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ANCIENT AND MODERN ALCHEMY[1]

FIRST of all let me express my high appreciation of the honor of the invitation to come to Cornell as non-resident lecturer for the present term. When I received the friendly letter of Professor Dennis, my first thought was that it would give me the opportunity of staying for some time in the finest laboratory of chemistry now existing in the world, with which I was already acquainted from the description of the building that had been sent to me. It was with great pleasure that I accepted the invitation to join the well-known staff of the department and to avail myself of the privilege of presenting throughout the term some of my researches to a Cornell audience, and to continue my investigations in this building which offers such excellent facilities for experimental work.

It may be a matter of surprise to you that as the subject of my introductory lecture I have chosen alchemy, since that is not generally believed to belong to exact chemistry at all. Only a few decades ago Hermann Kopp, one of the best historians of chemistry, called the history of alchemy "the history of an error." If, however, it was an error, it was one of the most persistent of the false doctrines in the development of any science, and my reason for selecting alchemy as the topic of my address is to be found in the fact that the trend of modern chemistry is toward rather than away from the theories which were condemned by the official science of the last century, of which Kopp may be regarded as the representative.

Alchemy was in disrepute during really only a comparatively short space of time. For many centuries it was highly esteemed as the "sacred science" and no independent science of chemistry existed. It retained its dignity even when chemistry, as distinguished from alchemy, was being developed. It was never entirely abandoned, although, after chemistry had won a much higher position, the disfavor of scientists forced it for a time to hide in the obscurity of private laboratories and secret societies. In recent years it has again emerged into the full daylight of modern scientific theory and research. There is no doubt that much of alchemists' creed was "an error," but their idea that it must be possible to change one chemical element into another, as lead to silver or

[1] Introductory public lecture by Professor Fritz Paneth, of the University of Berlin, non-resident lecturer in chemistry at Cornell University.

silver to gold, has been strongly supported by the researches of our time.

But if the difficulty of observing an artificial transmutation of an element is so great that all the careful experiments of the chemists of a few years ago seemed definitely to disapprove such change, how is it to be explained that in former centuries the confidence in its correctness was so deep-rooted and that alchemy and the alchemists played such an important part in the life of that period? For the influence of the alchemists can hardly be overestimated. For example, official state papers of the sixteenth and seventeenth centuries make it clear that one of the important problems confronting a monarch or elector in Central Europe was to procure for his country an able alchemist who was expected to improve the financial status of the realm by transmuting base metals into valuable gold. It naturally followed that the alchemist was highly favored at court—so long as belief in his ability lasted. He was honored by the friendship of his sovereign and sometimes by elevation to nobility, and more than one of the crowned protectors of alchemy assisted personally in the experiments, so that he might convince himself of the correctness of the achievements of his alchemistic employee. The Emperor Rudolph II is reported to have himself worked with his alchemists, and a visitor to the Hradshin, the beautiful castle of Prague, the residence of the emperor, may even to-day see the five or six little houses, with disproportionately large fireplaces, which were built by Rudolph's command close to his own palace and which were used by his "gold-cooks." Rudolph appointed to a high position in his court Tycho de Brahe, who, although usually referred to in the history of science as an astronomer, was perhaps chosen by Rudolph because he was also of high repute as an alchemist. This is evidenced by the fact that the emperor provided him not only with an observatory but also with a laboratory for his chemical experiments.

In a more practical way Henry VI of England supported alchemistical experiments. To aid in the payment of the debts of the state he recommended to all noblemen, scholars and theologians the study of alchemy, and he conferred upon a company the privilege of making gold from base metals. This firm produced a metal (probably an alloy of copper and mercury) which had the appearance of gold and from this coins were stamped. History does not record whether King Henry believed that transmutation had actually been accomplished, but the careful Scotch were evidently skeptical, for the Scotch Parliament issued an order that this English "gold" should not be allowed to enter any of their ports or to cross their frontier.

The example given by the mightiest rulers of the time was imitated on a more modest scale by several of the smaller princes of Europe. Historical records tell us of one who tried to obtain a first-class alchemist from his neighbor, first by kindness and then by force; of another prince who loaned his alchemist to another court for a definite period, and of treaties between two states in which alchemists were regarded as mere chattels. Many of the rulers of that time were such firm believers in alchemistical doctrines that a lawyer of the period advocated making disbelief in these theories a *crimen laesae majestatis*. But although the lords of the realms generously supported the experiments of their alchemists, the financial returns never seemed to equal the disbursements. One repeatedly finds in the records that at the end of the research the sovereign lost his temper and that the alchemist, when hard pressed to show his product of manufactured gold, was usually well satisfied if he succeeded in escaping from the clutches of his former benefactor. If he failed to do so, he was severely punished and generally put to death. As showing the cruel humor of the times, it was a frequent joke to gild with tinsel the gibbet on which the alchemist was to meet his end.

We read of a great number of such executions and of innumerable failures of experiments. The successful transmutation of some cheap material into gold was very seldom reported, and in every case the transmutation, for some reason or other, could not be repeated: either the alchemist had disappeared or the stock of the "philosophers' stone," the miraculous powder which alone enabled him to accomplish "the great work," had been exhausted. The value of the gold that he claimed to have produced always amounted to a very small fraction of the money that had been spent upon him and his experiments.

How is it to be explained that in view of such constant and utter failures the belief in the possibility of the production of gold was not destroyed? *Three reasons may be offered.*

In the first place, there were some observations, which even from a critical standpoint seemed to prove the possibility of transmutation. The best chemical experts of that time were not greatly impressed by the results of the alchemists, for success invariably disappeared as soon as the experimenter was forced to permit a sharp control of his materials and apparatus. It was clearly recognized that in all such cases the element that the alchemist claimed to have manufactured was present in the material from the beginning, but was so well hidden, or so finely distributed, or in such chemical combination that the layman was unable to detect its presence. In the reputed art of gold-making they had no further proofs of success than vague historical statements that on a certain occasion a powder, provided nearly always by an "unknown stranger," had exhibited the properties of the "philosophers' stone" and as evidence of the miraculous transmutation into gold accomplished by experiment a gold nugget of metal was shown. One may see at the present time in some of the European museums such gold products of the alchemists with detailed explanations of the manner of their production. But in no case the invaluable powder itself that had brought this about is to be found in any museum.

The early chemists were, however, firmly convinced that transmutation was possible and their conviction rested largely upon an experiment which clearly seemed to create copper and which could successfully be repeated at any time. This experiment consisted in immersing an iron vessel in the water of certain natural springs and allowing it to remain there for some hours. When it was removed its shape was unaltered but the vessel had apparently been changed to copper. I have seen such copper utensils with poetical inscriptions upon them to remind one of the mysterious origin of the metal. One reads thus:

> Hart Eisen ich einst war.
> Ein wasser rein und klar
> Macht mich in wenig Stund'
> Zu Kupfer in Herrngrund.[2]

Apparently a "water pure and clear" produced the transmutation. This water, however, was not as pure as it appeared to be, but contained traces of a copper salt, and when the iron vessel was immersed in the liquid the metallic copper, the "nobler" metal, was deposited upon the less noble metal, iron. The vessel was not, of course, changed as a whole into copper but simply received a thin coating of that metal. But the coating was real copper and showed all the details of the former iron surface.

It is not surprising that in those times when the small content of copper in the water could not be detected by chemical analysis, the phenomenon which I have just described was thought to be the transmutation of iron into copper; but on reading alchemistical treatises, one is nevertheless astonished to meet again and again this one example as the chief uncontested experimental argument for the whole doctrine of transmutation. This fact shows how scanty was the experimental evidence, in spite of the innumerable attempts which were not only made in the laboratories of emperors, kings and noblemen, but were also carried on by many commoners, and which never yielded gold in any appreciable quantity. From all this we may safely conclude that the reason for the firmness of the belief in the doctrine of alchemy was not the strength of the experimental evidence, but that it had quite a different basis, namely, psychological motives.

It is an old-known fact that men readily believe what they wish to believe. Modern psychology has deepened and extended the scientific knowledge of this fact by the discovery that such a wish is not less effective if it remains in our subconscious mind. Its presence may then be even more dangerous, since we are generally not aware to what degree it influences our thoughts and acts. Any strong wish may by "repression" obscure or extrude from our memory all that does not conform to it. Those of you who are acquainted with the work of the Vienna scientist, Sigmund Freud, will realize the importance of this field. I do not think that any psychologist will wonder that the judgment of those who lived in the days of the alchemists was misled by the wishes of such overpowering strength as played a rôle in connection with the idea of transmutation. It is not easy for us to-day to correctly estimate the power of this wish. It was not merely the hunger for gold. The habit of mind in those times found it quite natural to believe that a thing capable of changing all the metals into gold would also possess the faculty of curing every kind of illness. The all-embracing astrological conception of the world, to which the alchemical doctrine belonged, brought certain ideas into close relation by what we now consider to be only a weak analogy. In the case which we are discussing the analogy might be formulated—*the cure of metals and the cure of men;* for, using the terms of Albertus Magnus, gold was "the only metal free from any illness." The philosophers' stone, that mysterious powder for which every alchemist was searching, was believed to be able to change any other metal into gold by mere contact (they termed it "projection"), the stone being capable of transmuting many thousand times its own weight. It was further supposed to guarantee to its owner extremely long life, free from any shadow of illness. *Wealth* and *health,* these were the gifts of the philosophers' stone, and when you consider further that in the dark ages the ghosts of poverty and illness threatened the people in far more dreadful forms than in the present day, you will probably not think absurd the quotation which I recently saw in an alchemical treatise:

> Everybody must try to get two things, eternal bliss and earthly happiness: the former is granted by the Kingdom of God, which is taught by the theologian, while the latter is granted by the philosopher's stone of the alchemist.

Thus we can easily understand that under the influence of this vital struggle, people who were not

[2] Herrngrund is a small town in Hungary.

trained by profession in critical skepticism overestimated all which looked like a successful transmutation. But what about the scientists of that day? Surely they must have realized the weakness of the chemical proof of transmutation. But the most prominent men of science did not doubt its essential correctness, and this is to be explained by the third pillar of the alchemical creed, namely, that the doctrine of transmutation was in accordance with the universally accepted philosophical conceptions of the day.

We know that in the Middle Ages, and even in modern times, the system of Aristotle ruled the minds of men and that in science his theories were almost as firmly believed as were in religion the dogmas of the church. Now, according to Aristotle, all bodies are formed from a fundamental substance—the "primordial matter." This is pure matter without any form, and therefore not yet truly existent. If united with the properties *cold* and *wet,* it becomes the element of water. If it has the two properties *warm* and *wet,* it becomes the element air. To the element earth were ascribed the properties *cold* and *dry,* and to the element fire the properties *warm* and *dry.* The "four elements" in the Aristotelian sense are therefore nothing ultimate but only modifications of the primordial matter. By changing the properties, one can transmute one element into another. If in such a manner even these foundation stones of the whole sublunar world, bodies as different from each other as are fire and water, could be transmuted, no scholar trained in the philosophy of Aristotle could doubt that bodies so closely allied as are the metals could interchange their differentiating qualities. In manuscripts of the thirteenth century we read, as something almost self-evident, that silver, which in many respects is related to gold, can be changed into real gold more easily than can any other metal. It was quite the same conception which centuries later made the alchemists believe that by making copper white, which can be done by alloying it with other metals, they were on the way towards its conversion into silver, and that by giving to the copper a yellow color—think of the color of brass—they had achieved the first steps of the production of gold. Although, in other regards, such as the specific gravity of the product, the transmutation did not seem to have fully succeeded, it was nevertheless clear that the copper had been transmuted into something better. For, according to his theory of perception, Aristotle did not believe that, in a mixture of two metals, the components remained. This would have led him to the standpoint of his opponents, the atomistic philosophers, who discriminated between appearance and reality. Just as a drop of wine in a barrel of water disappears, according to Aristotle, not only for our senses but even in reality, so the element copper was supposed to be no longer present in brass.

From these brief references to the Aristotelian philosophy, it is easy to see that nothing could be more natural to a scholar educated in these ideas than the transmutation of metals. If the alchemists were not successful, it was surely the fault of those "sooty empirics," for the experimental workers were quite as highly disdained by the scientists of that time as by the philosophers of ancient Greece.

The authority of Aristotle in chemical theories was broken only when experimental research had won its independent position in science. The conviction then became general that metals could not be changed one into another in spite of the doctrine of the "primordial matter" and the transmutability of all bodies; and there gradually developed the belief that elements were not the four hypothetical bodies of Aristotle, nor the three "principles," salt, sulphur and mercury which some alchemists preferred, but were all such substances as could not experimentally be divided into simpler ones. It was urged that instead of fixing the number of elements *a priori* one should try to ascertain this number *a posteriori,* that is, by systematic experimental study. This new program was first developed by Joachim Jungius, a many-sided and ingenious scientist who lived at Hamburg in the first half of the seventeenth century. It is especially remarkable that Jungius further made a very clear attempt to substitute for the doctrine of Aristotle the atomic theory which later played such an important part in the development of modern chemistry. He, the author of a textbook on logic, was such a well-trained thinker that he did not fail to recognize that on the ground of the atomic theory the existence of isomerism and even stereoisomerism could be foreseen. Most of the papers of Jungius were distributed in the form of manuscripts and reached only a small number of sympathetic readers, but shortly after his death, there appeared a book of similar tendency in which the problems were presented in such attractive literary style that they appealed to the widest circles: that was "The Sceptical Chymist," by Robert Boyle. But even the immense influence of Boyle did not succeed in immediately subduing the elements of Aristotle. Only when Lavoisier, holding to the same definition that "a chemical element is a body which can not be resolved into simpler ones," found in the chemical balance a definite instrument for critically testing this belief, did the modern conception of a chemical element find general acceptance. Dalton completed the foundation of modern chemistry by the assumption that every chemical element consisted of a special kind of indestructible atoms, and you know that this theory of the composition of matter dominated the tremendous development of chemistry during the nineteenth century.

This assumption of Dalton's, that there existed as many kinds of atoms with different qualities as there were chemical elements, so completely satisfied the theoretical needs of the chemist that the idea of a primordial matter fell into disrepute, but it was never completely forgotten. There were always some who felt that the existence of a great number of independent elements was unnatural. This feeling was strengthened by the discovery of the periodic system. The harmony which appeared in the ordering of the approximately seventy elements that were then known clearly showed that they did not consist of that number of perfectly independent chemical atoms; one had to return to the conception of something common to all these atoms or abandon all hope of explaining the interrelationships between the elements. Mendeleeff himself, it is true, was so convinced of the stability of the chemical elements that he violently criticized any hint that his periodic table supported the view that there existed a primordial substance. But it is a characteristic of important ideas that they very soon begin to live their own life in the mind of mankind, independent of the brain which first produced them. Just as the deeper understanding of Dalton's theory had to be developed against Dalton's opposition by Gay Lussac, Berzelius and others, in similar manner, quite contrary to the ideas of Mendeleeff, the periodic system has come to be regarded as strong evidence that the atoms of the elements are built up of smaller particles.

This view, derived by observation of the chemical behavior of the elements, was independently confirmed by physical researches. To explain the optical spectra of the elements, physicists were compelled to picture the atom not as a solid sphere but as a very complicated structure consisting of much smaller particles which moved inside the space formerly ascribed to the spherical atom. As to the nature of these particles the investigations of the physicists during recent years seem inevitably to lead to the conclusion that they are nothing else than the positive and negative building-stones of electricity.

One difficulty, however, seems immediately to arise. If the atomic structure of all the elements is so closely akin, how is the constancy of the elements to be explained? Why is it that they can not easily be transformed one into the other? Why did not the alchemists succeed in transmutation? The answer is that while *theoretically* we must concede the possibility of such transmutation as soon as we accept the view that the atoms are aggregations of smaller particles, yet *practically* the forces inside the atoms which hold these particles together may be so strong as to defeat attempts to effect a change.

Let me at this point call your attention to a historical fact which does not appear to be so widely known as it deserves. What I refer to is the theory of the structure of matter which was proposed by Robert Boyle. As experimental chemist, Boyle saw earlier than his contemporaries the necessity of assuming that there were many different chemical elements, but he considered this conception to be merely a necessary aid for the understanding of chemical reactions. As theorist and philosopher he adhered firmly to the old idea of a primary matter and he sought to explain in wholly modern fashion the qualitative differences of the elemental atoms by assuming different numbers and arrangements of the minute particles of the primary substance. That the elements remain unchanged in chemical reactions he considers to be due to the *relative* stability of these atoms. The "corpuscles of gold and mercury" are composed of minute particles of the primordial matter, but are nevertheless (I quote his words) "able to concur plentifully to the composition of several very different bodies without losing their own nature or texture, or having their cohesion violated by the divorce of their associated parts or ingredients." With an insight more remarkable even than that of his successors, Lavoisier, Dalton and Mendeleeff, he thus brought forward more than two hundred years ago a theory for bringing into accord the multiplicity of the chemical elements with the existence of a simple fundamental substance, a theory which modern science now bases upon an immeasurably richer assembly of facts. He lacked every possibility of experimentally demonstrating the composite nature of those substances which the strongest reagents of chemical analysis can not even to-day decompose. The theory of the complicated structure of the atoms of all elements was therefore with him only a philosophical postulate. Yet since he stated "that it will be scarce denyed that corpuscles of compounded nature may in all the wonted examples of chymists pass for elementary," it is self-evident that he always had in mind the possibility that a specially active agent might be discovered which would be able to pull the parts of the corpuscle asunder. He says, "There may be some agent found out so subtile and so powerful, at least in respect of those particular compounded corpuscles, as to be able to resolve them into those more simple ones, whereof they consist."

I have quoted Boyle's exact words because they seem to be almost prophetic of Rutherford's experiments on the breakdown of the atom. Rutherford actually found this "agent so subtile and powerful." Yet previous to his success in experimentally disrupting an element, nature had given a much more definite indication than was furnished by the periodic system, spectra, etc., that the endeavors of the alchemists could perhaps be realized. This indication was found in the newly discovered radioactive bodies which furnished examples of chemical elements which *spontaneously* changed into other elements.

After Rutherford and Soddy had conceived the idea that the radiation from such substances resulted from the disruption of these radioactive bodies and the expulsion of fragments of the atoms with enormous velocity it seemed to them probable, for reasons which I will not take the time to present, that these fragments were nothing else than atoms of helium. If their supposition was correct, it appeared to follow that one should be able to detect the formation of the element helium from radio-active bodies and Ramsay and Soddy actually succeeded in experimentally proving that when radium breaks down helium is formed. This was the first instance in which one element, helium, was evolved from another element, radium. Both of them are real elements, for they can not be resolved by chemical means, and both show different chemical qualities and characteristic spectra. The experiment, therefore, established beyond a doubt the possibility of the transmutation of elements. But in a transmutation of this character it has been found that man has no power to influence it. The production of helium from radium takes place with absolute constancy, and no means at man's disposal, neither extremely high nor extremely low temperature, nor very high nor very low pressure, nor electric or chemical energy, can quicken or retard the rate of the transmutation. The radioactive substances appeared therefore to support fairly well the view that many held in the Middle Ages and even later. They thought that elements were formed in nature, that for example in the depths of the mountains bismuth changed in the progress of time into silver, and silver into gold, but that man could do nothing except to interrupt this ripening process at the proper moment and withdraw from the influence of the "mountain fire" the noble metal that had been produced. This withdrawal at the proper stage was deemed necessary, for they believed that with the further lapse of time the silver and the gold deteriorated and again reverted to base metal. (It may be pointed out in this connection that the alchemists claimed also to possess a substance, which as a negative philosophers' stone could destroy gold. This negative body was naturally much less highly prized than the real philosophers' stone.)

Several years after the experiments of Ramsay and Soddy, it developed that radioactive substances not merely show the elemental change which takes place of itself, but also have put in our hands the agent which can cause such a change at the will of the experimenter. It was again Rutherford who established this fact. His experiments, which are to be regarded as the first successful ones of alchemistical nature, are of such extraordinary significance that I will endeavor to give you an approximate idea of his technique so far as that is possible without the use of the special phraseology of radioactivity. A metal tube some decimeters in length is placed in a carefully darkened room and a radioactive preparation is put into one end of this tube. The substance sends through this tube rays which are themselves invisible to the naked eye. The preparation can be pushed into the tube to any desired distance. A glass plate in the further end of the tube is coated with zinc sulphide, a substance that possesses the property of glowing under the action of radium rays, just as the well-known Röntgen screen renders the X-rays visible. When the radium preparation stands at a distance of more than seven centimeters from the screen the latter does not glow, because this particular kind of radioactive rays travels only that distance. If a thin sheet of aluminum is placed between the radium preparation and the zinc sulphide screen it is to be expected that this barrier to the rays will extinguish the glowing of the screen at a shorter distance than seven centimeters. Experiments show that although the screen now becomes almost entirely dark there is still perceptible a very weak luminosity caused undoubtedly by the action of a small residue of the rays. But these residual rays behave in a very surprising manner. They reach the screen even when it is removed to a distance of ninety centimeters, although at this greater distance the glow is extremely faint. One can scarcely imagine a less striking experiment. The glow of the screen is indeed so feeble that only the trained eye can perceive it under the most favorable conditions. We must therefore marvel at the boldness of Rutherford, who ventured to draw revolutionary conclusions from this apparently negligible phenomenon. He argued that if behind the sheet of aluminum rays appear which reach further than those which fall upon the aluminum, these new rays must come from the aluminum itself; in other words, the aluminum atoms must be disrupted and send out particles from their inner structure, and the glow of the screen at a distance of ninety centimeters must be due to the impact of these fragments of the atoms. These particles can easily be caused to deviate from their paths by electrical or magnetic forces, and from the amount of this deviation Rutherford concluded that they are particles of the size of the hydrogen atom. This means that the aluminum atom has been broken down and that hydrogen has been generated, although in so small an amount that it would take about a million years to obtain in this manner one cubic centimeter of the gas.

This experiment demonstrated actual atomic disintegration, and it has been found by Rutherford and by investigators in the Radium Institute of Vienna that not only aluminum, but also quite a number of other elements, such as sodium, potassium, phosphorus and chlorine, break down in this manner. This evidence seems clearly to indicate that hydrogen is the long-suspected primordial element. In spite of the unimpressive character of this experiment, the conclusions which one may draw from it are of far-reaching significance, and we have here a striking example of the fact that the importance of an investigation is to be judged not by its external brilliancy, but rather by the deductions that can logically be based upon it.

Thus we see that in a certain sense radium possesses the first and principal property ascribed to the philosophers' stone: it has the power of transmuting elements, although not of producing gold. And, oddly enough, even in respect to the second property which was ascribed to the philosophers' stone radium seems to have gotten something from its fabulous predecessor: it is a very valuable aid in the treatment of some severe diseases, although not a perfect remedy for every illness. So that to a certain degree the radium rays really produce the two very different effects of the philosophers' stone, transmutation and healing.

But in another direction this modern substitute of the philosophers' stone brought a severe disappointment. You remember the expectation of the alchemists that "by projection" the stone would transmute many thousand times its own weight. Unfortunately quite the contrary happens in such a case as the breakdown of aluminum by radium rays, for many hundred thousand atoms of the new stone must disintegrate before only one atom of hydrogen is formed.

The spontaneous disintegration of the radio-elements, and particularly Rutherford's success in artificially disrupting the atoms of some other elements, inspired investigations upon the artificial transmutation by other means. For the disruption of elements in the way shown by Rutherford is, strictly speaking, nothing but "induced radioactivity," if we may employ a term originally coined for another phenomenon, but which to-day is no longer used. With very large quantities of radioactive material, we can "induce" a hardly detectable activity in elements which are usually inactive. Of course it would be much more valuable to find a method of transmutation not limited to this very expensive and very slightly effective form of energy, and this thought revived the alchemistical experiments with renewed force. Scientific opinion had now reverted to the view of some critical scientists in the alchemical period, which is perhaps in the most concise form stated in a book by the polyhistoric Jesuit Athanasius Kircher: "Alchymia scibilis est, non tamen adhuc scitur." ("Alchemy is a science not yet known, but which may become known.")

Our return to this very view explains why to-day not only the daily papers but also scientific journals are ready to accept contributions to this theme. Even if we were to limit the present review to the articles appearing in scientific journals, the number of papers would be too large to allow of full discussion. But this need not cause us sorrow, because the publications of some of these modern authors remind us of the chemical ignorance and credulity of their ancient forerunners. Let me call to your attention, however, one or two publications of a higher type which caused wide discussion. You may have heard that just before the war, from the laboratory of Ramsay, Collie and Patterson announced that helium and neon were formed when an electric discharge was sent through hydrogen that was in a closed vessel. But shortly afterwards, Strutt, the present Lord Rayleigh, showed that this experiment could not be repeated if air, which always contains both helium and neon, was perfectly excluded. Nevertheless the assertion that they are thus formed was repeated a few months ago in the Proceedings of the Royal Society of London, but this experiment fails to convince one that Strutt's criticism is incorrect.

Many of you are doubtless familiar with the fact that last year a German chemist, Miethe, and a Japanese physicist, Nagaoka, independently asserted that by electric discharge gold may be formed from mercury. It is a special irony of fate that in this case alchemy reappeared in the old-known vestment of the artificial production of gold. Gold is particularly apt to cause this error because it may be present in various materials but so finely distributed as to escape detection by ordinary methods of analysis. But in various ways the gold may be concentrated to such an extent that it can now be detected without difficulty. Concentration was, therefore, in all the ages very often misunderstood as production. In the experiments of Miethe and of Nagaoka quite the same happened. To-day extremely small quantities of gold can be recognized and the scarcely visible beads of gold which Miethe could identify under the microscope would have entirely escaped the observation of the alchemists of the seventeenth century. But if in the final product we are satisfied with such small quantities of gold, this necessitates the employment of much more delicate methods of ascertaining that the original material is perfectly free from gold. Hence the difficulties and the danger of error have been about the same in all centuries. That this modern "transmutation," like that of old, amounted only to a concentration of gold and not to its genesis, has been proved by Tiede, Riesenfeld, Haber and their coworkers in Germany and by Sheldon, Estey and Harkins in this country.

Permit me, before closing, to mention the latest experiments upon the transmutation of elements. These are described in an article by my assistant, Dr. Peters, and myself in the last number of the *Journal* of the German Chemical Society, under the title, "The Transmutation of Hydrogen into Helium." I am compelled to confess to you that I was not only interested in the literature of alchemy, but I even ventured to take up experiments along this line. For some reasons, particularly because of the sharpness with which the smallest quantities of helium can be recognized, I thought it promising to test the transmutability of hydrogen into helium and the paper mentioned above contains the results of experiments which we have carried on during the last three years. To discuss the details of these experiments would carry me beyond the limits of an address upon the general subject of alchemy. This transmutation we accomplished not by electric discharges, as tried by others, but by simple catalytic action. It is my hope that they soon may be substantiated by others. I hope further to be able here at Cornell to show that these experiments work as well in the new world as in the old.

If at the end of this lecture we try to compare ancient and modern alchemy, we can not fail to realize that modern alchemy, at least in so far as serious workers are concerned, is a matter of theoretical knowledge, not of practical utility. This distinguishes it from the attempts of the many thousands who carried on alchemistical work in the earlier centuries with the purpose of getting rich as quickly as possible. But let us not be unjust toward those in earlier times who were interested in alchemical experiments in the same manner as in the other theoretical problems of natural history. As early as in the thirteenth century the Franciscan monk, Roger Bacon, distinguished between *alchimia practica* and *alchimia speculativa.* Later we note that Newton, Leibnitz, Tycho de Brahe and Goethe, to mention the names of only a few of the greatest, showed in some periods or during their whole life a distinct interest for this much-disputed science, and their interests are surely to be classified under *alchimia speculativa.* But such men were exceptions in the olden time, as great exceptions as are to-day, we hope, the men who expect pecuniary profit from such experiments. Of course, we will not deny the possibility that sometime in the future practical profit may result. We should not forget that, for example, wireless telegraphy, with its enormous importance for most of the branches of modern civilization, has its origin in the purely scientific and practically useless experiments of Heinrich Hertz. It is quite impossible to prophesy that alchemy will never have practical importance, but any one who to-day would enter this field with the idea of deriving pecuniary advantage from it will surely be disappointed.

These considerations remind us of the three pillars on which old alchemy rested. We see that two of them rotted away. The pretended transmutation of visible quantities was recognized as a mistake, and the longing for riches and health, which by no means has disappeared in our times, can be more quickly and safely realized in other ways than by experiments in transmutation. But the third, the pillar of natural philosophy, as we may concisely call it, still stands. The tendency which induced the old Greek philosophers to search for a uniform primordial matter behind the complexity of phenomena is still at work in the considerations of modern natural philosophers and, curiously enough, this struggle at last shows success. The ancient hypothesis that a uniform primordial matter might exist has been substantiated by modern knowledge, at first theoretically and later experimentally.

Here we arrive at the gate of a new problem. Its discussion belongs to the field of philosophy rather than of chemistry and consequently I will only briefly touch upon it in this lecture. How is it possible that philosophers, so often despised by naturalists, could predict a scientific result centuries in advance? Different answers are possible. One could regard it as a mere casual coincidence of some old doctrines with the present state of our experimental knowledge. In this connection it is worth while to remind oneself that only one and a half centuries ago the well-known French chemist, Macquer, pointed out the important coincidence that the four elements of Aristotle were substantiated by the results of the most modern chemical analyses. But I am not willing to concede that the conclusions of to-day are based on such an unsteady foundation as that so-called "experimental proof for the Aristotelian elements." Secondly, following the school of the New-Kantian Philosophers, one could regard our problem as an example that the laws of nature are in the deepest sense created by the human mind and do not exist in an objective world. It is quite impossible on this occasion to discuss this philosophical tenet which has so large a number of followers, but I think you will agree with me that careful scrutiny of the very history of alchemy shows that it does not support this doctrine. Astrology, to which alchemy belonged, attempted to prescribe to nature the laws which it should follow, laws which, developed in detail, were expected to govern the mutual relationships between metals and planets, between microcosmos and macrocosmos, etc. But nature did not consent to be governed by these laws, and generations of thinkers could not impress them upon her. But when the chemist, following the example of Boyle, abandoned the idea of establishing laws *a priori* and entered upon the experimental study of natural phenomena, the way was opened for the successful development of chemistry. And thus we see that in contrast with the philosophical standpoint mentioned above, the history of chemistry can only strengthen our belief that the laws of nature are independent of the human mind in their existence, not in their conception, a belief shared since antiquity by some schools of philosophy.

We must therefore regard the return of modern science to the old ideas of the Greek philosophers as a sign that they have correctly realized a principle which was formulated in different ways during the development of science and which Kepler worded as follows—"Nature likes simplicity." This term "simplicity" does not mean that nature always acts in the simplest manner that can be imagined. Kepler's own example serves to demonstrate this. The astronomical system which he developed and in which it was assumed that the planets revolved in elliptic orbits is infinitely more simple than the old one which it replaced, but elliptic orbits are not the most simple that we can imagine: circles would be still simpler, but the planets do not rotate in circles. The same considerations hold as regards the idea of primordial matter. Strictly speaking, we do not now think that there is one primordial substance but rather that there are two. The atom of hydrogen consists of both positively and negatively charged particles, protons and electrons, and it now does not seem probable that we will reach a simpler view of this structure. But the general tendency of the Greek philosophers, especially of those belonging to the Atomistic School, to remove complexity as far as possible and to assume quantitative differences instead of the qualitative ones we must regard as a sound principle of natural philosophy throughout the ages. Therefore, if modern and ancient alchemy are very closely in agreement as to the existence of a primordial matter, this should be regarded not as a mere accident nor as an impress of human ideas upon nature, but as a distinct evidence that from earliest times eminent thinkers have rightly conceived the unity in the multiplicity of things. The greatest significance of modern alchemy is that it has enormously strengthened this early conception and has furnished convincing proof of the unity of the material universe.

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A SUGGESTED COURSE IN PLANT PHYSIOLOGY

Lepeschkin,[1] in his recent book "Pflanzenphysiologie," states that plant physiology can only further develop hand in hand with physics and chemistry. Van't Hoff[2] also recognized the dependence of one branch of science upon another. He represented this relation of the sciences by arranging them in order of their increasing complexity—mathematics, physics, chemistry and biology. The rapid development in the last few years of new and more exact methods in physics and chemistry makes this relation appear much more important than it did a generation ago. Thus a student who endeavors to further the development of plant physiology must be prepared in the fundamental principles of at least three branches of science. Under the system of prescribed work common in most American universities, a student has little opportunity to get more than the required courses for a major in one department and a minor in another. The prerequisite for plant physiology as found in all university catalogues is elementary botany. An examination of the catalogues of thirty-three of the larger universities and colleges offering courses in plant physiology shows the following:

No prerequisites in physics or chemistry	14
Elementary physics or chemistry desirable or required	19
Required chemistry or physics beyond an elementary course	0

When one considers the complexity of physiological problems, it is evident that the preparation of students for progressive work in plant physiology is quite inadequate. Experience with advanced students of botany extending over a period of six or seven years has shown that only the exceptional ones have the ability to do experiments accurately which involve simple physical and chemical methods. If we admit the truth of Lepeschkin's contention, it is difficult to foresee a rapid development of plant physiology as a

[1] Lepeschkin, W., "Pflanzenphysiologie," Vorwort, 1925.

[2] Van't Hoff, J. H., *Zeit. für Anorganische Chemie*, 18, p. 1, 1898.