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Presidential Address.

ALCHEMY, ANCIENT AND MODERN.

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Perhaps the first step taken by one under the necessity of writing a presidential address is to find what his predecessors in office have talked about. I find, as is natural, addresses on general or particular scientific subjects, especially recent advances; though on several occasions speakers have rather discussed scientific aspects of human affairs in general, and our own in particular. This I consider all to the good. While a Royal Society exists for the encouragement of science and the extension of scientific knowledge, it would be quite wrong to neglect the relationship of that knowledge to the community.

With increasing application of scientific knowledge to practical ends and evidence that some social disturbance is so created, it is a bounden duty of the scientist to take his part in helping towards a scientific ordering of the general life. You may not agree with the suggestion that the people who pay the piper should call the tune, but those who pay certainly would. It is our duty to show that our music is the best—that a scientific outlook and ordering of affairs will lead to greater general progress.

If in my subject to-night—"Alchemy, Ancient and Modern"—I try to give a human interest to the historical development of science and to point to practical and useful results of most modern developments, I make no apology, for I feel that none is needed.

The popular idea of the mediæval alchemist as a knave and impostor taking advantage of the credulity of the time is far from the truth. The early history of science is largely the early history of chemistry, and the many important early discoveries are entirely the work of the alchemists.

As the first scientists, lost in prehistoric time, we may consider the men who reasoned out the cause of fire and learned how to produce it at will. Given fire, we have other prehistoric Newtons who developed crude cooking and metallurgy. Accidental use of ores, such as those of iron, in the fireplace would give rise to metal, followed by crude metallurgy. As chemistry deals largely with changes produced by change of conditions, we have here crude chemical operations—of course, treated as yet as arts.

By the beginning of the Christian era knowledge of arts had so developed that intelligent beings had sufficient facts to attempt to reason as to cause and effect.

The Greeks were among the first in the field with a theory of matter not very different from that at present accepted—that matter consisted of atoms alike for one type of matter, indestructible but composed of some common constituents. Though nearly true, it was based on speculation rather than evidence. The Greeks, and later the Romans, seem to have despised labour, and experimental work was hardly thought of. Soldiering and administration were accepted occupations; work was left to slaves. Even the engineers of Greek and, especially, Roman times were often slaves. (I have even heard friends in that profession suggest that their case is not very different now.) Practical achievement only began when the Greek theories were taken up practically by workers in Egypt at Alexandria, where alchemy apparently originated. It has been suggested that actually there was a considerable chemical knowledge in Egypt centuries earlier, in the hands of the priests. If so, they were careful to keep their knowledge secret, and we know nothing of it. It would be a valuable source of miracles and wonders with which to amaze and awe a very ignorant and superstitious populace. Be this true or not, there is no doubt that by the third century A.D. a considerable knowledge of chemical operations was gained, classed under the name, at first, of "chemeia," later by the Arabs named "alchemy." Alchemy is now usually associated with the early period when, following Greek theory, transmutation of elements was considered possible, and early experimental work was chiefly directed to this end, particularly the conversion of base metals to gold.

Much of the Alexandrian knowledge has been lost to us through this belief. Though most of the workers were honest and convinced of the possibility of converting one metal to another, there were, as at present, those ready to take advantage of an opportunity, and these, selling various alloys as gold, finally became such a nuisance that the Roman emperor Diocletian, who was in control of Egypt, ordered all books on alchemy to be destroyed. Although Egypt was the birthplace of alchemy, its cradle was Arabia, for by the sixth century Islam had spread over Asia Minor, Arabia, North Africa, and Spain. The centres of this empire were Damascus and Baghdad, where culture and knowledge were encouraged, the learning of Greece and Egpyt being fully utilised. Here from 600 to 800 A.D.—the European dark ages—learning flourished and alchemy grew exceedingly. Its exponents were still guided by the search for transmutation, believing in the common origin of matter. They were not impostors, however, but serious and exceedingly intelligent workers. The ordinary chemical operations of calcination, extraction, filtration, distillation, &c., were developed. Naturally, many new substances were produced, including nitric acid—not an easy substance to handle.

The most famous of these Arabians—Geber—lived and worked at the time of Haroun al-Raschid. He wrote a number of works still in existence describing his discoveries, and I might quote from one to show his outlook:—

> "The first essential in chemistry is that thou shouldst perform practical work and conduct experiments, for he who performs not practical work nor makes experiments will never attain to the least degree of mastery. But thou, O my son, do thou experiment so that thou mayst acquire knowledge.
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> "Scientists delight not in abundance of material; they rejoice only in the excellence of their experimental methods."

With the revival of learning in Europe which was coincident with the decay of the Arab empire, Arabian knowledge spread to Europe, particularly through the monasteries.

Through the Middle Ages the practice of what we may call "alchemy" flourished and increased in Europe. Still transmutation was a guiding principle. Though workers believed in the "philosopher's stone" that, if discovered, would enable them to achieve their object of making gold, they followed up any discoveries with a true spirit of inquiry. Apart from the monks, interest spread among the nobility—the only other group with leisure and wealth to devote to it. In England Prince Rupert was a skilled worker. Often princes and rulers, interested but not skilled, would support and employ alchemists. This naturally lead to imposture, and several impostors in Europe were hanged for their pains. One alchemist, wiser than most, refused the invitation of a German noble on the grounds that if he could make gold he had no need for the prince, and if not the prince had no need for him. Another German prince and his court were persuaded by an Arab impostor that he could make gold, but that he needed some gold to start his process. The whole court gathered in the workroom and threw their contribution into a furnace. The Arab threw in his own preparation, when there was an explosion, with much fume and smoke. When the smoke cleared, so had the Arab and the gold.

Happenings of this sort do not alter the fact that the real alchemist was an investigator who made many discoveries of new chemical compounds and investigated their properties. Astrology and similar nonsense were mixed with the more serious work at times. This mixture of humbug and valuable knowledge is used by Scott in "Kenilworth," where Weyland Smith poses to the ignorant as something of a magician, but on occasion is able to provide drugs necessary for saving of life. The humbug doubtless impressed the ignorant, and from them could be collected the wherewithal to carry on.

Although the doctrine of transmutation persisted until the seventeenth century, it was realized by the fifteenth century that its actual achievement was unlikely, and gradually interest turned to various substances discovered and their possible use in medicine.

The most famous name in this connection is Paracelsus, a Swiss, born in 1493, the son of a physician, who taught him the scientific knowledge of the time. Time would not permit an account of his life, but while quite young he wandered through Europe gathering further knowledge of alchemy, astrology, and medicine. Possessed of forceful personality and great conceit of his own ability, he was able to persuade others to take him at his valuation, and secured the post of city physician at Basel. Being exceedingly bombastic and quarrelsome, he soon had the whole of his medical fraternity "by the ears." He attracted general attention by his attacks on alchemy as then practised, and he preached the doctrine of medical chemistry, possibly mainly to be in opposition to his colleagues. While one shudders at the probable sufferings of the mute, inglorious victim of his experiments, his preaching did much to start alchemy on more useful lines.

Before leaving the alchemists I will mention one of the earliest scientific nutrition experiments of which we have record. This was due, according to tradition, to a German monk—Basil Valentine—who is supposed to have lived at the same period as Paracelsus, but who, unlike him, was the author of a large volume of chemical discovery, including antimony and some of its compounds. His antimony residues were thrown out and eaten by the monastery pigs, who grew and flourished exceedingly. Ascribing this to the antimony, Valentine decided to see whether it would have a similar effect on his fellow monks. With true scientific spirit, he added an antimony preparation to their food, but, in accord with scientific procedure, he used a control whose food had no antimony added. He himself was the control. The derivation of the word "antimony" is supposed to be "anti moine" —monks' enemy. Evidently pigs and monks present different nutrition problems.

This tale of the old alchemists ends with the Civil War in England. A new one begins with Charles II. During his reign lived two of England's most famous men—Newton and Boyle. During his reign, also, was founded the Royal Society of London. To Boyle we owe the final abandonment of the doctrine of transmutation accepted for nearly 2,000 years. He set out the actual position of what he called the elementary substances, which could by no means be split up. From Boyle's time—say, 1660—until the end of the last century, we have what we might call the "atomic period," when it was accepted that the group of about ninety substances so called elements were quite indestructible and unchangeable—as, indeed, they were with the means, chemical and physical, at that time available. It was J. J. Thomson, of the Cavendish Laboratory, who in 1897 first shattered the beliefs of the chemists in the unique nature of their atoms when he showed that electrons less than one-thousandth the size of the smallest atom (hydrogen) could be produced by electric discharge from all types of atoms, and that all atoms furnished identical negatively charged electrons. The discovery of radium and other radio-active elements a little later, in the hands of Rutherford—Thomson's successor at Cambridge—gave rise to what I may call the modern period of alchemy where first elements were shown to be changing and later new elements were built up.

One need refer but briefly to the general facts of radio-activity—that radium and other radio-active elements emit radiation of three types—a very penetrating group: first, gamma rays, which are a true radiation of the same nature as X-rays; second, the beta rays, identical with the negatively charged electrons of the electric discharge tube; and third, the alpha radiation; this was found to consist of positively charged particles of considerable mass, actually about four times as heavy as the hydrogen atom. The alpha particles were soon shown by Rutherford and Soddy to end their life as helium atoms. Helium is a gas present in very small amount in the air. It has not been very difficult to prove that the loss of alpha particles leaves new and lighter atoms behind until finally an inert residue of lead only remains. This disintegration theory is now generally accepted, and consequently the nineteenth-century conception of the atom as something unalterable and indestructible has had to be modified. Until quite recently, however, man had no control over such atomic disintegration. No change of condition within his reach had any effect whatever on the rate or nature of radio change. Of these radiations, the alpha particles have proved the most interesting scientifically, as they have enabled the interior of the atom to be explored and for the first time have enabled the actual breakdown of non-radio-active atoms to be accomplished. The alpha particle moves with a velocity of tens of thousands of miles per second and can penetrate not only through matter but through the atoms themselves, usually in a straight path. This path can be determined by electrical measurements and actually demonstrated photographically. Occasionally the particles are deflected from the straight path. A study of the deflection enabled Rutherford to give us a very definite picture of an atom. The atom consists of a small central nucleus positively charged, with sufficient negative electrons, forming a sort of planetary system, just to neutralise the positive charge of the nucleus. By study of spectra, of alpha particle scattering, and of the nature of X-rays emitted from different elements, the actual number of electrons has been determined for all atoms, the extremes being one only for hydrogen and ninety-two for the heaviest atom—uranium. The weight of an atom lies in the nucleus; the simplest and lightest atom (hydrogen) is considered to have a simple nucleus. This hydrogen nucleus or proton is almost certainly the unit from which the nucleus of heavier atoms is built. The proton carries a positive charge of electricity. Heavier atoms contain in the nucleus sufficient protons to balance the total negative charge of the surrounding electrons. The atoms in general have, however, a greater weight compared with hydrogen than can be accounted for by the number of electrons (and corresponding number of protons). The extra weight is accounted for by neutral groups consisting of pairs of electron plus proton actually contained within the nucleus. Those electrons are in addition to what may be called the free electrons surrounding the nucleus. Such neutral pairs, called "neutrons," have recently actually been detected, driven from atomic nuclei by alpha-ray bombardment.

The chemical properties of atoms are due almost entirely to the external electron grouping; the weight and certain physical properties depend on the nucleus. Recently it has been found possible to separate most chemical elements into separate fractions whose atomic weights are slightly different though their chemical properties are identical. For our purpose we may consider the atomic weight as the weight of an atom compared with the weight of an atom of hydrogen; thus the atomic weight represents the number of protons and neutrons in the atom. The different atoms with the same electron grouping have the same chemical properties, and all represent chemically one element. They are called "isotopes." They differ only in the number of inert neutron groups in the nucleus. While a few elements have no isotope, some have two and many have several; tin has about a dozen. Except in one case, the isotopes of one element have atomic weights close together. The exception is hydrogen, which contains but the one proton and one free electron; it is the one element that contains no neutron.

It has one isotope now called "deuterium," which still has one free electron and one proton, but has also one neutron in the nucleus. In this case one isotope is twice as heavy as the other; this great difference causes considerable difference in properties, and deuterium is the one isotope that has been separated in a pure state. Hydrogen and its isotope differ from other atoms in another way. I have already told how a high-tension electric discharge in a vacuum can remove electrons from atoms. Actually, it is very difficult to remove more than one electron, so that hydrogen and deuterium are the only elements that have a bare nucleus left in the process.

Atoms with an electron removed have, of course, a positive charge and are said to be ionised. Such ionised gases quickly pick up the necessary electron and revert to ordinary atoms. The only other particles with no electrons that we know of are the neutron already mentioned and the alpha particle. This last is formed by break-up of the nucleus of radio-active elements. It is formed of two neutrons and two protons. Ejected with high velocity, it quickly slows down and picks up the necessary electrons to form helium. Although the bare particle can apparently penetrate actually through atoms, the final helium atom has lost this power. While the planetary electrons occupy only a minute fraction of the effective volume of the atom, they are in such rapid movement that different portions are continually occupied and interpenetration is entirely prevented. Thus it is easy to remove an electron, but very difficult to reach the nucleus, which it is necessary to attack if a permanent change in the atom is to be effected. Success has been attained by the use of four high-speed particles free from planetary electrons—the proton, deuteron, alpha particle, and neutron. Of these, the neutron is itself obtained by bombarding atoms of small atomic weight with alpha particles, and is itself a product of actual atomic break-up.

All four are now used to attack the nucleus, and all cause nuclear rearrangement with the actual formation of new elements. The first and classic experiment is that carried out in Rutherford's laboratory, where nitrogen gas was exposed to alpha-ray bombardment. There is a very beautiful method for following the passage of the alpha or similar fast-moving particles through moist gas, where they leave a trail of ionised gas in their track. The ions act as nuclei for condensation of water vapour and produce a thin fog track which can be photographed. The alpha-ray track is nearly always a straight line, but in nitrogen very occasionally a forked track appears, one branch of the fork being longer than the original tracks. From its behaviour, this new track could only be ascribed to a proton or hydrogen nucleus, which, of course, as it slowed down, would acquire an electron and become an ordinary atom. The second branch of the fork is shorter than the original. As we have to assume that the helium and nitrogen nuclei have collided and the proton has escaped, we must regard the second track as due to the combined residues. From the number of protons (8) and neutrons (9), we should have a new combined nucleus with an atomic weight of 1-17, but with an electron grouping and chemical properties of oxygen, atomic weight 16—an oxygen isotope. It is interesting to know that quite recently this isotope has been found to exist in small proportion in the atmosphere, and a partial separation has even been effected. This experiment, carried out in 1925, is an effective demonstration of the first artificial transmutation of an element. The actual amount of material changed was almost infinitely small and quite incapable of chemical recognition. Later it was found that protons could be driven from most of the lighter elements up to potassium, but that the heavier elements could not be attacked, possibly because the greater number of positively charged protons in the nucleus exerted so great a repulsive force on the positively charged alpha particle that it could not approach the nucleus.

Rutherford's explanation of transmutation was at first regarded as ingenious and very probable, but later accumulation of evidence has shown him to have been actually correct. The most important of the recent discoveries was that made by the daughter of Madam Curie, the discoverer of radium, in collaboration with M. Joliot. They found that some of the lighter elements already known to undergo nuclear change also acquired a temporary radio-activity which persisted after removal from the alpha-ray bombardment. Next it was shown that both protons from hydrogen and deuterons from its isotope, accelerated to high speed in an electric field, could also induce temporary radio-activity.

There is no doubt that we have here an actual transmutation with formation of new elements. The projectile particles penetrate the atomic nuclei, forming new and unstable atoms. So far the quantities produced have been far too small for actual chemical isolation, but there is undoubted chemical proof that new properties have been developed. Electrical methods are far more sensitive than chemical, and the radio-activity of the minute quantities is readily detected and may be used to follow the atoms during chemical reactions. As an example, we may take aluminium bombarded with alpha particles. The aluminium is dissolved in acid containing a small amount of phosphate. The added phosphate is then separated from the aluminium. All the radio-activity is now with the phosphorus, and no chemical process will separate it. The new element is thus a new isotope of phosphorus; in fact, all of the many new radio-active elements are isotopes of common stable elements. During their radio change they revert sometimes to an ordinary stable form of an element, sometimes to a new stable isotope. If carbon is bombarded with protons and then burnt, a minute quantity of gas is produced which gives all the tests for nitrogen except that it is radio-active. From the numbers of protons and neutrons involved, this unstable nitrogen has the same 7 protons as nitrogen, but has 6 instead of 7 neutrons and an atomic weight of 13 instead of 14. Both these new elements have a short life, half-disappearing in a few minutes.

Transformations produced by protons and deuterons are more definitely artificially produced than those first discovered with alpha particles, as these are natural products, while the protons are themselves artificial and the whole series of changes becomes artificial.

An interesting feature of many of the large number of artificial elements now known is that they emit, not electrons, but particles of electron size with a positive instead of negative charge. These positrons had just been discovered as a product of the strange cosmic rays that reach us from space, when their production in quantity from the new elements was discovered. They disappear when they lose their velocity, by interaction with electrons, both apparently being converted to some form of radiant energy. The loss of a positron causes a positive proton of the nucleus to change to a neutron, and the nucleus, with now a different total charge, forms a new type of atom naturally more stable. Thus the active nitrogen previously described has in its nucleus 7 protons and 6 neutrons. The radio change evolves a positron, leaving a nucleus with 6 protons and 7 neutrons. This will hold externally 6 electrons, as does carbon, of which it will be an isotope.

The neutron, already mentioned as a nuclear constituent and as a product driven from lighter nuclei by alpha particles, can itself be used as a projectile with most interesting results. Having no electric charge, it can penetrate the larger nuclei that, as already explained, the charged proton and alpha particle cannot reach.

An Italian worker (Fermi) claims to have thus added a neutron to the nucleus of uranium, the heaviest known element, producing a new element heavier than any natural one.

With sulphur, neutrons produce an isotope of phosphorus that must be assigned an atomic weight of 32. This is different from natural phosphorus of atomic weight 31, and also it is radio-active. It is also different from the active phosphorus from aluminium, which must have an atomic weight of 30. This sulphur product has a life of several weeks, instead of the few minutes of the aluminium product. All three forms of phosphorus have the same chemical reactions and cannot be separated from one another. All have 15 protons in the nucleus, but the different forms have 15, 16, and 17 neutrons.

The sulphur product gives off electrons from the neutrons in its nucleus and reverts to sulphur. Not all the active elements revert to their original parent. Sodium bombarded with deuterons sets free protons which can be detected by the method already described for nitrogen.

The neutrons of the deuterium are absorbed by the sodium. This produces no change in the electron system. The new product is still sodium, but it is an isotope, and the new nucleus is unstable; the product is radio-active. Like the phosphorus just described, it gives off an electron from its neuclear neutron. This electron omission, of course, is readily measured. The original sodium contained 11 electrons and 12 neutrons in the nucleus; the radio-active sodium 11 electrons and 13 neutrons. After emitting an electron from a neutron, the nucleus will contain 12 electrons and 12 protons. This is a change to an entirely new element—magnesium. At present some of the changes have an entirely speculative basis. I have described some of the chemical evidence in the case of the radio-active bodies, but once stable products are formed this method fails, and, as the quantities are so small, we are left only with the evidence of the various types of interacting groups and emitted particles. In this case there is no direct evidence for the magnesium.

This radio-active sodium is one of the most interesting of the new bodies. Professor Lawrence, of California, has built an exceedingly powerful apparatus for producing by electrical acceleration a very intense stream of deuterons. With this he has produced sufficient radio-active sodium to have for a few hours an activity nearly equal to a milligram of radium—a quantity often used medicinally. This has two important aspects: First, it suggests a cheap source of material for cancer treatment—a material, moreover, that would in a few days become a harmless natural substance already in the body in quantity, while radium products may maintain harmful activity; second, with a more powerful deuteron stream, which is possible, quantities sufficient for chemical examination and determination of nature of final product may be obtained.

As another example of the practical value of the new discoveries, I will describe how radio-active phosphorus from sulphur has been used to trace the history of the phosphorus in living organisms. Rats have been fed with a ration containing sodium phosphate which itself contained sufficient radio-phosphorus for easy detection electrically. All chemical tests have shown that the active and ordinary phosphorus are quite inseparable, and where one is the other will be.

By examining the excreta and finally killing the animals, it was possible to trace the movement of all the phosphorus fed. It was thus shown that the average phosphorus atom only stays in the body of the rat a couple of months, and even in the skeleton 30 per cent. of the element is replaced every three weeks. Similar experiments were made with maize seedlings. These were grown in ordinary nutrient medium containing phosphate till two leaves had fully developed, when radio-phosphorus was added to the solution and the two next leaves were developed. Both sets of leaves had the same radio content, showing that phosphorus taken up later was added equally to all the leaves. This, of course, means that the element was continually shifting and that phosphorus compounds are not permanently fixed in a plant. Possibly we are at the beginning of a new era in physiological as well as chemical and physical history.