Seventy-Five Years of Research in General Electric

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ONE OF THE OUTSTANDING FEATURES in the development of American industry has been the utilization of science and the application of scientific methods to the development of technologies. The total number of scientists in industry and the rate at which their numbers are increasing, together with the great growth of industrial research facilities, present striking assurances of our industrial strength and vitality. The application of science is undoubtedly a keystone in the development of modern industrial technology. It is a part and parcel of all its corollaries, including the great and increasing productivity of the American workman, the enhanced standard of living of our people, and the extensive use of labor-saving devices, even in the home.

It must be admitted that not all segments of American industry have been equally alert in utilizing the advantages of science, but the electrical, along with the chemical and aircraft industries, have been among the foremost in this regard. This is well exemplified by the history of the General Electric Company, now celebrating the seventy-fifth anniversary of the founding of its earliest component, the Edison Electric Light Company.

This company grew out of the scientific studies of Thomas A. Edison, who had established his laboratory in a long, white building at Menlo Park, New Jersey, in 1876. Arc lights were then coming into wide use, particularly for outdoor illumination, but indoor use required a smaller lamp, and there was much discussion of the problem of "subdividing the electric light."

Edison had some ideas as to how it might be done with an incandescent filament sealed in an evacuated bulb. On October 15, 1878, the Edison Electric Light Company was incorporated, and Edison was provided with ample funds for his researches. Hundreds of experiments took place during the next year. Finally, on October 19, 1879, Edison placed a carbonized cotton thread, bent into hairpin shape, inside one of his glass bulbs. The air was exhausted and the current was switched on; light came from the glowing thread. It burned for forty hours. Edison realized that success had come at last, for if the thread burned forty hours, it could be made to burn a hundred, or a thousand.

Thus the electric lamp was born. In the next few years it came into wider and wider use. The establishment of Edison's Pearl Street Station in 1882 in New York, inaugurated the era of electrical service supplied from a central station.

FIG. 1. Thomas A. Edison shown in the Menlo Park Laboratory with his first successful electric lamp, on October 19, 1879. (From a painting by Dean Cornwell.)

Meanwhile, at the Philadelphia Central High School, a young chemistry professor, Elihu Thomson, with the aid of a colleague, Edwin J. Houston, had invented a dynamo and other electrical devices. To exploit these, the American Electric Company had been organized in New Britain, Connecticut, whence Thomson had moved. In 1883 this firm was bought by a syndicate under Charles A. Coffin, a Massachusetts shoe manufacturer, was reorganized as the Thomson-Houston Company, and was moved to Lynn, Massachusetts. Nine years later, under Coffin's leadership, this company merged with the Edison General Electric Company, and the General Electric Company was the offspring.

Thus, even when the company was organized, it already had a distinguished technical background, with Edison on one side and Thomson on the other. In that same year another name destined for fame was added to the rolls—that of Charles Proteus Steinmetz. A German immigrant, possessed of a brilliant mind, he had arrived in New York in 1889 and had gone to work for Eickemeyer and Osterheld in Yonkers. There he developed the mathematics of the law of hysteresis, which governs losses in the magnetic circuit of an electric motor. This gave electrical engineers a powerful tool for designing efficient electric equipment. Mainly to secure Steinmetz' services, the Eickemeyer firm was purchased by General Electric in the summer of 1892. At first Steinmetz was employed in the calculating department at Lynn, but in 1894 this department was expanded and moved to Schenectady, with Steinmetz heading it as Head Engineer for the Company. Here he did important work on the mathematics of alternating current, which had shown its advantages and was then coming into extensive use. Later he also taught at Union College.

Professor Thomson had his personal laboratory at Lynn, but the first formal Company laboratory was established at Schenectady in 1895, for "standardizing" work, which meant simply the cleaning, repairing, and calibration of electrical measuring instruments. A special building was erected for this Standardizing Laboratory, with copper nails and brass radiators, to insure freedom from the effects of unknown magnetic fields. This was the forerunner of the General Engineering Laboratory, which now performs an important function in helping apply to everyday life the new facts brought out by scientific research. Much of its activity relates to instruments, measuring devices, and other equipment used by scientists and engineers. Its guiding motto has been the famous words of Lord Kelvin: "When you cannot measure it, when you cannot express it in numbers . . . you have scarcely, in your thoughts, advanced to the stage of Science, whatever the matter may be."

Under its skilled engineering leadership, the new company advanced rapidly, but by the turn of the century it became apparent to several of its officials that something was lacking. Since engineering depends upon applied science, it is evident that scientific knowledge is the most important raw material of engineering development. Research, in turn, is the source of scientific knowledge. The electrical industry in 1900 was based on research that had been done a half century earlier by such men as Alessandro Volta, Joseph Henry, and Michael Faraday. Without a continuing supply of new scientific facts as a product of research, it was recognized that future engineering development would be impossible.

The leaders of the Company felt the need to participate in the fundamental research on which the industry was based. Why should not General Electric itself engage in fundamental research and so contribute to this source of its most essential raw material for future growth? Who first thought of this is still uncertain—the idea seems to have come simultaneously to E. W. Rice, vice president and technical director of the Company, Professor Thomson, Dr. Steinmetz, and Albert G. Davis, who headed the Company's patent department.

One day in the fall of 1900 Steinmetz and Davis entered Rice's office. "Mr. Steinmetz and I," said Davis, "believe it would be an excellent idea to create a laboratory where scientific investigations might go forward on the incandescent lamp and other problems. We should like to recommend such a step for your serious consideration."

"To improve electric lighting is our foremost thought," he went on. "I personally feel, and Mr. Steinmetz endorses my views, that the electric light has a future more brilliant than its past. We should not like to assert that the carbon-filament lamp is the best lamp we can have. There may be a better type of electrode for arc lamps than the carbon electrode. These things cannot be determined properly without research."

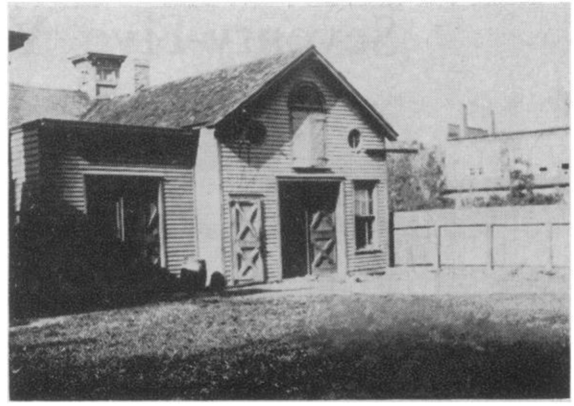

FIG. 2. When the General Electric Research Laboratory was organized in 1900 it was housed in this barn at the rear of the home of Dr. C. P. Steinmetz in Schenectady.

Since Rice had already been thinking along similar lines, the idea fell on fertile ground. They agreed to establish such a laboratory, entirely divorced from the factory and sales organization, where the guiding principle would be that of adding to fundamental knowledge. As director of the new undertaking they selected Dr. Willis R. Whitney, a young chemistry professor at the Massachusetts Institute of Technology, whom Thomson had met and admired.

The first home of the laboratory was a barn back of Steinmetz' home; the second, a building in the General Electric Schenectady Works which had been vacated by the Standardizing Laboratory when it moved to larger quarters. Next came another converted factory building, and in 1914 the Research Laboratory moved into a building erected especially for its

FIG. 3. Present home of the General Electric Research Laboratory is in Niskayuna, near Schenectady, on the bank of the Mohawk River. This shows the main building and (right) the Radiation Building which houses a large synchrotron as well as other equipment for high-energy radiation. Additional new buildings are now being planned, including a large metallurgical laboratory, to be erected to the rear of the water tower, and a combustion laboratory.

needs. Eleven years later another building, connected with the older structure by a bridge, was added; but, at the end of World War II, even these were inadequate. The Research Laboratory moved to its new quarters on a 260-acre site at the Knolls, outside Schenectady, which was dedicated in October, 1950, at the time of the Laboratory's fiftieth anniversary.

From the start, electric lighting engaged the attention of a large section of the laboratory, and indeed it still does. One of Whitney's first developments was the metallized carbon filament, utilized in the Gem lamp, introduced in 1905, which gave a 25 per cent higher efficiency than its predecessor and had the same life. But this lamp was soon superseded by the tungsten lamp. Filaments for this were first made by a process developed in Europe whereby a tungsten powder in paste form was squirted through a die to form a thread. This thread was then heated to drive out the binder and make the metal particles cohere in a filament. Even though such filaments were very fragile, their superiority in producing light led to the manufacture and use of tungsten lamps in large numbers.

In that same year of 1905 Whitney had induced another chemist at the Massachusetts Institute of Technology, Dr. William D. Coolidge, to join his staff. Coolidge also became interested in the lamp problem and soon made a considerable improvement in the process of making squirted filaments. But by 1908 he had developed a process of making tungsten ductile. Since the metal could then be drawn into a wire, the modern tungsten lamp, able to withstand rough treatment, was developed and made its appearance in 1910.

Dr. Irving Langmuir, who had come to the laboratory from the Stevens Institute of Technology in 1909 to spend the summer vacation—and remained—made the next important improvement in lamps. At that time it was supposed that a better vacuum was necessary to make a better lamp. To learn whether this might be a hopeful approach, Langmuir set out to find the basic effects of a number of different gases in experimental lamps at various degrees of vacuum.

Eventually this showed that a better vacuum was not needed, but that a higher efficiency could be secured with an inert gas, such as nitrogen, inside the bulb, provided the filament was properly designed. The original gas-filled lamp, introduced in 1913, was about twice as efficient as the vacuum lamp, and since then additional improvements have increased its efficiency.

Langmuir's work on heat losses from hot filaments also led to the atomic-hydrogen welding torch. In this device a stream of hydrogen is passed through an electric arc between two tungsten electrodes, and the hydrogen molecules are dissociated into atoms. However, as the atoms leave the arc they recombine, producing a flame far hotter than ordinary welding flames. In addition to the high temperature, there is the further advantage that the nitrogen, as well as the oxygen, of the air is kept away from the weld by the cloud of hydrogen around it. This prevents the formation of nitrides, which would weaken the weld. Atomic-hydrogen welding made possible for the first time the

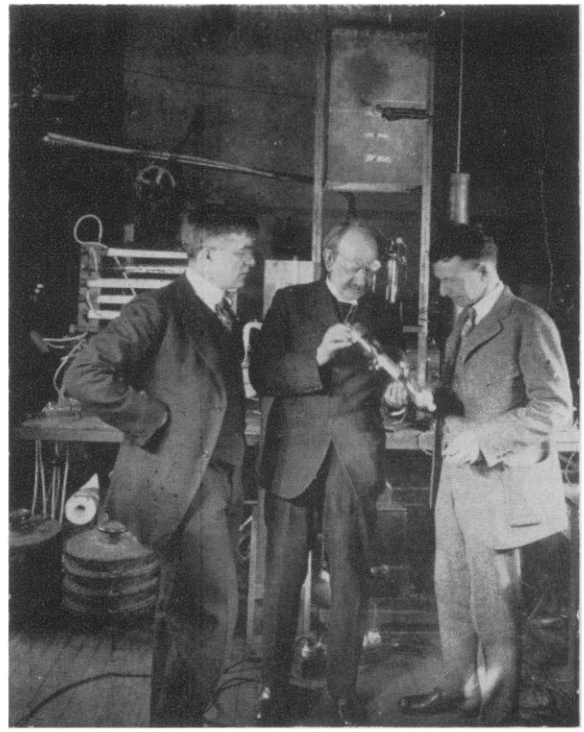

FIG. 4. Sir J. J. Thomson (center) examined a new type of electron tube when he visited the General Electric Research Laboratory in 1923. He is shown here with Dr. Irving Langmuir (left) and Dr. William D. Coolidge.

easy welding of aluminum, chromium, and other previously unweldable metals.

After Coolidge had developed ductile tungsten, he looked for other uses for the novel material and found that it made an excellent target for x-ray tubes. But even with a tungsten target, x-ray tubes of that period were erratic affairs, since the electron emission from the cold aluminum cathode depended on a complex process involving the small amount of residual gas remaining in the tube. In the Coolidge x-ray tube, introduced in 1913, electrons are emitted from a heated tungsten filament and are accelerated toward the target by a high voltage. With the need for residual gas eliminated, the tube could be evacuated to a high vacuum. Before many years had passed, the reliability and ease of control of the Coolidge tube had led to its replacing the cold-cathode tube in nearly all applications.

At about this time, Langmuir was working on another problem involving electrons and gas in tubes. De Forest's audion, the original three-element electron tube, had recently been introduced and was used as a detector for radio signals and as an amplifier, and also in an oscillator in the transmitter. Its use as a transmitting tube, however, was severely limited, since its power output was low. Like the pre-Coolidge x-ray tube, it also would not function without a small amount of residual gas.

Langmuir discovered what limited the power of the audion. Even with the highest attainable vacuum, electrons were emitted from the hot filament, but they tended to accumulate around it in a cloud. Thus they formed a "space charge," which repelled additional electrons seeking to leave the filament. If some gas was present, enough electrons were utilized in producing ionization so that the space charge did not form. Langmuir found it possible to use a high vacuum if the parts of the tube were quite close together, so that the electrons did not have far to travel. Using extra-high voltage to pull them across the intervening space, the effect of space charge could be eliminated and the tubes operated at high power. This made possible tubes operating at as much as 100,000 watts, or even more, which are used today in radio and industrial applications.

FIG. 5. Dr. Albert W. Hull, for many years assistant director of the General Electric Research Laboratory, with some of the electron tubes which he developed.

After these pioneer studies by Langmuir and Coolidge, electronics continued to occupy the attention of a large laboratory group. Dr. Albert W. Hull, who joined the staff in 1914, is credited with developing more types of electron tubes than any other man. One of his contributions was the thyratron, used in controlling heavy currents, such as those used in large industrial motors, or the lights in a large theater like Radio City Music Hall.

Another Hull invention was the original magnetron, a tube in which the variations in a magnetic field control the electrons, and hence the flow of current. With important modifications introduced later by scientists in several countries, the magnetron played an important role in radar as used in World War II and in peacetime radars now used by ships and airplanes. During the war, a laboratory group, under Hull, developed magnetrons to produce high-power waves at high frequency for jamming enemy radar. Tubes of this type are now employed to produce such waves for the heating of plastics and similar materials.

In the Laboratory's metallurgy division, a continuing research has resulted in improved iron for the magnetic circuits of electrical apparatus such as transformers. Operating on alternating current, these transformer cores become magnetized and demagnetized many times a second. Their properties, therefore, must be exactly opposite to those of permanent magnets, which should retain their magnetism despite surrounding effects. Transformer iron, therefore, must give up its magnetism as quickly as possible, otherwise energy is wasted. As a result of an extensive research program to find the factors that determine such magnetic losses in silicon steel, the iron alloy generally used for transformer cores, losses are now a third of what they were when these studies began.

At the same time that one group of Research Laboratory metallurgists were working on these problems, another group was engaged in the development of permanent magnets. The result was whole series of alloys, many of which are forms of Alnico, an alloy of iron, aluminum, nickel, and cobalt. Other metallurgical research has developed alloys able to withstand the extremely high temperatures encountered inside gas and steam turbines and jet engines.

Particularly significant is the work of a large group in our Metallurgy Research Department concerned with the fundamental properties of metals. Much of metallurgy in the past has been an empirical study—an art rather than a science—but now, unquestionably, a real revolution in the theory and practice of metals and alloys is taking place. In many important properties of metals, such as tensile strength, magnetic energy and high-temperature rupture strength, theoretical limits imposed by nature are vastly higher than practical values in present use. The properties of metals and alloys provide a limit to the performance and capability of a vast array of mechanical things, and hence there is a great premium upon improved metallic materials.

One of the most important of many chemical developments has had to do with the silicones. Although these had been discovered about 1870 and had been extensively studied in England, they were regarded as chemical curiosities, without practical value. They consist of long-chain molecules, with a backbone of alternate silicon and carbon atoms to which groups of hydrogen and carbon atoms are attached on the side. Their structure suggested that they would have high resistance to thermal effects. This was confirmed by studies in the Research Laboratory, which ultimately developed a new and simplified direct synthesis of the compounds. In addition to their use as electrical insulation in applications where high temperatures are encountered, silicones are used for making water-repellents, elastomers, which remain flexible at temperatures well above those at which ordinary rubber hardens, for synthetic oils, which flow easily at very low temperatures, yet do not decompose when hot, and for chemical- and heat-resistant finishes for metals.

As a direct outgrowth of Dr. Coolidge's early work on x-rays, a series of high-voltage x-ray units has been developed in recent years. It proved impracticable to operate a tube of the ordinary type at more than about

250,000 volts, but Coolidge applied a "cascade" principle for higher voltages. That is, instead of accelerating the electrons to the required energy in one stage, he used several stages, which made it possible to reach a million volts, or more.

The first units embodying these principles were made for various hospitals for cancer therapy. Later, a series of improvements made it possible to make them much more compact and mobile, and these were applied industrially for radiography of thick steel castings. Million-volt, and later two million-volt, units of this type are used in many industries, while similar principles have been applied to improved medical units as well.

In the last few years, one of these million-volt units, modified to let a beam of electrons emerge into the open air, has been used as a source of 900,000-volt cathode rays, which have been found to have interesting physical as well as chemical effects. For example, they may be used for sterilizing things like blood plasma and pharmaceuticals, without causing any significant increase in temperature. Also, by their aid, many new chemical reactions may be produced; the polymerization, depolymerization, and crosslinking of organics offer interesting possibilities, so that a whole new field of "electron chemistry" seems to be emerging from such work.

To go to even higher voltages, the betatron was developed, a task in which the Research Laboratory played an important role. In this device electrons are accelerated inside a toroidal vacuum tube in a fluctuating magnetic field. A 20-million-volt betatron, completed in 1941, was later loaned to the University of Illinois and was the prototype for a number of machines built for wartime applications. In 1943 a 100-million-volt betatron was completed and this has since been used extensively for nuclear research.

About 1945 a new type of accelerator, now known as the synchrotron, was proposed independently by E. M. McMillan, of the University of California, and V. I. Veksler, in Russia. A synchrotron yielding x-rays of 80,000,000 volts energy was completed in the Research Laboratory in 1947. This, the first in the United States, was sponsored by the Office of Naval Research. Another laboratory group, also originally supported by the ONR, has since built a synchrotron of novel type, with the coils of wire around a core of air, rather than of iron, as in its predecessors. This machine is capable of generating radiation of 300,000,000 volts energy.

In the late 1930's it was first realized that the fission of uranium might be a source of nuclear energy. It was in March, 1940, that two groups, the one composed of two Research Laboratory scientists, K. H. Kingdon and H. C. Pollock, and the other directed by A. O. Nier, at the University of Minnesota, simultaneously and independently made the first separation from natural uranium of U^{235}, which was thereby shown to be the isotope that underwent the fission reaction.

At the end of World War II an Atomic Power Division was organized within the Research Laboratory to study possible applications of atomic energy for peacetime uses. This later became the Knolls Atomic Power Laboratory, operated by the General Electric Company for the Atomic Energy Commission. Later, it was separated from the Research Laboratory and set up as an independent unit. Since 1950 its principal activity has been the construction of a nuclear reactor, utilizing neutrons of intermediate energy, to power a submarine for the U.S. Navy.

Probably the best-known research activity of the Laboratory in recent years has been its work in experimental meteorology. During the war, Dr. Irving Langmuir and his associate, Dr. Vincent J. Schaefer, worked on smoke and fog particles, devising the highly efficient smoke generator used to provide cover for landings in the South Pacific as well as for the crossing of the Rhine. They also worked on the causes of static produced in aircraft radio when flying through a snowstorm.

This work led Schaefer to try to discover how snow crystals were formed. In a home freezer, at a temperature of about −18 C, he formed a cloud of moisture. Although it was well below the ordinary freezing point, it consisted of supercooled water droplets, and various nuclei were introduced in an unsuccessful effort to change it to a cloud of ice crystals. Finally, on a hot day in the summer of 1946, he happened to drop into the box a large piece of dry-ice, to help get the desired low temperature. A cloud of ice crystals immediately formed. Schaefer, who had previously found that snow will form from a supercooled cloud spontaneously at −39 C, recognized that the dry-ice had cooled it below this critical temperature, thus forming millions of tiny ice crystals, which then acted as nuclei on which the rest of the moisture in the cloud could deposit.

On November 13, 1946, he dropped dry-ice from an airplane over a supercooled natural cloud and found that it turned to snow. Later, another General Electric scientist found that silver iodide could form nuclei that would produce similar effects, and other methods were also discovered. As a result of these discoveries, a weather research program known as Project Cirrus was set up in March, 1947. This was a joint study by the U.S. Army Signal Corps and the Office of Naval Research, in consultation with the Research Laboratory. Although Project Cirrus was terminated in May, 1952, much of the research has continued. It is not easy to predict the ultimate results, but it seems certain that the pioneering work of these General Electric scientists in cloud physics, cloud seeding, and weather modification will eventually have a profound influence on all of us. Rainmaking, which has been popularly identified with this project, is really only one aspect of the very broad subject of experimental meteorology.

In American industry there is a wide variation in what is considered research. Some research laboratories range all the way from fundamental studies of properties of matter through development to services for patent licensees. In our own company, from the start, the Research Laboratory has had a primary interest in exploratory research. However, there is no sharp dividing line between this and applied research, and necessarily we do a great deal of the latter as well. There are more than a score of other laboratories in the Company, all doing important and necessary applied scientific work, since a new development, to be of the greatest value, has to be put into use, and there are usually many important practical problems to be solved after a new result of research leaves the Research Laboratory.

Our experience shows that the technological process frequently requires a great many distinct steps, which seldom can be negotiated by broad leaps and short cuts. Very infrequently does a research development go directly to manufacture and use. It seldom goes directly to the design engineering point in the technological chain.

The typical research result has great promise; because of one or two irritating features which are extremely minor in the eyes of the scientist, but which loom as major obstacles to the engineer, the new result cannot be of immediate use. This impasse is overcome by very skillful people engaged in what is variously termed development work, or engineering development, or advanced engineering. Whatever the name, the activity comprises the one or more important steps in technology that lie between research and design engineering. We have found that these development steps are practically indispensable to the success of the technological process.

Furthermore, this task is best accomplished by development scientists and engineers who have this important work as a primary responsibility. It is seldom done well by people who are supposed to do it in time left over from a more important assignment. Thus, the development step, preferably a separate laboratory, is a vital step in the technological process; to be most effective it must be given organizational identity and a clear responsibility for this work.

The widespread interests of the General Electric Company, in a great variety of fields, have made possible our varied research activities, since any one of many different developments may be of potential value to some operating division.

In a highly specialized industry, on the other hand, research must be specialized to fit the industry. For example, the manufacturer of a line of organic chemical products, which are highly specialized with respect to raw materials, manufacturing equipment, and markets, is happiest if the results of his research fit immediately into his present manufacturing and marketing capabilities without change, and of course at very much lower cost. Basically, the degree of freedom of the industrial research scientist is thus determined by the diversity of the industry in which he works.

If the research chemist, for example, can work only toward results that fit like a glove into the capabilities of a specialized industry, little room is left for the play of his originality, for following the byways of research in the investigation of the unexpected result, and for the exploration of the nearby area of a great, but speculative promise. Worse still, scientists of skill and imagination will not long work within a closely limited scope; if one must be certain of the results of research in advance, the objective must be of such short range that it hardly partakes of a research character. The net result is likely to be frustrating to the scientist and disappointing to the sponsor.

It is better to leave some room for originality and imagination, which are important attributes of creative individuals. Furthermore, a little diversity may do no harm to the industry and may provide a degree of stimulation that is reflected in old as well as new products.

Despite the great development in American industrial research since 1900, when the General Electric Research Laboratory was founded, there remain important areas where scientific research has not yet been fully established. Throughout the technical industries we still have much to learn about the most effective pursuit of research and development and its detailed problems. Still more important, however, is the fact that, by and large, industry is not sufficiently speculative in its research. We often control our research too closely and confine it so narrowly to existing product areas that it fails to develop its full potentialities for new results. In short, in a free enterprise system we could well afford to be a bit more enterprising in exploring the greatest frontier the world has ever known—the frontier of science.