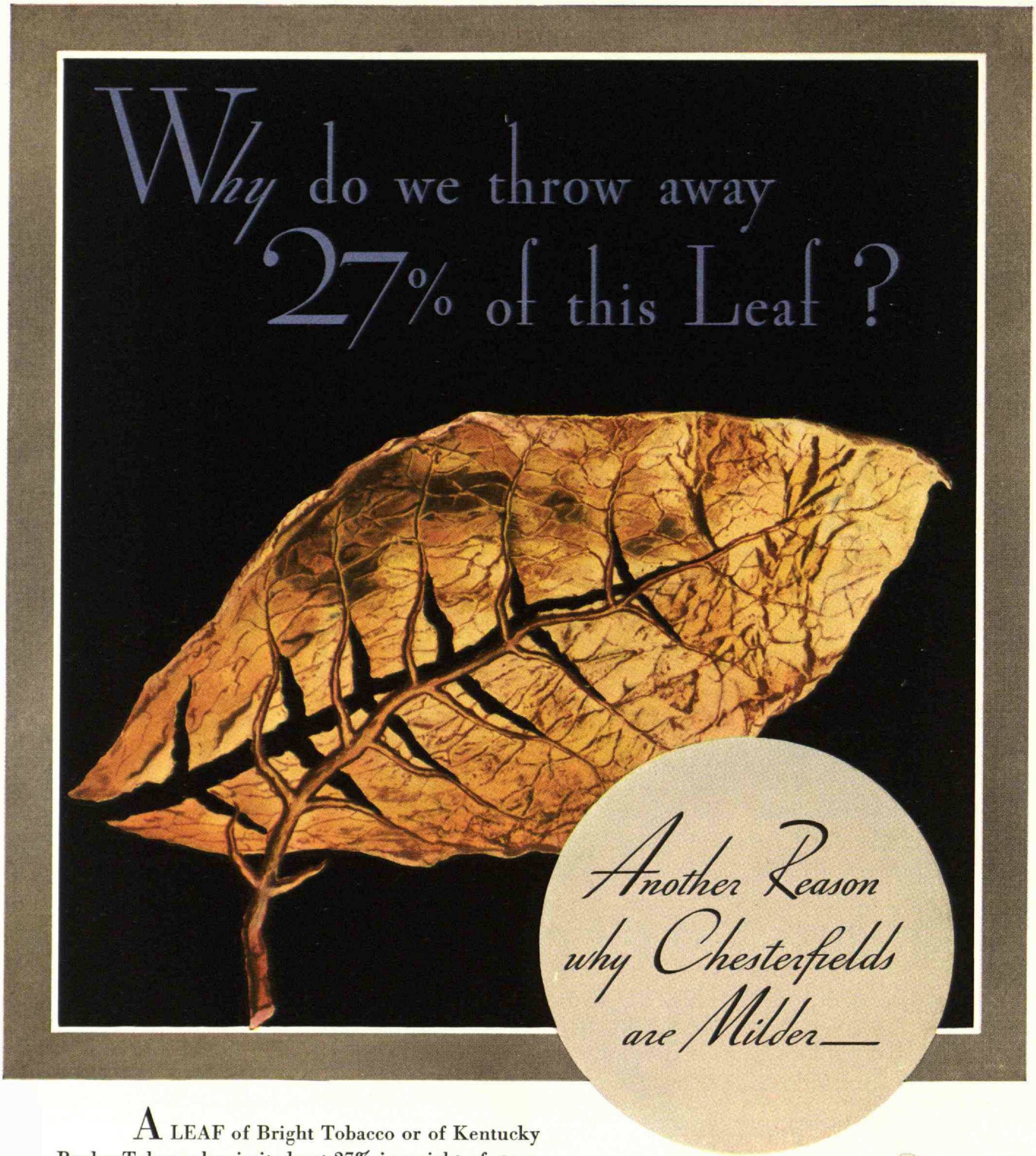
February 1933

TECHNOLOGY REVIEW



A LEAF of Bright Tobacco or of Kentucky Burley Tobacco has in it about 27% in weight of stem.

The stem is woody. It does not contain the same ingredients as the tobacco. It does not burn like tobacco.

There would be necessarily a sort of rankness or bitterness about the smoke from the stem. This 27% in weight of stem, therefore, is removed before the leaf tobacco is used in Chesterfields.

Everything is done that can be done to make Chesterfield milder and taste better.

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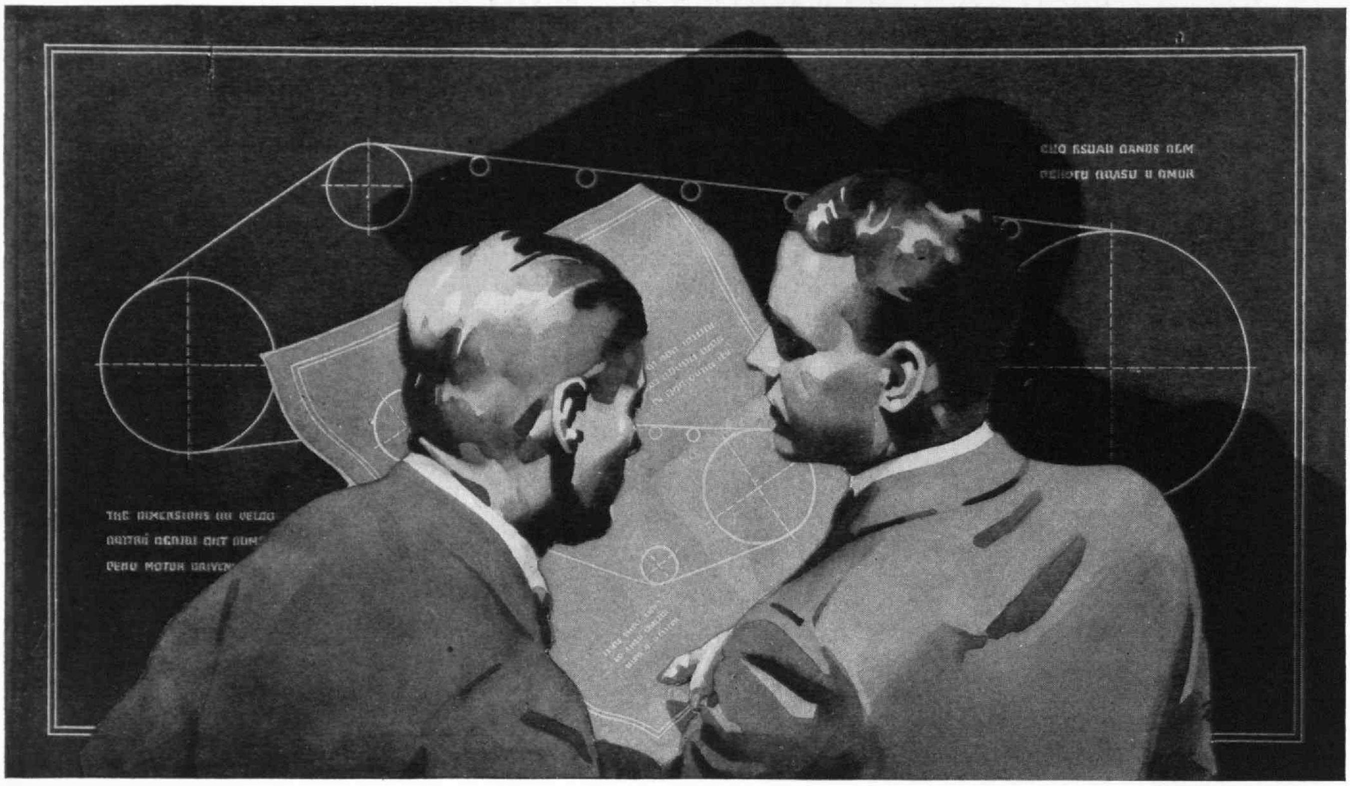
THE TABULAR VIEW

AT the end of every year it has become customary for publications to survey the achievements of that year. Feeling that looking into the future is equally as important as recalling the dear, dead past, The Review in this issue has worked a variation of the yearly survey vogue by presenting a forecast of what may be the outstanding developments of 1933. In short, it anticipates by 11 months many of the achievements that doubtless will be listed next January by publications which catalogue engineering achievements. The method by which the curve of engineering progress has thus been extrapolated has been explained on Page 170, but it is meet to add here that The Review Editors are grateful to the many engineers, educators, and journalists who not only suggested trends and projects to be included in this pre-view but recommended the exclusion of many others.

DESPITE his burdens as President of M. I. T., Dr. KARL T. COMPTON is still actively engaged in scientific research. He speaks, therefore, not only as the administrator of a great scientific institution, but as one who knows intimately the trials and triumphs of the laboratory. The dual nature of his work peculiarly fits him to describe the technique and objects of modern physical research in terms understandable to the layman, and his article on Page 165 is a scientist's history, addressed to laymen, of man's efforts to transmute the elements. At the risk of violating the rule of etiquette prohibiting "pointing," The Review Editors call the attention of all readers to this article as an example of lucid scientific exposition. Those who would be informed of the trends and aims of modern physics in general and of the particular efforts which have been directed towards disintegrating the atom, should not fail to read "The Battle of the Alchemists." ¶ Professor ERWIN H. SCHELL, '12, is Head of M. I. T.'s Department of Business and Engineering Administration. This Department has been conducting some very revealing studies of the occupations, salaries, and progress of its graduates. Readers of The Review will recall the article in the March, 1930, issue entitled "What Engineers Become." Professor Schell has taught not only at M. I. T. but in the Harvard School of Business. He has also practised as a consulting engineer on problems of industrial management.

HAROLD G. CROWLEY, '23, is an experienced pilot and aviator. He was in charge of air operations for the two Forbes-Grenfell Expeditions for the mapping of the Labrador Coast. ¶ Dr. TENNEY L. DAVIS, '13 is a Contributing Editor to The Review and an Associate Professor of Organic Chemistry at Technology. Aside from his contributions to various technical journals on chemical research, he has written much on the history of science, and he participates in the editing of several journals devoted to science history. He contributes every month to *The Trend of Affairs.*

A Man and a Plan



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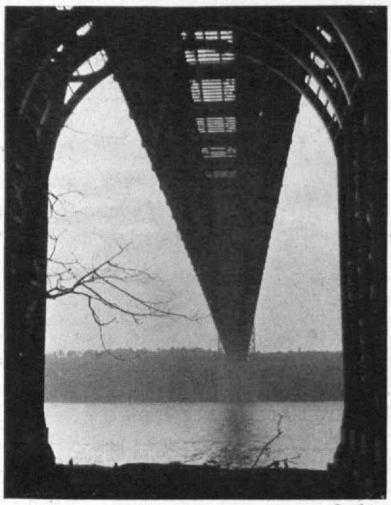

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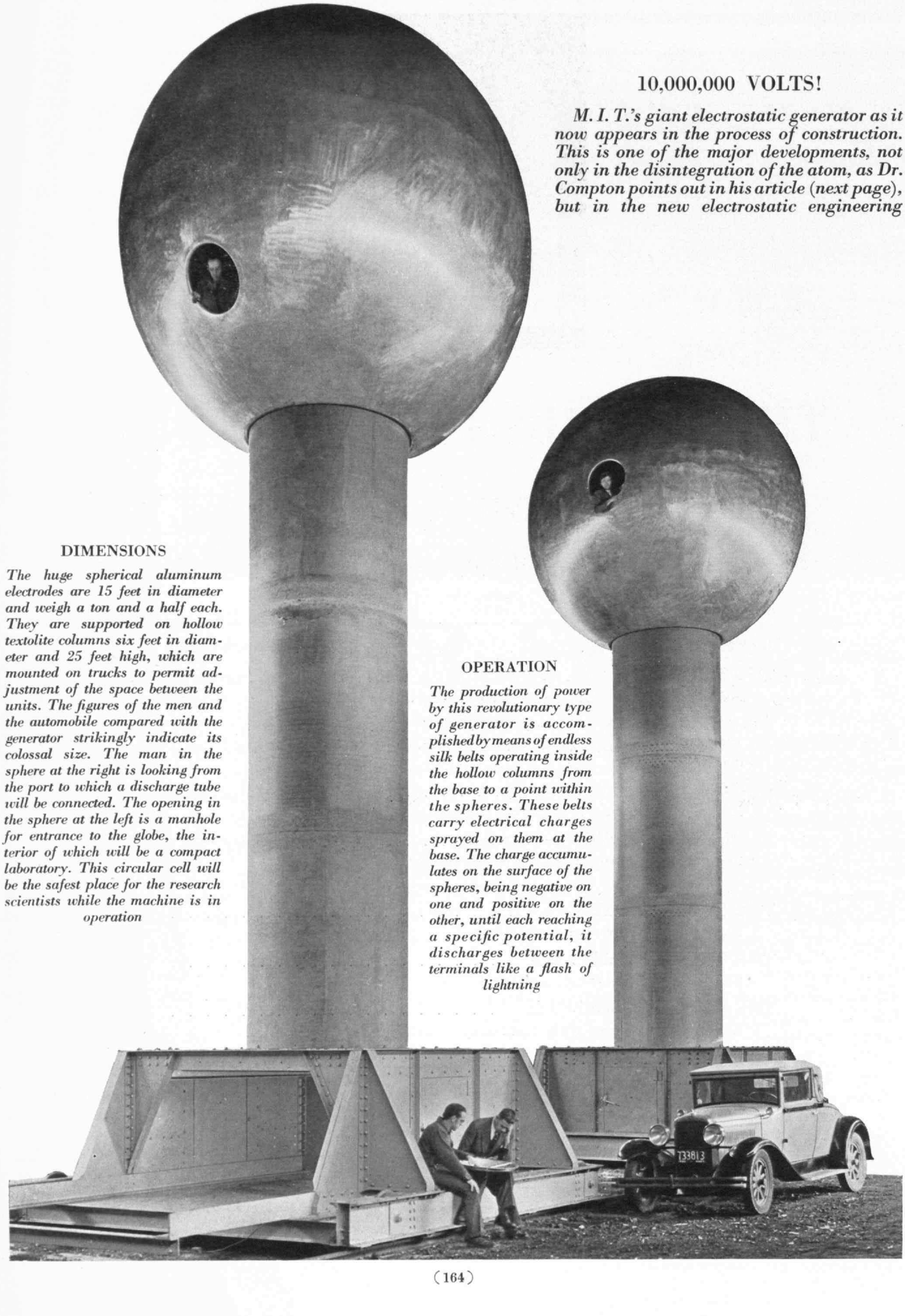


10,000,000 VOLTS!

M. I. T.'s giant electrostatic generator as it now appears in the process of construction. This is one of the major developments, not only in the disintegration of the atom, as Dr. Compton points out in his article (next page), but in the new electrostatic engineering

DIMENSIONS

The huge spherical aluminum electrodes are 15 feet in diameter and weigh a ton and a half each. They are supported on hollow textolite columns six feet in diameter and 25 feet high, which are mounted on trucks to permit adjustment of the space between the units. The figures of the men and the automobile compared with the generator strikingly indicate its colossal size. The man in the sphere at the right is looking from the port to which a discharge tube will be connected. The opening in the sphere at the left is a manhole for entrance to the globe, the interior of which will be a compact laboratory. This circular cell will be the safest place for the research scientists while the machine is in operation

OPERATION

The production of power by this revolutionary type of generator is accomplished by means of endless silk belts operating inside the hollow columns from the base to a point within the spheres. These belts carry electrical charges sprayed on them at the base. The charge accumulates on the surface of the spheres, being negative on one and positive on the other, until each reaching a specific potential, it discharges between the terminals like a flash of lightning

THE
TECHNOLOGY
REVIEW

Vol. 35, No. 5 February, 1933

The Battle of the Alchemists

Attacks, Ancient and Modern, on the Citadel of the Atom

BY KARL T. COMPTON

HOW MODERN EXPERIMENTAL PHYSICISTS ARE MARSHALLING ALL THE RESOURCES OF SCIENCE TO STORM THE SEAT OF THE ATOM, AND THUS TO DISPEL MAN'S GROSS IGNORANCE OF THE MOST POWERFUL ELEMENTS OF HIS MATERIAL WORLD

LONG, long ago, when gods mingled among men, the god Hermes established the first laboratory on this earth and discovered many new and interesting substances by subjecting various kinds and mixtures of earth and rocks to the influence of fire or water. Not being blessed with the protection of the U. S. Patent Office, he kept his discoveries secret by putting his products into jars which were carefully closed and sealed. Hence arose the term "hermetically sealed," and the chemistry and metallurgy which thus sprang from the god Hermes was long known as the "hermetic art."

According to another legend, a group of wicked angels were expelled from heaven and settled on the earth, taking unto themselves human wives. To these wives the fallen angels disclosed the magic secrets of science, and the wives recorded these secrets in a book which was called "Chema" — the first handbook of chemistry. Thereafter those who practised this art were called "alchemists." The ancient historian Tertullian tells of these fallen angels who thus revealed to mankind the knowledge of gold and silver, precious stones, and medicines.

However these things may be, there is ample documentary evidence from Egypt that alchemy was a flourishing science and art in Alexandria before the third century A.D. and it is probable that a famous book whose destruction was ordered by Diocletian in about 290 A.D. was one containing receipts and formulas for producing alloys to simulate gold and silver and for manufacturing artificial jewels.

These early alchemists, like modern chemists, were guided by a theory. Like our modern theories, theirs was imperfect and like ours it was an attempt to interpret and predict on the basis of a generalization of experience. They started with Aristotle's conception of four fundamental elements — earth, water, air, fire. (These are not so different from, for example, the notion of the four states of matter proposed by Sir William Crookes: the solid state, the liquid state, the gaseous state and the ionized state.) The alchemists also believed that there was one basic entity — *prima materia,* which was identical in all bodies but which took different forms according as it was brought into combination with one or more of the fundamental elements, earth, water, air, and fire. (In our time, we recognize this *prima materia* to be electricity existing in two forms as electrons and protons.) By action of earth, water, air, or fire on the various manifestations of the *prima materia,* these alchemists performed oxidation, reduction, solution, smelting, alloying — and it is not to be wondered that they interpreted their work as a "transmutation of matter." From their standpoint it was transmutation.

On account of the variety of colors which their compounds exhibit, and their ease of chemical change, it is not surprising that mercury and sulfur were of particular interest to the alchemists, and were supposed to be quite close to this *prima materia* which they sought. It is not so easy, however, to understand their choice of some of the other substances. For example, Beauvais, in 1250, classified matter as consisting of four spirits and six bodies: the four spirits were mercury, sulfur, arsenic and sal ammoniac; and the six bodies were gold, silver, copper, tin, lead and iron — of which gold and silver were pure and the rest impure.

We must not despise the efforts of these alchemists. Among them were numbered such great minds as Newton, Leibnitz and Boyle, all of whom studied and practised alchemy, though they were beginning to realize its defects. But from this mixed ancestry of legend, experiment and magic was born the modern science of chemistry!

IN THE rapid rise of chemistry during the 19th Century, a beautiful and nearly perfect scientific theory of atoms and molecules was developed as a far extension of the ancient philosophical ideas of atoms of Democritus. The soundness of this theory was demonstrated by the fact that it was only extended, but not essentially changed, when physicists devised methods of counting and weighing molecules individually, and of measuring their separate velocities and the energy and force required individually to pull them apart into their constituent atoms. The puzzles of the old alchemists were solved by the recognition of two classes of substances, elements and compounds, of which the former retain their identity throughout all action of earth, water, air, fire — or any other physical or chemical agent. Thus alchemy, which sought to transmute the elements, became supplanted by chemistry, which occupied itself with the various combinations of these elements to form chemical compounds. "Alchemy was dead! Long live chemistry!" But is this the end of the story?

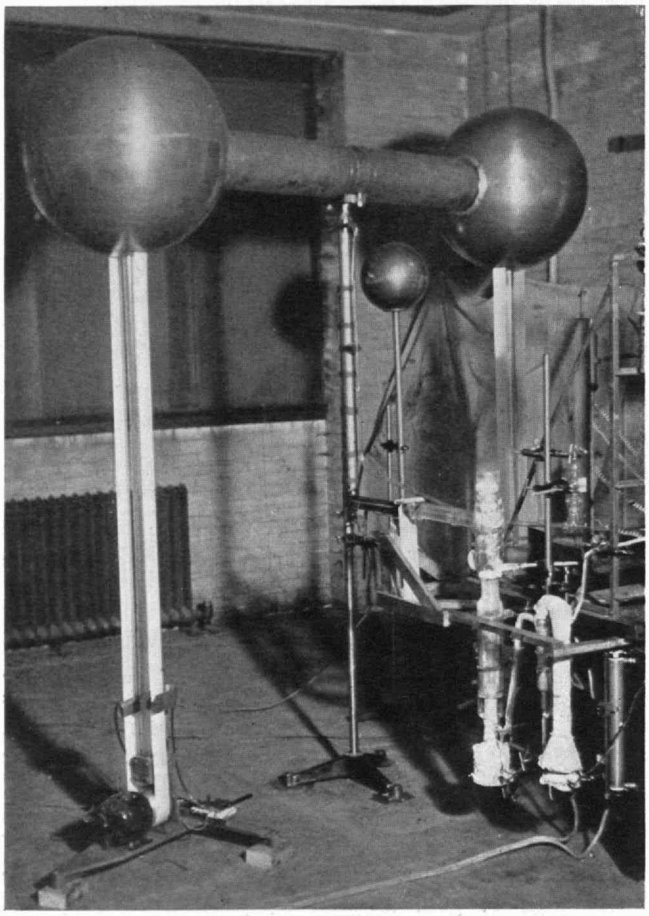
The text book in which I first studied chemistry in 1904 defined an atom as "an indivisible, indestructible and unchangeable unit of matter." Yet five years earlier J. J. Thomson and his colleagues had split up atoms into electrons and positive ions and within twenty years it had come to be realized that the atom could be very changeable, could in fact exist in any one of an infinitely infinite variety of conditions commonly termed "excited states." Thus the atom is *not* indivisible and is *not* unchangeable. But these changes do not really affect the identity of the atom; the electrons which it loses come back to it or others take their places; it does not stay in its excited states very long but reverts to its normal state usually within a hundred millionth of a second. So, after all, the atom is still the same old atom, and its new attributes which have been discovered by the physicists, while they add to its versatility, do not undermine its fundamental character of good old-fashioned chemical respectability.

In its ionization and its excited states the identity of the atom is like that of a man. You may cut off his hair or his nails; they come back. You may even amputate a finger or a leg, but he is still the same man. Or you may excite him to a fit of anger or activity, but he cools down again. Through it all he retains his identity through that mysterious something that we call his soul.

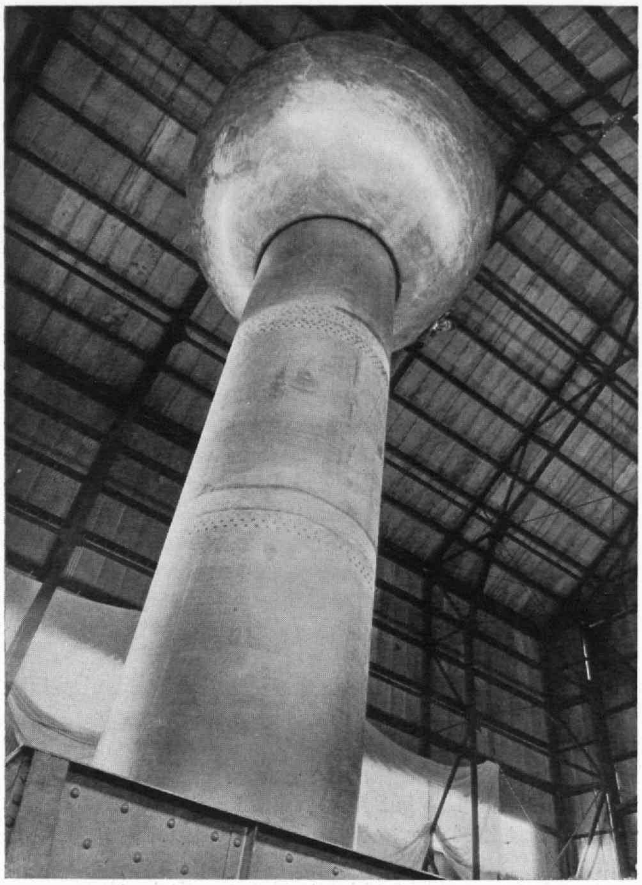
Now the soul of an atom is its nucleus. Through ionization and excited states this nucleus remains, so far as we know, unchanged. Until we know the nucleus of the atom we no more know the atom than do we know a man by his hair, nails, fingers or legs. What do we know about the nucleus?

Beyond a doubt we know very exactly the mass of every kind of atomic nucleus and that it is composed of a definite number of protons and electrons, which we know, and that it has a positive electric charge, which we know accurately. Thus the hydrogen nucleus consists of a single proton; the helium nucleus consists of four protons and two electrons and has a mass which is 0.77% less than the sum of four hydrogen nuclei; the uranium nucleus consists of 238 protons and 146 electrons, etc. We also know that the nucleus is very small in comparison with the over-all atomic dimensions, i.e., much smaller than 10^{-10} cm. in diameter — probably less than 10^{-11} cm.

We have good reason for thinking that some atomic nuclei are magnets, with a magnetic moment equal to that of one electron, and that this is true if there is an



Van de Graaff's first model 1,500,000-volt generator, with a discharge tube of new design connected between the terminals. The spheres in this model were two feet in diameter as compared with the 15-foot diameter spheres in the new generator at Round Hill. The characteristics of the tube shown in this picture are described in the current issue of the Physical Review



Looking up one of the two giant spherical terminals of M. I. T.'s new electrostatic generator. (*See pages 164 and 189.*)

odd number of electrons in the nucleus. But there are some phenomena which have not as yet been reconciled with this idea of the magnetic properties of the nucleus. Furthermore there is reason to believe that the proton configurations in the nucleus may also contribute a magnetic moment, far smaller than that due to the electrons.

We know that atomic nuclei are deformable under the action of intense forces, such as can only be exerted by electrified particles, like alpha particles from radium, which are shot toward the nuclei with such tremendous velocities that they may come very close before being deflected away by the repulsive force between nucleus and alpha particle. When their distances are greater than 10^{-10} cm., this force varies inversely as the square of the distance as nearly as we can tell, which shows us that the nuclei are practically electrified points so far as distances greater than 10^{-10} cm. are concerned. With closer approach, however, the force departs more and more from the inverse square law, showing that the nuclei have a structure or arrangement of electricity within their tiny domain, and that this structure may be deformed by strong electrical forces. All this information is inferred from studies of the angular distribution of scattering when alpha particles pass through thin films.

We know that the nuclei are the seats of tremendous energies, as evidenced directly by phenomena of radioactivity and indirectly by certain aspects of the theory of relativity to which I will refer later. From radioactivity, also, we find that groups of four protons and two electrons (helium nuclei) appear to be particularly stable configurations within the larger structure of the nuclei of heavy atoms. We call these groups "alpha particles."

Having said these things, we have told almost everything that is known about atomic nuclei. Many other things we would tremendously like to know. How are the protons and electrons arranged in the nucleus? What is their state of motion? What forces hold them together? How is their energy stored away? Under what conditions can the nucleus be disrupted or this energy released, or the configuration changed? To all of these questions we must confess almost total ignorance.

Think for a moment what this ignorance implies. All of the positive electricity, most of the negative electricity, most of the mass and by far the greater part of the energy of the world reside in atomic nuclei. We must therefore confess that we know as yet very little about most of the world of matter, electricity and energy. This should make us rather careful about making such statements as one recently published by a leading exponent of the new school of theoretical physicists who wrote, "The underlying physical laws necessary for the mathematical theory of a large part of physics and the whole of chemistry are thus completely known. . . ." It should also warn us against such rash terms and statements as "the breakdown of the law of causality" and "the law of conservation of energy does not apply to individual processes, but only statistically as an average." It would be far better simply to admit that, successful as we have been in describing by equations much of the behavior of those extra-nuclear electrons, we are still grossly ignorant of the most powerful elements of our material world.

A very crude analogy will illustrate the relative advancement of our present state of knowledge of atoms. Liken the nucleus to a building and the extra-nuclear electrons to a group of pebbles resting on the steps of a fire escape on the outside of the building. As we observe these pebbles, we notice that, from time to time, a pebble falls from one step to another. We do not understand why it falls, and make various attempts to hypothecate some model or mechanism which will explain the dropping of these pebbles. Bohr, Sommerfeld, and Langmuir all take their turn, but none of them invents a mechanism which satisfies all of the observations. We become discouraged with model building. Finally a brilliant young man, Heisenberg, proposes that we do away with models entirely and concentrate entirely upon the observable quantities — the steps, the pebbles and their falling. He finds a mathematical expression which accurately correlates the height of the steps (energy levels) with the probability that a pebble will fall (radiate) from one step to another. To the mathematician this accurate formulation of the mathematical relationship between the observable quantities is a complete and satisfactory explanation or theory. The physicist, however, guided perhaps by instinct (which is the accumulated wisdom of the ages) rather than by formal logic, is not satisfied. He feels impressed but a bit confused by the logic of the mathematician, and also a bit distrustful. Down in his heart he feels that there must be something more than a law of probability which makes those pebbles drop. He goes to in-

A model of the Van de Graaff generator built by Dr. Merle Tuve at the Department of Terrestrial Magnetism of the Carnegie Institution in Washington. It has a six-foot sphere and is shown with an x-ray tube connected between the terminal and the earth. Its outdoor operation has been interrupted by the bugs and fireflies drawn to the sphere

vestigate. He finds the door of the building locked. He pushes; he knocks; he gets help; he rigs up a machine to batter down the door; he makes a small hole through which he sees signs of activity within the building; he builds a bigger and better battering ram; he finally breaks down the door and goes in. Within the building he finds a huge factory; giant cranes carry around great masses of material; enormous machines press, hammer and draw this material into various shapes. Stupendous forces are at work. The building shakes, and from time to time a little pebble on the fire escape is shaken down from one step to another.

So, I suspect, may sometime be resolved the peculiarities and puzzles of our present quantum theory — by small external manifestations of the enormous energy which we know to exist within the nucleus, but about which we now know too little even to make a guess as to how it may influence our present theories.

BE this as it may, where have we left the alchemist? We left him dead, killed by the chemist who had destroyed his hopes of effecting the transmutation of elements. But now the physicist has brought him to life again, with renewed vigor and enthusiasm. For if the atomic nucleus is a structure of electrons and protons, it should be possible to break up this structure or to add to it, and thus to change one chemical element into another. The agencies are no longer earth, water, air, and fire, but electricity and probably electrical particles shot with tremendous speeds into nuclei. The goal is not gold and silver, but energy. And with the alchemist, who is a practical man trying to get something, is working the physicist, who is not an impractical man, trying to learn something. In fact they are one and the same man.

A most significant event in this story was the discovery of radioactivity by Becquerel thirty-six years ago. Its significance became evident when Rutherford showed that the alpha and beta particles are, respectively, helium nuclei and electrons which are shot out of the nuclei of radioactive atoms with tremendous speeds, approaching that of light. Its significance became greater when Rutherford further showed that the parent atoms, in thus ejecting these particles, transform into atoms of different chemical elements. The law of this transmutation was stated by Fajans: expulsion of a beta particle changes the atom into the next higher one in the Periodic Table, and the expulsion of an alpha particle changes the atom into one which is two steps lower in the Table. Here, for the first time, were authenticated cases of transmutation of elements.

The energies liberated in radioactive transformation are prodigious, in comparison with the amount of material involved. For example, radium continually gives off enough energy to raise its own weight of water from freezing to boiling temperature every hour. By the end of 2000 years it will be only half used up. By the time it is completely transmuted into its final products, helium and lead, any given amount of radium will have generated an amount of heat equal to that from the combustion of 500,000 times its weight of coal. One pound of radium gives off enough energy to heat to boiling more than 13,000 tons of melted ice.

At first sight it appeared that here was at last in sight the goal of the alchemists. But, alas, there was one difficulty, the process is so slow. Suppose you have a gram of radium (which is a notable amount). You would have to wait 2000 years to get half of its energy, another 2000 years to get half of what is left, and so on. By that time you and your grandchildren will long have ceased to worry about a source of heat. Great as it is, the energy comes off so slowly that it leaks away and cannot be stored up for use when wanted. As a practical source of energy it is useless. Alchemists and others have tried every physical and chemical agency that they could devise in an effort artificially to speed up radioactive processes, but without avail. The process of radioactive transmutation proceeds in its own characteristic slow and sure manner most provokingly unaffected by man's best, but puny efforts.

There are, however, some very decided rays of hope, for artificial transmutation has been produced in three distinct ways, on a small scale. One of these dates back to about the time of the war, while the others have both been achieved within the past couple of years.

During the war I was charged with arranging for the demonstration of a French device for locating submarines, for the benefit of British and American scientists who were engaged in the same problem. One of the British experts was Sir Ernest Rutherford. He sent word by the late Professor Bumstead, however, that he would be delayed through the necessity of completing certain laboratory experiments in which he thought that he had split hydrogen nuclei into two parts. "If this is true," he said, "its ultimate importance is far greater than that of the war." With true scientific caution, however, he asked us to keep this matter confidential, since he was not yet sure of his interpretation. This caution was justified, for his subsequent work showed that he had not broken up hydrogen nuclei; but what he did find was equally significant: he had succeeded in knocking protons out of the nuclei of nitrogen, aluminum and various