The intermediation of a chemical agent between the nerve and the responsive mechanism in smooth muscle requires, as Loewi[38] has noted, a readjustment of our ideas regarding the mode of action of certain drugs. Atropine, for example, does not paralyze vagal endings in the heart; when the vagi of an atropinized heart are stimulated, quite as much vagus substance is produced as if the heart were not atropinized. The effect of atropine, therefore, is not to prevent the passage of vagal impulses, but to prevent the vagus substance from influencing the responsive mechanism of the cell. Similarly, Cannon and Bacq (1931) found that a dose of ergotoxine which abolished any obvious contraction of the pilomotors did not prevent the production of sympathin E; for the heart was accelerated, by sympathetic stimulation of the pilomotors, quite as much after ergotoxine as before. Again, as Loewi[38] has pointed out, it is commonly supposed that physostigmine sensitizes the heart to vagus stimulation; experiment proves, however, that physostigmine is not directly concerned with vagal impulses, but augments and prolongs the influence of the vagus substance. With increase of knowledge of the rôle of chemical mediators of nerve impulses probably other occasions for modifying ideas of pharmacological action will arise.

The evidence for the existence of two substances, sympathin E and I, resembling adrenin in action but differing from it in discriminative relations to excitatory and inhibitory effects, suggests the possibility of so modifying adrenin by chemical means that it too might be used in a discriminative manner. Thus adrenin E, if made, could be used to stimulate the heart, raise blood pressure, etc., without inhibiting the digestive process. And adrenin I could be employed to relax spasm of the intestine or bronchioles, for example, without raising arterial pressure or increasing blood sugar. Such possibilities render important the attempt to obtain modified forms of adrenin.

# HIGH VOLTAGE. II

By Dr. KARL T. COMPTON

PRESIDENT OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

AFTER this historic survey of electrostatic generators, let me now return to the text of my address, "Necessity is the Mother of Invention." Until very recently there was no compelling need to force physicists to seek ever higher and higher voltages in electrical-generating devices. Their needs were met by existing devices of the electromagnetic type. Within the past dozen years, however, it has become evident that a whole new range of fundamental investigation into the properties of atoms will be opened up by a suitable source of high potentials.

This new inducement may be said to have arisen with Rutherford's discovery that it is possible to transmute one chemical element into another by bombarding it by the fast electrified particles known as alpha particles, which are spontaneously given off by radioactive materials in the process of their disintegration. These brilliant experiments opened up a whole range of new explorations into the structure of the atomic nucleus, and stimulated the imagination of scientists in regard to what might be done if only they had available some more powerful and better controllable source of high-speed missiles to shoot at the atomic nuclei. The alpha particles from radium do have tremendous velocities, but they are relatively few in number and all the radium that could conceivably be gathered together in the world would not produce a stream of electrified particles comparable to that which can be obtained in an ordinary discharge of electricity through a vacuum tube. If only the voltage as applied to a vacuum tube could be made high enough to give the ions in a vacuum tube speeds comparable with or even exceeding those of alpha particles from radium, what a powerful attack could be made upon the nucleus! Not only could particles in billion-fold larger numbers be used, but different kinds of particles could be tried, such as hydrogen-nuclei, helium-nuclei, lithium-nuclei, neon-nuclei and so forth, and these could be given any desired speed up to the maximum limit determined by the highest voltage available. So for the past dozen years, thoughts of scientists have again been turned to means for producing ever and ever higher voltages.

It was to this end that the million-volt installation at the California Institute of Technology was designed. It was also to this end that a system of high potential transformers and condensers was built by Cockcroft and Walton in Cambridge, with which they were the first successfully to disintegrate atoms by means of electrified particles produced from an artificial source and speeded up by an applied voltage. However, the necessities of the case have led to other suggestions for securing high voltages because the inherent limitations of electromagnetic induction devices lead to prohibitive expense and complexity if voltages much above a million volts are sought by such means.

[38] O. Loewi, *Internat. ärztl. Fortbildungskursus,* xii: 325, 1931.

There have thus been three very interesting new developments in the art of securing high voltages, or perhaps more generally, electrified particles with those speeds which would be acquired with tremendously high voltages. Of these, in order of apparent utility, are the devices of Brasch and Lange in Germany, of Lawrence at the University of California and of Van de Graaff at the Massachusetts Institute of Technology.

The greatest natural source of high voltage of which we have any knowledge is the thunderstorm. It is estimated that the voltages in lightning flashes frequently exceed a billion volts; consequently it was natural for Brasch and Lange to look to the lightning flash as a source of high potential and to set up what may be considered as a glorified Franklin kite. Their apparatus consisted of a pair of long cables suspended between mountain peaks in that region of the Alps where thunderstorms are most frequent. These cables may be thought of as huge wireless antennae for receiving the electrical impulses of nearby lightning flashes. This was an installation of real engineering proportions, since the porcelain insulators alone at each end of the cable weighed upwards of two tons. The terminals of the two conducting cables consisted of large spheres, whose distance apart could be varied by drawing in or letting out cable. The voltage obtained was estimated by the sparking distance between these spheres, and voltages were obtained ranging between eight and fifteen million volts.

Although the voltage was tremendously high, its erratic occurrence and uncontrollable nature has led Brasch and Lange to give it up in favor of somewhat more conventional means of producing their high voltage, and at present they are working with an impulse generator.

An extremely clever device is that invented by Professor Ernest Lawrence, of the University of California, by means of which electrified particles may be given energy characteristic of several millions of volts with the application of a much smaller voltage. The principle is that of repeated impulses, analogous to the way by which the amplitude of swing of a child in a swing may be made very great by a succession of small pushes, properly timed. In Lawrence's apparatus, an oscillating voltage is applied to the ions, first in one direction and then in the other, while they are moving in approximately circular paths in a magnetic field and conditions are adjusted so that every time the voltage is applied the ions are speeded up by just that amount. Thus, by applying only a few thousand volts, protons have been obtained with energy corresponding to nearly two and a half million volts.

Fig. 4 shows a diagram of the apparatus. The pro-

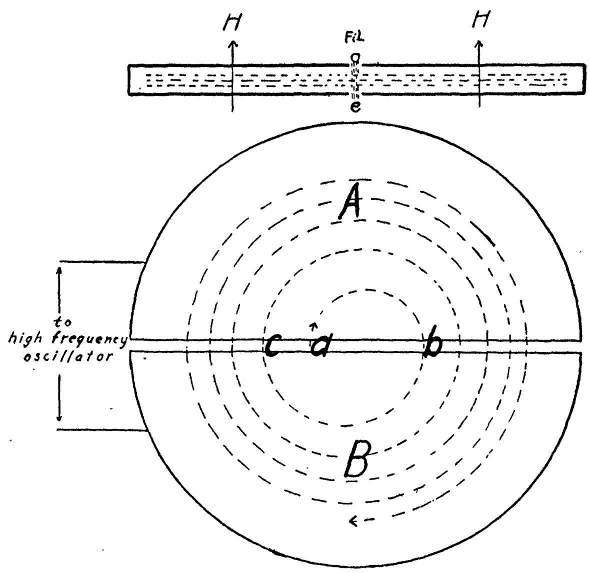


FIG. 4. Diagram of Professor Lawrence's apparatus for producing high-speed, electrified particles

tons or other ions are liberated, by a suitable device, near the center of a flat hollow cylinder which is divided into two parts separated from each other. The oscillating high frequency voltage is applied to these two parts, and at the same time the whole cylinder is placed between the poles of a powerful magnet. An ion starting at *a* is pulled by the momentary electric field across the gap, and it takes, in the magnetic field, a circular path around to *b*. The frequency is adjusted so that by the time it reaches *b* the direction of the voltage has reversed so that the ion is again speeded up as it crosses *b* back into the half-cylinder from which it started. Then by the time it reaches *c* the voltage has again reversed to its original direction and it is given another push, and so on and so on. The few-thousand-volts push is given to the ion every time it crosses the gap. It proceeds in ever-widening circles, attaining a speed limited only by the dimensions of the apparatus. With this device, Lawrence and his colleagues have reason for hoping that the speeds may ultimately be increased to perhaps the equivalent of ten million volts.

The currents are not very large, being reported of the order of a thousandth of a microampere. Nevertheless, these currents are tremendous in comparison with anything which can be obtained from radioactive material and this source of high-speed, electrified particles will evidently be an important tool in nuclear investigation, as is in fact evident from very recent reports from Professor Lawrence's laboratory, in which the experiments of Cockcroft and Walton in disintegrating lithium nuclei by means of high speed protons have been confirmed and extended.

In the construction of this apparatus, the largest magnet ever built in this country has been put into use.

We come now to what I believe to be the most important development that has ever taken place in the field of extremely high voltages, namely the Van de Graaff generator, invented by Dr. Van de Graaff, as a result of considerations which were developed while he was a Rhodes scholar in England and which first took shape in the form of physical laboratory experiments at Princeton and which are now being developed and extended in the laboratories of the Massachusetts Institute of Technology.

From every point of view it is advantageous for very high voltages to have direct uniform currents. Van de Graaff was therefore led to develop an electrostatic generator, since electrostatic methods yield directly a steady unidirectional voltage such as is desired. Maximum simplicity was sought in the design. The simplest terminal assembly appeared to be a sphere mounted on an insulating column. Since the sphere must be charged and since the process should be continuous, the charge carrier should approach the sphere, enter it and, after depositing its charge inside, should return parallel to its path of approach. This immediately suggested the action of a belt, a device long used for the transmission of mechanical power.

The logic of the situation therefore pointed directly to a generator consisting of a hollow spherical conducting terminal supported on an insulating column, a moving belt to carry electric charge to the sphere, a device for depositing the charge onto the belt in a region of low potential remote from the sphere, and a device for removing this charge from the belt inside the sphere and transferring it to the sphere. A refinement of these essentials was the addition of an induction device whereby charge of the opposite sign was carried by the belt on its return journey, thus doubling the current output. A second refinement consisted of a self-exciting charging device whereby the entire generator could be made to operate independently of any external source of electricity. Not only does this device attain the desired result in what appears to be the simplest possible manner, but it is also interesting to note that the energy transformations in its operations are exceedingly simple, consisting only in the transformation of the energy required to drive the belt into work done in separating and transferring electric charge from earth potential to sphere potential. Fig. 5 shows, schematically, the operation of this generator.

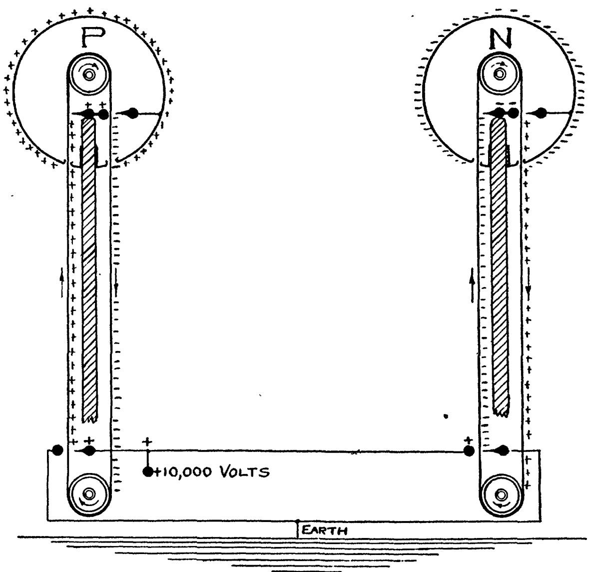


FIG. 5. Schematic diagram of Van de Graaff electrostatic generator

By this means electricity is continually conveyed to the spherical terminal, whose potential consequently rises until limited by the breakdown of the insulation of the air in the form of a corona discharge at the surface of the spheres. This breakdown voltage depends on the size of the sphere, being approximately 750,000 volts for a 2-foot sphere and increasing to 5,000,000 volts for a 15-foot sphere. Thus the attainable voltage depends upon the size of the spherical terminal.

The current, on the other hand, is simply equal to the rate at which electricity is carried to and from the sphere by means of the belts, and this in turn depends upon the size, speed and number of belts and the quantity of electricity which can be placed on unit area of the belt. This latter quantity is also limited by the breakdown voltage of the surrounding air, to an amount of about $5 \times 10^{-9}$ coulombs per sq. cm. of belt area. Under these conditions it is readily shown that a belt running at 6,000 feet per minute could theoretically carry a maximum current of 150 microamperes per inch width of belt. Actually, the best adjustments have given about half of this theoretical maximum, probably because the breakdown strength of the air is reduced by the mechanism whereby charge is sprayed onto the belts.

Theory and practise also show that these belts may be placed as close together as is geometrically possible, in fact, practically in contact, without interfering with their capacity to carry charge. By packing many belts together it is therefore possible to produce very sizable currents. For example, a small laboratory model for demonstration purposes, constructed this year in the laboratories at Massachusetts Institute of Technology, develops one and one half million volts between a pair of 2-foot spherical terminals, and delivers a current of 900 microamperes carried on two 8-inch belts in each sphere. Even in this small model the currents are approximately a million times greater than those which have been obtained in the high speed ion source designed by Lawrence.

The first model of such a generator which was actually constructed was built in Princeton in the fall of 1929, being built out of a tin can, a silk ribbon and a small motor, at no expense. This model developed 80,000 volts, being limited by the corona discharge from the edges of the can.

The next model was designed and built for operation in a vacuum tank for reasons to be outlined later.

The third model was built to give a quick and easy demonstration of the possibilities of the machine, using 2-foot spherical terminals supported on pyrex rods, and supplied by current carried on silk belts 2¼ inches wide, driven by small motors. This apparatus was demonstrated successively in Princeton, New York, Washington, Boston and elsewhere. Although built at a total cost of less than $100, it developed more than twice as high a voltage as any direct current generator of which we have knowledge.

Encouraged by the success of this model, plans were immediately made for the construction of as large a generator as seemed practical for operation in air, the limitation being placed by the size of the house in which it must operate. The largest place available was a dock built for a Goodyear dirigible on the estate of Colonel E. H. R. Green at South Dartmouth, Massachusetts, and which Colonel Green kindly put at the disposal of the institute. Ten million volts was selected as the highest voltage which could be used in a building of this size without excessive loss of current through the air to the roof and walls. For this voltage, therefore, there has been built a generator with 15-foot spherical terminals made of welded aluminum, mounted on 24-foot textolite insulating columns in the form of 6-foot cylinders, and carried on large fabricated steel trucks, running on a 14-foot gauge railway track in order to vary the position of the terminals when desired.

In this construction the Research Corporation gave invaluable aid through assistance in the engineering drawings and through a grant of $10,000, which defrayed approximately half the cost of the generator.

In using this generator for experimental purposes it is planned to use the inside of the spheres as laboratory rooms, and to mount the discharge tube, suitably designed for producing high speed ions, between two spheres.

Every feature in the construction and operation of this large generator has gone as expected and a few days ago the first belt was put into operation and voltage generated as expected. This belt is made of paper 3 feet wide and running at about 5,000 feet per minute. The initial trials gave an output of 600 microamperes, and previous experience indicates that with the proper adjustments this output may be increased to a milliampere. The design of the apparatus is such that a large number of belts may be made to operate in parallel, so that there will be no difficulty whatsoever in securing an output of between a tenth and a hundredth of an ampere if such large currents become desirable. It will be noted, however, that if currents as large as a tenth of an ampere are used at 10,000,000 volts, the generator will be delivering 1,000 kilowatts!

The enormous possibilities of this machine become evident when we compare a possible input of 1,000 kilowatts in the form of 10,000,000 volt electrified particles, with the sources which up to the present have been available for experiments on atomic disintegration and which have been principally small amounts of radioactive material.

We come now to a very interesting aspect of this type of generator, namely, the influence of the surrounding insulating medium. If the generator is placed in some medium whose electrical breakdown strength is greater than that of air, then the voltage and the current both increase proportionately and the power output increases as the square of the breakdown strength. The two media most convenient are either some gas such as air at high pressure, or a vacuum. With gas at high pressure, the breakdown strength is approximately proportional to the pressure, so that the operation of a generator in a tank of gas at 30 atmospheres pressure should give 30 times the voltage, 30 times the current and 900 times the power of the same device mounted in the open air. It is relatively easy to build a container for compressed gases and to mount a generator in it, and this, in fact, has been done by Dr. Barton at Princeton, originally with the collaboration of Dr. Van de Graaff.

By far the most intriguing possibilities of this generator are found in its vacuum embodiment, because a high vacuum is the best of all insulators, since it offers no "windage" resistance to the motion of the belt and since many of the applications of the high voltage will themselves go in vacuum discharge tubes which can be built right into the generating system.

Such a generator has been designed and built. It is still in the experimental stage, but various complicating factors have one by one been overcome. Experience to date indicates that there is in sight no insurmountable obstacle to the construction of generators which may even reach considerably higher voltages than the generator at Round Hill.

In conclusion you will be interested to know, if you do not know this already, that two Van de Graaff generators have been built and operated in Washington under the direction of Dr. Merle A. Tuve, of the Department of Terrestrial Magnetism of the Carnegie Institution. One of these has been actually used for experiments on atomic disintegration and the other instrument, a larger one developing upwards of 2,000,000 volts, is awaiting a suitable housing, now under construction, for its satisfactory operation. Dr. Tuve in Washington, Dr. Coolidge, of the General Electric Company, and Dr. Slack, of the Westinghouse Company, all of whom have built and experimented with Van de Graaff generators subsequent to the demonstration of Van de Graaff's first air-operated instrument in the summer of 1931, have been very helpful in reporting their experiences with the generators.

In conclusion it may fairly be said that this new type of generator as an electrical instrument has already been highly successful and shows promise of very considerable further development. It remains to be seen whether the necessity which was the mother of this invention—namely, the desire for high speed particles for the study of atomic nuclei—will lead to important new knowledge of atomic structure with the aid of this device. Several good men are beginning work on the application of these voltages to nuclear disintegration, and it will not be long before some indications, at any rate, may be obtained as to the significance of the new developments in high voltage technique.

Whether or not the apparatus will be successful in opening up new fields of atomic investigation, it has already opened up the possibility for electrical investigations and possible practical applications of electricity in a new voltage range, and it will be surprising indeed if there are not some developments of scientific and practical significance which will eventually emerge from this new field of activity.

# SCIENTIFIC EVENTS

## THE EMERGENCY CONSERVATION PROGRAM

IN a statement issued on July 17 Robert Fechner, director of the Emergency Conservation Work, described the work being performed in the 102 camps now in operation. Seventy-four of the President's conservation camps are on state parks in nineteen states; eleven are on county parks in four states; eleven are on metropolitan sections of city park systems, and seven are on miscellaneous federal and state owned areas in two states—all under the supervision of the National Park Service.

In addition to purely forest protection work—and some of the finest forests in America are found in state parks—many miles of foot trails and bridle trails are being constructed; safe water supply and sewage disposal systems are being installed; picnic and camp grounds built and shelter structures erected; small recreation lakes impounded, as well as a great variety of other work that will add immensely to the usefulness of the areas.

The President, early in May, authorized an extensive work program for the state parks and later, by executive order, approved the extension of conservation work to county parks and to metropolitan sections of city parks. In the state parks the types of work authorized are numerous, and are necessary to safeguard the scenic resources of the parks under the heavy use to which most of them are subjected.

Supervision of Emergency Conservation Work in state, county and metropolitan parks was placed with the National Park Service because of the similarity of many of their problems and undertakings with those in the national parks. In addition, the federal agency has maintained close touch with state park developments during the past fourteen years. Until the present, however, there has been no official connection between the National Park Service and the state park authorities. Supervision of these camps, therefore, has required the establishment of a small new field organization.

General direction of park emergency conservation work has been assigned to the branch of planning, National Park Service, headed by Conrad L. Wirth, assistant director. With him as supervisor is Herbert Evison, for the past four and a half years executive secretary of the National Conference on State Parks.

The entire United States has been divided into four districts, under four district officers, each of whom is experienced in state park work. Under their immediate direction is a field force of sixteen inspectors, each in charge of a group of from five to seven camps. These men, of whom all are graduate engineers or landscape architects, help to plan the work and keep in close touch with it through all its stages.

In some states, even where there are extensive and valuable holdings, this is the first time that technically trained men have been available for state park work. In each camp the services of the inspectors are supplemented by four landscape foremen, many of whom are experienced landscape architects. These highly qualified men are charged with responsibility for upholding generally accepted state park standards in the constructive work being performed in the parks.

## THE EMERGENCY COMMITTEE IN AID OF DISPLACED GERMAN SCHOLARS

THERE has been formed an Emergency Committee in Aid of Displaced German Scholars, with President Livingston Farrand as *chairman* and Dr. Stephen