG. 8. PHOTOMICROGRAPH OF COPPER, MAGNIFICATION × 250 (RAWDON AND LORENTZ)
Gold presents a similar crystal structure.

to determine whether or not a metal or alloy has the proper constitution or has been given a specified heat treatment.

Now by the aid of a supermicroscope we shall magnify a sample of gold thirty million diameters, Fig. 9. We see a space-lattice arrangement of solid spheres, each sphere an atom of the precious metal. Elastic vibration of these spheres about their positions of equilibrium accounts in a qualitative way for the specific heat of gold. The entire structure of the kinetic theory owes its success to the fact that atoms, magnified as shown, by virtue of their electric forces, do approximate hard spheres or billiard balls, especially in gases where their separation is many times that here illustrated.

We shall now use an objective of higher power and magnify a single atom 240 million times, Fig. 10. This is an atom of copper. We have a planetary system consisting of a positively charged sun

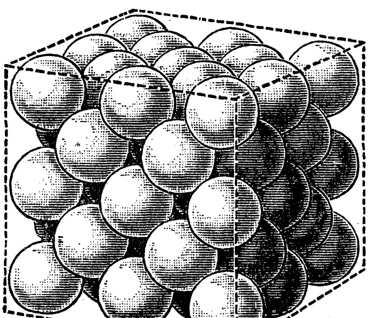


FIG. 9. GOLD MAGNIFIED THIRTY MILLION DIAMETERS
Each sphere represents an atom.

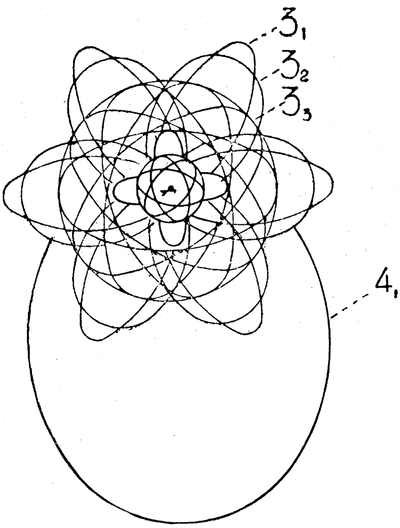


FIG. 10. AN ATOM OF COPPER MAGNIFIED 240 MILLION TIMES

There are 29 elliptical orbits each one occupied by a single electron. Gold has a similar general appearance but its inner structure is much more complicated by the presence of 50 additional orbits. The original drawing and model are due to Bohr.

surrounded by revolving planets or electrons. Each elliptical orbit is occupied by a single electron. Copper possesses a nucleus carrying a positive charge of 29 units and a planetary system of 29 revolving electrons. Gold has a positive nucleus of 79 units with 79 electrons, each revolving in its own elliptical orbit. Nearly all the mass of any atom is contained within the nucleus. The surrounding electrons contribute practically nothing to the total atomic mass, and yet the nucleus is so small as to be scarcely representable on this scale of magnification. The electrons revolving in the outer elliptical orbits are responsible for the ordinary spectrum of an element and for its chemical and physical behavior; the electrons on the inner orbits give rise to x-ray spectra. The net positive charge on the nucleus is numerically equal to the atomic number of an element, or to the ordinal number characterizing its position in the Periodic Table; 1 for hydrogen, 2 for helium, 10 for neon, 79 for gold and 92 for uranium.

The nucleus also has a very complicated structure. The sun in the atomic solar system is itself a planetary system built up of hydrogen suns, helium suns and electrons. Our microscope has not sufficient resolving power to clearly indicate the configurations which these three units assume when grouped together to form the nucleus of a heavy atom such as gold. Fig. 11 shows the sun of the helium atom magnified four thousand billion diameters. It con-

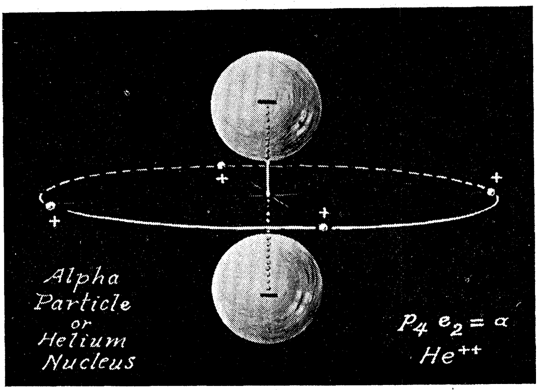


FIG. 11. THE SUN OR NUCLEUS OF A HELIUM ATOM MAGNIFIED 4,000 BILLION DIAMETERS (Drawn by H. D. Hubbard)

sists of four minute hydrogen nuclei and two relatively large electrons. Now the sun in an atom of gold may have 49 of these helium suns, one extra hydrogen sun and 20 electrons, all packed in the space of 30 billionth billionth billionth billionth of a cubic centimeter. Alchemy is concerned with reactions involving the disintegration of these minute nuclear suns.

Nature has always performed transmutations of the elements, but these were not noticed by scientists until 1896, when the discovery of radioactivity was made. Since then we have isolated about 40 radioactive atomic species each with well-known physical and chemical properties and each with a definite and characteristic kind of radioactivity. All in this group have atomic weights lying between about 200 and 238, and hence are our heaviest elements.

One of these elements is radium, which chemically and physically resembles barium and which belongs to the second Group of the Periodic Table. This atom possesses a planetary system of 88 electrons revolving about a complicated nucleus having a net positive charge of 88 units, as shown in Fig. 12. The nucleus is located at the center of the configuration, but is too small to appear in the figure. Now every once in a while a radium atom spontaneously ejects a particle from its nuclear structure. This particle, which is known as an α-ray, is emitted with a velocity of about 10,000 miles per second, or twenty thousand times greater than that of the swiftest rifle bullet. Mass for mass, its energy of motion is four hundred million times greater than that of the bullet.

The atom of the metal radium which emitted this α-particle is no longer radium.[4] It has been transmuted into an atom of a gas

[4] The "mortality" of radium atoms is 4 "deaths" per 10,000 per year; that of human beings is around 140.

called niton or radium emanation, belonging to the family of rare gases, helium, neon, argon, etc. Niton consists of a nuclear structure containing a net positive charge of 86 units surrounded by 86 planetary electrons. The schematic representation of these orbits is similar to that of Fig. 12 except the two orbits extending to the extreme upper right and left hand corners of the illustration are absent. The real difference between neon and radium, however, is due to the transformation which has taken place in the nuclear structure. One may remove the two protruding orbits (the valence electrons) of radium without producing niton. This is possible in a simple chemical reaction.

The atoms of the gas niton similarly explode once in a while and each atom emits an α-particle from its nucleus with a definite velocity, while the parent gaseous atom is transmuted into an atom of a new material, a solid, having the chemical properties of an element in the sixth group of the Periodic Table. And so the process continues as will appear later.

If these α-particles are allowed to strike a photographic plate, fogging is produced. If they fall on a fluorescent screen, such as zinc sulphide, they give rise to luminosity or scintillations, an effect which may be seen in the spinthariscope. If they pass through a gas they are capable of rendering the gas electrically conducting. It is because of these properties that the α-particle may be easily studied. In this way we have determined the following facts:

(1) By observing the deflection of the α-particles in electric and magnetic fields we learn that the particle carries a positive charge, and the velocity with which the particle is projected is characteristic of the parent atom.

(2) By counting the scintillations produced by a definite amount of radioactive material upon a screen of a definite size we

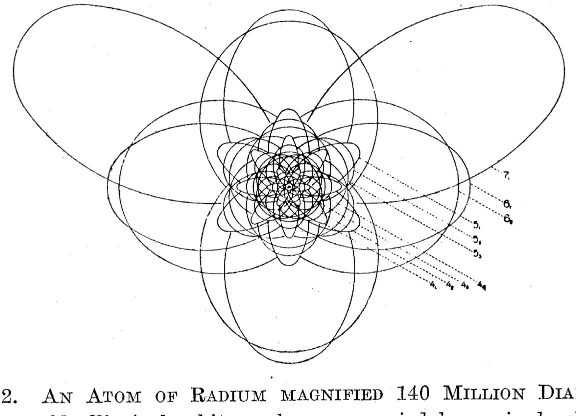


FIG. 12. AN ATOM OF RADIUM MAGNIFIED 140 MILLION DIAMETERS
There are 88 elliptical orbits each one occupied by a single electron.
Original drawing and model are due to Bohr.

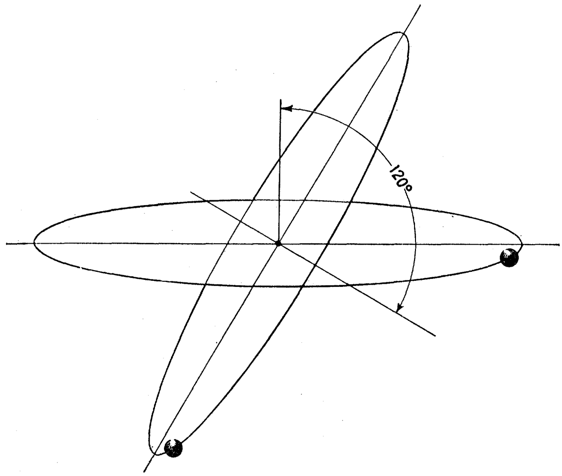


FIG. 13. KEMBLE-BOHR MODEL FOR THE HELIUM ATOM MAGNIFIED ONE BILLION DIAMETERS

The small dot in the center is the α-particle of which Fig. 11 is a magnified picture.

are able to determine the number of α-particles which the material emits per second.

(3) By collecting these particles in a suitable electrical apparatus we may measure their total charge and hence the charge on a single α-particle. This is found to be two units of positive electricity.

(4) Knowing the charge, it is possible to determine the mass of the α-particle by measuring its deflection in electric and magnetic fields. The mass so observed is 4 relative to oxygen 16. That is, the mass of an α-particle is the same as the mass of a helium atom.

(5) The α-particle is capable of passing through very thin glass. If a quantity of niton gas is compressed and sealed in a thin glass bulb and this bulb is placed inside a larger evacuated and sealed bulb, having heavy walls, it is found that the pressure in the outer bulb gradually increases as the α-particles penetrate into the space. After a few days enough gas accumulates so that an electrical discharge may be passed through it. The spectrum reveals the newly formed gas as pure helium. Hence not only does the α-particle have the same mass as a helium atom, but it *is* a helium atom, from which the two outer planetary electrons have been removed. The α-particle or helium nucleus in the outer bulb immediately picks up two electrons and becomes an ordinary helium atom as shown in

Fig. 13. The small dot in the center is the α-particle or helium nucleus of which Fig. 11 is a magnified picture.

The atomic weight of radium is 226. An atom of radium emits an atom of helium of weight 4 and is transmuted into an atom of the rare gas niton of atomic weight 222. This gas emits helium and is transmuted into RaA, a solid weighing four units less, namely, 218; RaA emits helium and is transmuted into RaB of weight 214. RaB does not emit helium, yet it also is transmuted into a new element called RaC, this time however without change in weight. Experiments similar to those performed with α-rays show that when RaB is transmuted into RaC, an electron is emitted with a velocity three quarters that of light. Since the mass of an electron is inappreciable compared to that of the nucleus of a heavy atom, the ejection of this high velocity electron or β-particle does not alter the mass of the parent atom.

We have in radioactive transformations, accordingly, two general processes, one in which an α-particle or helium nucleus is emitted and the other in which a high speed electron or β-particle is projected from the nucleus of the parent atom. Since an α-particle has two units of positive charge, the total net charge on the nucleus of a radioactive atom decreases by two units after the ejection of an α-particle. The atomic number of the transmuted element is accordingly two units less than that of its parent. The new element belongs to the family two columns to the left in the Periodic Table. When a β-particle is emitted, the nucleus loses one unit of negative charge. The net positive charge therefore increases by one unit; the atomic number increases by one; and the new element belongs to the family one column to the right of its parent in the periodic table.

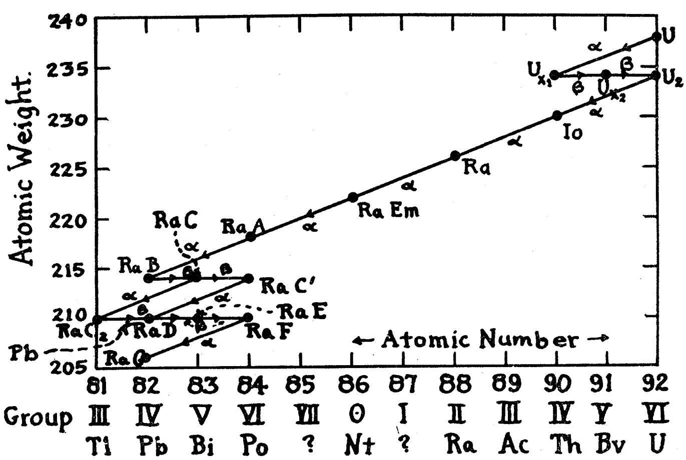


FIG. 14. TRANSMUTATION PRODUCTS OF URANIUM BY RADIOACTIVE DISINTEGRATION

Fig. 14 illustrates this clearly for the entire radioactive group related to radium. Here we have plotted atomic number versus atomic weight. Uranium, a metal of Group VI, atomic number 92, atomic weight 238, emits a helium nucleus and becomes an atom called UX_I, for lack of a better name, a material belonging to Group IV, identical chemically to ordinary thorium and having an atomic number 90 and atomic weight 234. Then follows the emission of two β-particles resulting in U_{II}, an isotope of uranium and exactly similar to uranium except that it weighs four units less. Uranium II is transmuted into ionium and helium; ionium is transmuted into radium and helium; radium is transmuted into niton and helium; niton is transmuted into radium A and helium; radium A is transmuted into radium B and helium. Up to this point the original atom has emitted 6 α-particles. The atomic weight of radium B is accordingly $4 \times 6 = 24$ units less than that of its first ancestor, uranium, or 214. Radium B then emits a β-particle becoming radium C without change in mass. Here it has a choice in regard to its mode of disintegration. Radium C which is chemically identical to bismuth may emit a helium nucleus and become RaC″ which is chemically identical to thallium, or it may emit a β-particle and become RaC′. Whichever course the atom decides to take, it eventually becomes RaD, an isotope of lead, and then, after the successive emission of two β-particles and one α-particle, the spontaneous disintegration is brought to a close with RaG or lead.

What a wonderful history this lead atom has had! Nature has produced from the uranium atom 15 different atomic species besides eight atoms of helium. Nine of these products may be differentiated by ordinary chemical or spectroscopic analysis; the others are isotopes of some of these fundamental nine, elements of different mass but having the same chemical properties. After being subjected to internal revolution after revolution the torn and distracted uranium atom finds haven as an atom of lead. Only so far as Mother Nature is concerned, however, for it is the intention of the alchemist to continue this process of trial and tribulation in order that lead may be transmuted into gold.

We have described but one family of the radioactive metals. There are two other families, one known as the thorium series and the other as the actinium series. The general mode of disintegration is similar to that of the uranium series. Thorium is transmuted successively into one element after the other, finally becoming lead. Actinium likewise is transmitted into a series of elements and here again the series is closed, as far as Mother Nature is concerned, with the comparatively worthless metal lead. Besides these transformations, potassium and rubidium emit β-rays, probably becoming calcium and strontium respectively. There is further the possibility that many of the other elements are radioactive but to so slight a degree that the effect is not definitely measurable. Certain experiments have indicated merely the suspicion of radioactivity in ordinary laboratory apparatus, which of course may be due to the actual presence of a recognized radioactive element as an exceedingly minute impurity.

What do these transmutations teach the alchemist? No one is anxious to convert a few milligrams of radium, of which he may be the proud possessor, into a corresponding amount of lead pipe. Nor need one worry seriously lest this occur. The rate at which the spontaneous transmutations take place is sometimes very slow. Thus if one possessed a gram of radium to-day, half of it would still remain as radium after 1,600 years. The production of radium from uranium might appear to be a profitable occupation as uranium is comparatively inexpensive, but here again the time required is too long to interest a single individual. Half of the uranium with which the process is initiated would be converted into uranium X_I, the first stage in the transmutation toward radium, only after the interval of five billion years.

What causes the spontaneous emission of an α-particle from the nucleus of a radioactive atom? We know that the nucleus of the uranium atom, itself a complicated structure, is surrounded by 92 planetary electrons which revolve with tremendous velocity, each in its own elliptical orbit. The orbits are not exactly elliptical however; they are perturbed by the repulsive actions of the other electrons. Each electron therefore travels in a path which may be described as a rosette or an ellipse with a progressive motion of perihelion. At perihelion it can be shown that the electrons in highly elliptical orbits almost penetrate the complicated structure of the nucleus of a heavy atom. It is not difficult to imagine that occasionally the configuration of the nucleus is such that one of these outer electrons at its instant of nearest approach may exert a very large influence upon component parts of the nucleus with which it is nearly in contact. Suppose the revolving electron pulled the α-particle just a small distance from the nuclear electrons which tend to hold it in the nucleus. The electrostatic repulsion of the rest of the nucleus is then sufficient to eject the α-particle from the atom with the tremendous velocity observed experimentally.[5] Now the reason that such a state of affairs happens only

[5] Stated conversely, the computation of this distance on the assumption that the velocity of the ejected α-particle is due wholly to the electrostatic repulsion of the rest of the nucleus gives values comparable with nuclear dimensions, and with perihelion distances for electrons in orbits of high eccentricity. For example, the distance $7 \cdot 10^{-12}$ cm is sufficient to account for the emission of α-particles from uranium with the observed velocity $1.37 \cdot 10^{9}$ cm/sec.

once in an eon, as far as the life of the uranium atom is concerned, may be due to the small probability that the perturbed orbits of the planetary electrons assume just exactly the correct relative positions in order that the forces which the electrons exert may be in resonance with the oscillations in the nucleus itself. If the alchemist had at his command magnetic fields of the magnitudes which must locally exist within the nucleus it is *possible* he could hasten these perturbations and reduce uranium to radium in a reasonable length of time. We are not able to produce such fields but there are other methods available by which the nuclear structure may be influenced, especially with the lighter elements.

We have found that radioactive elements eject helium nuclei and electrons from their nuclear structures. This fact suggests that the nuclei of all atoms are made up of helium nuclei possibly cemented together by the nuclear electrons. The atomic weight of an element should be accordingly an integral multiple of 4, the atomic weight of helium. This is true for a great many elements, but we have elements of atomic weight $4q + 1$, $4q + 2$, $4q + 3$ where q is an integer. The integers 1, 2, and 3 are thought to arise in hydrogen nuclei also present in the nuclear structure. Accordingly, it has been conjectured[6] that the nucleus of any atom is composed of three different types of building block, the hydrogen nuclei or protons, the helium nuclei or α-particles, and electrons. By properly combining these three units we may correctly represent the atomic weight and net nuclear charge of any element, as illustrated in the following table.[7] Here α, p and e refer, respec-

[6] Speculations on this date from Prout 1815, but the theory was first put in quantitative form by Harkins who supports it with evidence from various sources. *Cf.* series of papers in J. Frank. Inst., 1922–3.

[7] The true atomic weight of every atomic species except hydrogen is integral, or at least is usually integral to within 1 part in 1,000. Thus ordinary lithium is a mixture of two kinds of lithium atoms, called isotopes since they are chemically identical, one of atomic weight 7 and other 6. These are present in the ratio 94:6 such that the *mean* atomic weight which the chemist measures is 6.94. While there are only 92 elements chemically distinguishable (five of these are as yet undiscovered) there are possibly 200 atomic species which may be separated and weighed by positive ray analysis.

Slight departures from exactly integral values for the true atomic weights of certain isotopes or elements may be expected from theoretical considerations. For example, higher precision in experimental determinations by the positive ray method *may* show that nitrogen weighs 14.015 instead of 14, and already Aston has observed small but definite deviations from whole numbers in the isotopes of tin.

The accompanying table shows the true atomic weights of the elements up to phosphorus, as *observed* by Aston and by Dempster. The formulae for the nuclear structures are, however, purely empirical; the protons, α-particles and electrons have been arbitrarily grouped to give the observed mass and correct atomic number. For the physical justification of such procedure one should refer to the papers by Harkins, *loc. cit.*, where evidence from many sources, both chemical and physical, is correlated.

tively, to α-particles, protons and electrons, and the subscripts show the number of each required. The expression $\alpha_x\ p_y\ e_z$ is a chemical formula for the nuclear molecule.

STRUCTURE OF THE NUCLEUS

Atomic Number	Elements	Formula	Atomic Weight
2	He	α	4
3	Li	$\alpha p_2 e_1$	6
		$\alpha p_3 e_2$	7[8]
4	Be	$\alpha_2 p e$	9
5	B	$\alpha_2 p_2 e_1$	10
		$\alpha_2 p_3 e_2$	11[8]
6	C	α_3	12
7	N	$\alpha_3 p_2 e$	14
8	O	α_4	16
9	F	$\alpha_4 p_3 e_2$	19
10	Ne	α_5	20[8]
		$\alpha_5 p_2 e_2$	22
11	Na	$\alpha_5 p_3 e_2$	23
12	Mg	α_6	24[8]
		$\alpha_6 p e$	25
		$\alpha_6 p_2 e_2$	26
13	Al	$\alpha_6 p_3 e_2$	27
14	Si	α_7	28[8]
		$\alpha_7 p e$	29
		$\alpha_7 p_2 e_2$	30
15	P	$\alpha_7 p_3 e_2$	31

Accordingly, if we could disintegrate the atoms, the atomic weights of which suggest the presence of hydrogen in the nucleus, we should be able to cause the ejection of hydrogen, in analogy to the ejection of α-particles by radioactive elements. To do this should obviously require considerable energy since atoms are stable in ordinary chemical reactions. Rutherford hoped that the high velocity α-particles, 12,000 miles per second, emitted by RaC would have sufficient energy to penetrate the nuclei of the lighter elements and produce disturbances leading to disintegration. This work proved successful. To Rutherford belongs the distinction of being the first alchemist who definitely transmuted one element into another by artificial means.[9]

It was found that by bombarding boron, nitrogen, fluorine, sodium, aluminium and phosphorus with α-particles of a known energy, hydrogen nuclei were projected from these atoms with

[8] More abundant isotope; *cf.* Aston "Isotopes"—Arnold, 1922.

[9] This may be stated more moderately although such conservatism is unusual. Rutherford was the first to *discover* that nitrogen or aluminium, for example, could be disintegrated by α-particles, a phenomenon which must take place in nature wherever these elements are in contact with a radioactive material. The process is artificial, however, as is the production of a synthetic ruby, because it may be controlled at will in the laboratory. Rutherford's recent work is summarized in four semi-technical lectures which contain references to the original sources. *Proc. Roy. Soc., 97,* pp. 374–400, 1920; *Nature, 110,* pp. 182–5, 1922; *idem, 112,* pp. 305–12, 1923; *Science, 58,* pp. 209–21, 1923.

enormous velocities and energies. The identification of the hydrogen nuclei was effected by measurements of their deflection in a magnetic field. Rutherford's experiments are especially conclusive because in every case the energy of the ejected H-nucleus, considered initially at rest, is *greater* than that which it should have derived directly from the impacting α-particle. That is, the α-particle merely disturbs the equilibrium in the nucleus of the disintegrated atom, and it is the repulsive force of the nucleus which contributes materially to the velocity of the ejected hydrogen particle.

This fact eliminates the possibility that the observed hydrogen particles were due to the presence of hydrogen gas as an impurity. Thus it may be shown from simple dynamics, and may be verified directly by experiment, that when α-particles are projected through hydrogen gas, the maximum energy of an ejected hydrogen nucleus, produced by a head-on collision, is 0.64 that of the impacting α-particle. Rutherford found, however, that the hydrogen particles, ejected from the six light elements mentioned, possessed more than 0.64 of the energy of the impacting α-particles, and, except for nitrogen, the energy even exceeded that of the α-particle. Thus the hydrogen particles ejected from aluminium possessed a kinetic energy 37 per cent. greater than that of the α-particles producing them, as illustrated in the following table:

KINETIC ENERGY OF HYDROGEN-NUCLEI

Atomic Number	Element	Energy of H particle / Energy of α-particle
5	B	1.02
7	N	.79
9	F	1.10
11	Na	1.02
13	Al	1.37
15	P	1.10
1	H	.64

Hydrogen could not be detected when the α-particles bombarded carbon or oxygen, nor indeed should one expect this, for there is no readily obtainable hydrogen in the nuclei of these atoms, their structural formulae being α_3 and α_4 respectively. Whether or not helium may be ejected from the nuclei of these and other light atoms has not been subjected to experimental test. The liberation of helium (or of any particles) of small range or velocity can not be detected by the experimental methods so far devised.[10]

[10] Let us *hope* that Rutherford's negative results with lithium, chlorine and potassium may be explained in such a manner, since the structural formulae for the nuclei of these atoms are similar to those for the elements showing disintegration. However the whole subject is much more involved than this inadequate summary would indicate. One must refer to Rutherford's original papers.

Rutherford's experiments accordingly definitely prove that the nuclei of light atoms may be disintegrated, resulting in the production of hydrogen. The ejection of a single hydrogen nucleus must decrease the atomic weight of an atom by one unit and likewise must correspondingly decrease its nuclear positive charge and atomic number. The disintegration product, if stable, should be therefore the element[11] immediately preceding in the Periodic Table, as represented by Fig. 15.

Phosphorus becomes silicon of atomic weight 30; aluminium becomes magnesium of atomic weight 26; sodium is transmuted into the gas neon of atomic weight 22; boron becomes beryllium of atomic weight 9. Fluorine should become 0^{18}; and nitrogen, C^{13}; but these isotopes are known *not* to exist, so that very likely the ejection of hydrogen from fluorine and nitrogen is followed by other disintegrations in order that stability may obtain. For example, nitrogen might emit both hydrogen and helium and become stable as an atom of beryllium.

With these experimental facts before us we are prepared for the consideration of the real problem of alchemy, the transmutation of the baser elements into gold and other precious metals. But may we pause a moment and reflect upon the economic situation here involved.

If the secret of transmutation of a baser metal into gold is suddenly made public property, and if thereby gold may be pro-

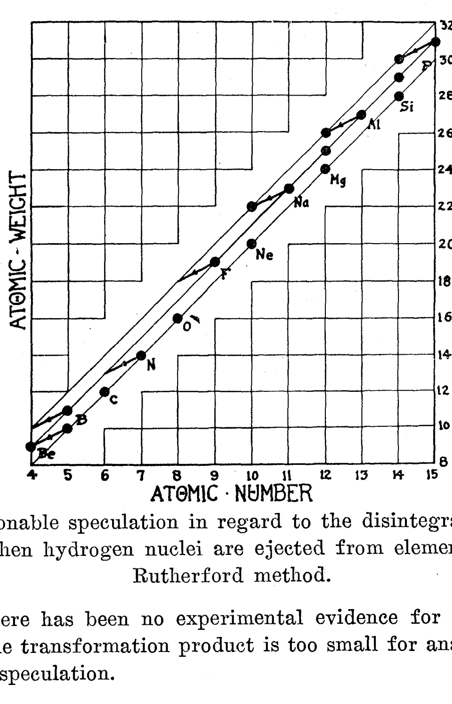


FIG. 15. A reasonable speculation in regard to the disintegration products obtained when hydrogen nuclei are ejected from elements by the Rutherford method.

11 So far there has been no experimental evidence for this conclusion as the amount of the transformation product is too small for analysis. It is, however, reasonable speculation.

duced in unlimited quantities, at the same cost, for example, as iron, a world-wide financial panic will be immediately precipitated, for the currency of every civilized country is based on a nominal or actual gold standard. All governments could immediately pay their total national and international indebtedness, including reparations. Measured in tons of gold, this is not such a huge quantity as one might expect. The holders of government securities would receive the correct amount of gold for their return, but suddenly this would have lost greatly in purchasing power by virtue of the resulting increase in the volume of currency and decrease in the value of the gold. In the same manner the creditor classes, the holders of securities and mortgages, the savings bank depositors, the life insurance policy holders, their fortunes and equities would be practically wiped out of existence. The debtor classes, the borrowers, for a time would luxuriate in the golden flood of wealth and would be able to pay their indebtedness in bullion now of value chiefly for its luster.[12] Undoubtedly the catastrophic situation may be easily saved by a corps of economists —and these are always available—so let us return to our problem.

In Fig. 16, we have plotted the atomic weights of all the known (or reasonably certain) isotopes of elements from atomic number 77 to 83. We shall consider the production of gold, platinum and iridium by the two conventional methods, that of Mother Nature, where an α-particle is emitted, and that of Rutherford which results in the emission of a hydrogen nucleus.

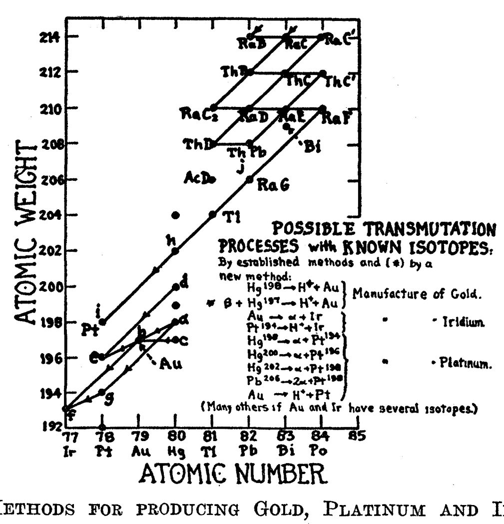


FIG. 16. METHODS FOR PRODUCING GOLD, PLATINUM AND IRIDIUM FROM BASER METALS

[12] These depressing predictions were suggested by my colleague, Dr. F. A. Wolff.

If a hydrogen nucleus is ejected from Hg^{198} by an experiment similar to that of Rutherford's, gold should result as shown by the transition *ab*. If gold can be made to emit an α-particle we should obtain the more valuable metal iridium by the transition *bf*. Performing the Rutherford experiment on Pt^{194} should also yield iridium, as shown by the line *gf*. Ejecting an α-particle from each of the three isotopes of mercury, Hg^{198}, Hg^{200}, Hg^{202}, should produce the three isotopes of platinum Pt^{194}, Pt^{196}, Pt^{198}, these transmutations being indicated by the lines *hi, de* and *ag*. From lead of atomic weight 206 we should obtain Pt^{198} after the emission of two α-particles, illustrated by the transition *ji*. The ejection of a hydrogen nucleus from gold by the Rutherford method should result in the production of Pt^{196}, as indicated by the line *be*. Many more transmutations of this type are possible (on paper) if later work shows that gold and iridium possess several isotopes. Still another reasonable means of transmutation is evident if one may drive an electron or β-particle into the nucleus of an atom and compel it to remain there. Thus, in the transition *cb* the nucleus of Hg^{197} attracts to itself a β-particle and becomes a gold atom. One would think that such transmutations should readily occur (experimental evidence to the contrary) since the positive nucleus should exert an attracting force on a negative charge.

These are the conventional or conservative methods for the production of rare metals by alchemical processes. Many other schemes have been proposed and tried but they rest upon a less secure, experimental foundation. For example, some have thought that transmutations may be effected by very high temperature. Now temperatures approaching 50,000° may be obtained by exploding metal wires with sudden application of high voltage and capacity. Wendt[13] has claimed that by so disintegrating a tungsten wire, a quantity of helium 26,000 times as great in volume as the original wire resulted. The tungsten was therefore practically completely dissociated into helium from which it must have been originally synthesized. Bell and Bassett[14] have found that the

[13] *J. Am. Chem. Soc., 44,* pp. 1887–94, 1922. The work is very questionable—in fact it is quite certain that the conclusions were based on unreliable data; others have failed to substantiate his results. However, the fact that huge quantities of energy per atom are involved in disintegration is not an argument, although frequently so stated, that anything like a similar quantity of energy is required to initiate the reaction. Radioactive transformations require no outside agency. The chief argument against disintegration by high temperatures is the fact that even at 50,000° the energy exchanges between atoms are far smaller than may be produced by electronic bombardment, while the latter has proven so far ineffective.

[14] *Science, 56,* p. 512, 1922. One can not find fault so easily with this work. The minute quantity of helium present in the atmosphere is certainly insuffi-

Sperry search-light arc shows seven lines of helium in its spectrum. Whence the origin of this helium if not from the disintegration of carbon or of the atmospheric gases?

Thus if high temperature is required, there are means for its production and the process can be readily commercialized. At present, however, methods involving electrical stimulation appear more definite and promising. The yield of transmuted elements so far secured is unfortunately very small, discouragingly so in fact. From Rutherford's experiments we find that if all the α-particles[15] emitted by a gram of radium and its products in a year were fired into an aluminium target, the liberated hydrogen would amount to 1/1000 cubic millimeter, with a correspondingly small amount of the transmutation product magnesium. Even were the product gold, the method, as so far developed, could not be looked upon as a menace to our present money standard.

Our hope must be therefore in some means for producing α-particles in tremendous quantity and with energy several times that of the fastest α-rays known in radioactive disintegration. There is a possibility that such hopes may be fulfilled. A helium ion falling through a potential difference of 4 million volts will have an energy equal to that of the fastest α-particles. X-ray bulbs have been made to operate at one tenth of this voltage. Much may be accomplished when electrons and ions may be driven through electric fields of a dozen times the magnitudes now available.[16] Possibly the general x-radiation from tubes of such high voltage may be employed for the disruption of atomic nuclei and for the transmutation of metals.

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cient to give the observed spectrum. If the helium was not produced by disintegration it must have been present in considerable amount as an impurity, which is obviously surprising.

[15] The number of α-particles emitted in a year attains the stupendous figure $4.5 \cdot 10^{18}$, four and one half billion billion. However, this amounts to less than 0.2 cm^3 of helium gas at atmospheric pressure. The large number of molecules in a small quantity of matter has been vividly illustrated by Aston, J. Frank, Inst., *193*, pp. 581–608, 1922, as follows: "Take a tumblerful of water and label all the molecules in it. Throw it into the sea and wait for a period sufficiently long that all the water on the earth, in seas, lakes, rivers and clouds is perfectly mixed. Then fill the tumbler from any hydrant. It will contain 2,000 of the original molecules, for although the number of tumblers of water on the earth is $5 \cdot 10^{21}$ the number of molecules of water in a single tumbler is 10^{25}." It may be noted that, at 25 cents per trillion, one German mark will still buy 1,150,000,000 atoms of gold.

[16] Experiments at the maximum voltages now attainable are worth while. Several years ago Dr. Trivelli, later of the Eastman Kodak Co., bombarded uranium with high-voltage electrons and obtained some evidence that the radioactivity of the material was increased. The experiments were not continued to the point where definite conclusions could be drawn.

Even if transmutation should be carried out on a large scale of production, its importance to the general welfare of humanity would shrink to insignificance compared to the greater interests which would develop simultaneously. However much may be the good arising in the use of non-corroding girders, in the replacement by platinum of our structural steel buildings and bridges;—however great may be the happiness of the housewife with an array of platinum utensils in the kitchen;—all these are really trivial. No alchemist of the past dared dream of the field opened to the modern physicist, the moment that transmutation is reduced to quantity production. For by whatever means this be effected, the same methods can be employed in the creation of energy by annihilation of mass.

We know from the theory of relativity that energy and mass are associated in the relation $E = c^2m$ where c is the velocity of light. There is more real alchemy in this little equation than in all the thousands of volumes written from the time of Hermes to Lavoisier. Can we grasp the significance of the numerical magnitudes here involved? Let us consider one of the simplest possibilities.

While it is proven that atoms are made up of protons, α-particles and electrons, we are convinced that the ultimate building blocks are simply two in number, the protons and the electrons. The α-particle or helium nucleus is therefore produced by the union of 4 hydrogen nuclei and two cementing electrons, as shown in Fig. 11. The helium atom *may* be synthetically constructed from 4 hydrogen atoms. That helium actually consists of hydrogen should be capable of verification by the Rutherford method of disintegration, so soon as we are able to produce bombarding α-particles with only four times the energy at present available.

Now we know that the atomic weight of helium is 4.00, while the atomic weight of hydrogen is 1.0077. Hence four separate atoms of hydrogen weighs 4.031, or 0.031 units more than when they are compressed together to form an atom of helium. Thus the formation of 1 atom of helium annihilates 0.031 units of mass, and, by the general principle of Einstein, results in the creation of c^2m units of energy. If a gram atom of hydrogen is thus converted into helium, the energy liberated is

$$c^2m = .0077 \times 9 \times 10^{20} = 6.9.10^{18} \text{ ergs.}$$

That is, if the hydrogen in two teaspoonsful of water be converted into helium, 200,000 kilowatt hours of energy is set free, representing \$20,000 worth of electrical current or ten thousand dollars to the teaspoonful.

This is a comparatively moderate reaction from the speculative standpoint. Since mass is undoubtedly electrical in nature one may wonder what would happen if the nucleus of the hydrogen atom should attract into itself an electron. If the nucleus and electron could be united, their charges should completely neutralize one another. It is possible that the original charges should therefore cease to exist and the atom should vanish. The complete annihilation of one gram of hydrogen in this manner would give rise to 130 times the energy available in the formation of helium or $2,600,000 in electrical power. The ancient alchemist desired to create gold. The modern alchemist would destroy it. Complete destruction of one pound of gold represents the production of 10,000,000,000 kilowatt hours of energy.

While these are mere speculations, indeed, so sure are we of the fundamental truth of the alchemical transmutation of hydrogen into helium that the chief scientific interest[17] no longer lies in the consideration of its *possibility*. The real problem from the scientific standpoint is the explanation why all hydrogen has *not* been already transmuted into helium. With such an exothermic reaction why should we have any hydrogen or hydrogen compounds at all? Tolman[18] has given serious thought to this question, which has puzzled the alchemist, and his paper may be commended to those who fear lest even the water disappear from the universe, and we really die of thirst.

In conclusion we have found that some forty different elements or atomic species are transmuted spontaneously in radioactive disintegrations. Many radioactive elements give off helium. The light elements may be transmuted into still lighter elements and hydrogen. We have learned how gold and other precious metals may be made from lead or mercury. When the scientist is able to utilize an electric field of 10 million volts there is small doubt but that every element may be produced by transmutation.

To do this on a large scale of production, to make it a commercial enterprise, is an entirely different proposition. I doubt if many of us will live to see its realization. But when that time comes, this world will be a true haven of rest for all its inhabitants. There will be no poverty, no suffering and no labor; atomic energy will do the work for all mankind. Humanity will be emancipated by the scientist.

Such emancipation is probably desirable, but philosophically it raises a very interesting question. Shall we ever be content to retire from all industrial and intellectual activity and, with atomic energy enslaved, submit to a life of ease and stagnation? I believe not. New problems will be opened requiring even more intense scientific study than those which at present engage our attention.

[17] Speculatively speaking.

[18] *J. Am. Chem. Soc.*, *44*, pp. 1902–8, 1922.

Possibly this world where we now live will no longer prove a satisfactory abode for the civilization of the future. Problems such as exploration of the stellar space will confront the daring navigator with atomic energy at his command. New worlds may be discovered, so attractive that the inhabitants of this earth all will migrate leaving their former home to the mercy of the processes of evolution. . . .

Life here is again evolved through the millions of years; intellectual development again advances to the discovery of atomic energy; the people leave, and so the cycle is repeated, forever and forever.

Now in benediction, may I counsel those who are discouraged and are disappointed in the present status of alchemy, to take comfort in the Proverbs of Solomon, the 16th chapter and the 16th verse, wherein it is written "How much better it is to get wisdom than gold."[19]

[19] Similar advice will be found in the First Epistle of Peter, 1:7.