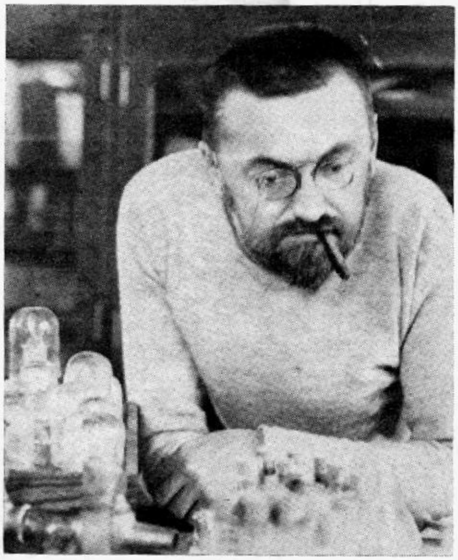
CHARLES P. STEINMETZ-Father of Modern Electrical Engineering

BY DAVID L. HEISERMAN



ON June 2, 1889, Karl Steinmetz stood before a New York customs official. The 24-year-old Swiss-German immigrant's clothing was sloppy, his beard ragged, and on the bridge of his nose were thick spectacles. He also was a hunchback and stood barely four feet tall, physical defects inherited from his father and grandfather. The official's first impulse was to put Steinmetz on the first boat returning to Europe. Fortunately for the world of electrical engineering, Steinmetz, with the aid of a friend and fellow immigrant, persuaded the official to let him pass through the customs office. The official could never have guessed that in a few short years this untidy hunchback whom he had almost refused entry to the United States would revolutionize twentieth century alternating-current technology.

Steinmetz' first job was with Eikenmeyer & Osterheld, designers and producers of ac motors for streetcars. Lacking training in electrical engineering (his training was in mathematics and mechanical engineering), Steinmetz wound up in the drafting department.

Meanwhile, Eikenmeyer and his engineers were encountering serious problems in fulfilling a large contract. Since no one had yet developed a way to accurately calculate the amount of heating in a motor before the motor was actually built, a lot of time and money was being wasted on trial-and-error experiments. All of the prototype motors the company was making were either too bulky or so small that they quickly burned out.

From Draftsman to Designer. While doing design drawings in the drafting department, Steinmetz began to notice logical relationships between the magnetic properties of the iron in the motors and the amount of heat the motors produced. He developed preliminary equations and motor designs which he showed to Eikenmeyer. Immediately recognizing the value of the work and already running behind schedule, Eikenmeyer decided to gamble on a revolutionary idea. He set up an industrial research and development laboratory. Putting Steinmetz in charge of the facility paid off. Steinmetz went on to perfect his theory of hysteresis losses, worked out equations for designing ac motors, and pulled the company out of debt.

In 1892, Steinmetz presented a paper dealing with his hysteresis losses laws and motor design to the American Institute of Electrical Engineering. A year later, he found himself working for the new General Electric Company in Massachusetts after they had bought out Eikenmeyer & Osterheld. At about the same time, he was completing his work for American citizenship. He Americanized his first name to Charles and took for a middle name his fraternity nickname "Protius." He signed his citizenship papers and last paycheck from Eikenmeyer & Osterheld "Charles Protius Steinmetz."

More Horizons. While working at the new General Electric plant, Steinmetz became involved with problems encountered in long-distance transmission of ac power. He found the graphical methods for designing power transformers and other ac devices too cumbersome and inaccurate for his work. He chucked the whole business and launched into a new line of reasoning that would eventually revolutionize every phase of electrical engineering.

Trained as a mathematician, Steinmetz was familiar with ideas generally held to have no value in the real world. He noted that the use of complex numbers—curiosities at the time—in his ac equations simplified the theoretical ideas and design procedures. Between 1893 and 1897, he used complex numbers as a foundation for completely revamping the world's knowledge of ac theory and design.

His ideas were so new that few engineers understood what he was talking about. Steinmetz found that he had to work harder explaining what he had done than he had in developing the ideas in the first place. His book *Theory and Calculation of Altenating Current Phenomena* (1897) was a failure simply because no one understood it. So was his later *Alternating Current Phenomena*.

Steinmetz made one final attempt. This time, his *Theoretical Elements of Electrical Engineering* was a success. It was adopted all over the world as a standard textbook for college programs in alternating current theory. Then, to give engineers and students a firm footing in the mathematics they would need in their studies and careers, he put together *Engineering Mathematics*, the first book to demonstrate a practical application of complex numbers.

Popular Fame. By the turn of the century, Charles Steinmetz was quite famous among the scientific and engineering communities. The general public, having no real appreciation for lofty engineering theories, heard little about him. However, his third major line of investigation made Steinmetz a very popular figure.

Steinmetz did not realize popular fame was coming his way when he designed the first long-distance (26 miles) ac power transmission system from Niagara Falls to Buffalo, New York. Nor was it the fact that the system worked that brought him into the public spotlight. What happened was that Steinmetz soon encountered difficulties with lightning that occasionally knocked out the power transmission system.

Rather than guessing at what was happening, Steinmetz decided to learn more about the nature of lightning by building a high-voltage laboratory. The image of this strange-looking little man fussing with gigantic bolts of artificial lightning caught the public's fancy. Steinmetz suddenly was the subject of hundreds of newspaper and magazine articles. He accepted the accolades of the public with humility and good humor, but he did not let this new kind of fame change his life style or keep him from his work.

High-voltage machines were not new at the turn of the century. Other investigators had already built "lightning machines" capable of generating a million volts at several hundred milliamperes. But Steinmetz rightly concluded that the essential characteristics of natural lightning included incredibly high currents with very high voltages. Not wanting to be misled by the low-current effects that characterized existing high-voltage generators, he designed a General Electric high-voltage generator that produced only a few hundred thousand volts at currents in excess of *10,000 amperes!*

The first tests with the new machine exhibited some dramatic effects. Instead of merely scorching the outside of a freshly cut piece of timber, the new lightning machine peeled away the bark, split the wood into several steaming-hot pieces, and occasionally blasted the wood into thousands of burning splinters. Although the effect was still feeble compared to natural lightning, the high-current component brought the tests more in line with the real thing.

Tests on commercial lightning rods revealed flaws that were invisible to detection with the million-volt, low-current generators. Finding these flaws explained why some lightning rods sometimes failed. This led Steinmetz to recommend immediate design changes that would make the rods more reliable.

By getting a better understanding of lightning, Steinmetz and his co-workers at General Electric made great strides toward absolute protection of power transmission systems. Although they did not solve all of the problems, their data contributed to the design changes and innovations that make modern power transmission systems safer, more reliable, and practical. ◆

The QUEST For The Crystal That Amplifies

WE CALL IT A TRANSISTOR—BUT 20 YEARS AGO IT WAS AN UGLY DUCKLING

by Daniel M. Costigan

THE BIRTH of the transistor was not something that happened overnight. It marked the culmination of many years of dreaming and searching, not only by scientists, but by a couple of generations of quixotic tinkerers as well, seeking to extract from a tiny chunk of the mineral galena some magical energy that might eliminate the need for power-consuming vacuum tubes in radio receivers. Some of these experimenters actually produced crystal sets that could operate loudspeakers—at low volume—perpetually and without need for external power.

These devotees of the galena mystique thrived for some thirty years on trial-and-error and wishful thinking. During this time, they were joined by a handful of scientists who worked unnoticed behind the scenes, taking a more methodical approach to essentially the same goal. The scientists were mostly engineers, metallurgists, and physicists who had been recruited by industry—some of them from university faculties—to help seek new ways to improve the efficiency of electric power and communications devices.

Finally, in the late 1940's, the quest for the crystal that amplifies ended in triumph for a trio of distinguished industrial scientists. The year 1968 marks the 20th anniversary of what has since become recognized as one of the most momentous events in the annals of electrical science.

How The Quest Began. The primordial spark to which this quest can be traced occurred around the turn of the century when the need for a practical rectifying device arose almost simultaneously in two budding young industries: electric power, and radio.

In electric power, the advocates of alternating current had won their battle against the d.c. interests and had begun to distribute a.c. power on a wide scale. This meant that some kind of practical converter, other than a motor-generator, would be needed to permit the operation of d.c. apparatus—battery chargers, electroplating equipment, telephonic devices, etc.—on commercial a.c. power.

The rectifying properties of selenium had been known for nearly a century, but it wasn't until 1924 that semiconductor rectifiers became commercially available.

By the early thirties, copper-oxide rectifiers had come into wide use as converters. Selenium, which had at first proved unsatisfactory for use in power conversion, was gradually improved and eventually surpassed copper-oxide in popularity.

The names Mott and Schottky are two that stand out in connection with the early evolution of rectifier theory. Working independently of one another—Sir Nevill Mott in England and W. Schottky in Germany—both men concluded that rectification took place in a thin electrical barrier that formed at the junction of a metal contact and a semiconductor. Schottky called this surface barrier an "inversion region" within the thickness of which a change of conductivity took place. The theory was to play a prominent role in the reasoning that later led to the invention of the transistor.

The "Coherer." Radio's need was for a practical rectifying detector of received signals, and it arose with the advent of voice transmission. In its embryonic stage (1894 to about 1906), a radio receiver had at its heart a "coherer," in which metal filings clung together on exposure to electromagnetic disturbances, thereby varying the current in a local battery circuit. The disturbances were set up by a spark transmitter being turned on and off with a telegraph key.

First used by England's Sir Oliver Lodge in 1894, the coherer* had been steadily improved in design and had reached a fairly high level of refinement by 1900 when Professor Reginald Fessenden of the University of Pittsburgh succeeded in transmitting voice on a continuous wave.

Radio suddenly found itself faced with much the same situation that had created the need for rectifiers in the electrical industry. The transmitted radio wave became a "carrier," its cargo a modulation envelope that was electrically self-cancelling until the alternating current could be made to flow in one direction only. Radio detection thus became a matter of rectification.

Fessenden's first detector was an electrolytic device of his own design. It was highly sensitive, but also critical and unreliable.

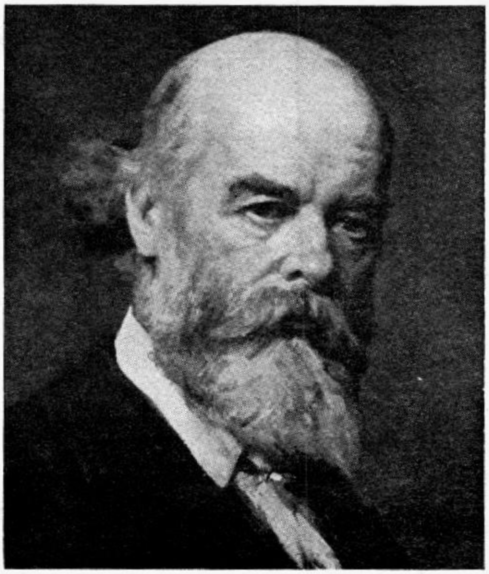
The first practical crystal detectors appeared in 1906. The one invented by G. W. Pickard used silicon and featured a "catwhisker" (fine wire) contacting arrangement similar to that suggested by a German experimenter named Braun some 30 years earlier. Another type, invented by H. H. Dunwoody, an executive of the De Forest Wireless Company, used a small chunk of carborundum clamped between two electrodes.

Vacuum Tubes and Diodes. The crystal detector reigned supreme until the early twenties when the vacuum tube began to make inroads. Silicon had proved to be the most stable crystal, but galena (lead sulphide) was the most sensitive and therefore the most popular.

As in everything, however, it takes power to beget power; thus, there were the inevitable "A" and "B" supplies wherever vacuum tubes were used. What's more, some of the power had to be wasted in heating the tube filament—an unfortunate requisite that was to impose serious restrictions on the tube's useful life and on the design of the tube-using equipment.

Crystal detectors needed no external

Sir Oliver Lodge (1851-1940) made many important contributions to wireless transmission and reception, which led to UHF transmission techniques.



For more details, see article entitled "The 'Coherer'" which appeared in the May, 1967, issue of POPULAR ELECTRONICS.

power supply; they were simple and compact, and there was no heat problem. But they couldn't amplify—at least not until a group of scientists at a major industrial research laboratory had undertaken an intensive investigation into the mysteries of solid-state semiconductors.

In 1934, the Bell Telephone Laboratories began to develop fixed semiconductor diodes for use in microwave experiments. The earlier ones were silicon and germanium point-contact devices resembling the "fixed" detectors that had been used in some crystal broadcast receivers. ("Point-contact" is a sophisticated term for the old familiar catwhisker.) The more advanced junction diodes were developed during and immediately following World War II.

A New Turn. Walter H. Brattain had come to Bell Labs shortly after having received his Ph.D from the University of Minnesota. His involvement during the thirties in the study of electrical conductivity in semiconducting materials eventually brought him in contact with William Shockley, a brilliant young Ph.D who joined the staff in 1936 and soon began to form some ideas of his own on the potentials of semiconductors.

In that same year (1936), Dr. Mervyn Kelly was appointed Director of Research at Bell Labs, and one of his first acts was to assemble a team of physicists to formally explore the behavior of electrons in solids. Brattain and Shockley were among those selected.

Professor Reginald Aubrey Fessenden (1866-1932), a pioneer in wireless communication, was the first man to voice-modulate a continuous-wave carrier.

Since the late thirties, Shockley had been entertaining the notion that a semiconductor ought somehow to be able to amplify an electric current. His attempts to achieve "valve action" in a copper-oxide device were interrupted by World War II. Immediately following the war, he constructed a special device based on a scheme he had worked out on paper. But, as is so often the case, what appeared workable on paper did not work in actuality.

Ironically, the device that had failed was the forerunner of the field-effect transistor (FET), which was to re-emerge many years later to be heralded as one of the more important advances in solid-state technology. Had Shockley's experiment been successful—if more had been known about the characteristics of semiconductor materials—the development of solid-state devices might have taken a completely different course.

It was about the time of Shockley's "field-effect" experiment that the Bell Labs team was enhanced by the addition of a new member. He was John Bardeen, a 37-year-old theoretical physicist and former university professor whom Shockley had personally recruited. During the preceding decade, Bardeen had done extensive work in the field of electroconductivity in solids. The fact that Shockley's experiment had not yielded the expected result interested Bardeen and set him working on a theory to explain why.

Breakthrough. Taking his cue from Mott and Schottky, Bardeen theorized that surplus electrons gathered at the surface of a semiconductor and became immobilized so that, in effect, they acted as a sort of barrier to externally applied currents. To test his "surface states" theory, he and Brattain performed a series of interesting experiments.

At first they used a liquid electrolytic as a current-carrying medium between one side of a power source and the surface of a piece of semiconducting silicon. They found that by passing a current through the electrolyte, the surface charge on the silicon could be altered.

This led Brattain to suggest a slightly modified approach. Germanium was substituted for silicon, and a thin layer of gold for the electrolyte as the special contacting interface. Two currents were made to flow in opposite directions through the germanium, one between the gold contact and a solid connection at the base of the material, and the other between the base connection and a catwhisker contacting the surface near the gold contact. As had by now been anticipated, varying the one current produced corresponding variations, *but of greater magnitude,* in the other. Amplification had been achieved!

The technical explanation for the phenomenon was highly complex and dealt with such things as atomic valences, "holes," "donors," and "defect conductivity." Stated simply, what had happened was that the tiniest *plus* charge at one of the two contact points on the semiconductor surface had drawn off enough of the material's surplus electrons to create "holes," which, in turn, were attracted to the adjacent negative point and therefore functioned as vehicles by which the lesser current could influence the greater one. In essence, then, the semiconductor had become a variable resistance, enabling control of current flow in one circuit by varying the current in another.

By the close of 1947, experiments had proved the new device capable of amplifying audio frequency signals. Bardeen and Brattain quietly announced their discovery via a letter to the editor of "The Physical Review," published in the July 15, 1948, issue.

The First Transistors. The name *transistor*, by which the device was to become known, was suggested by another Bell Labs physicist, John R. Pierce. Pierce observed that, where a vacuum tube amplified by transconductance—the effect of the grid voltage on plate current—the new device did its amplifying by what might more aptly be termed "transresistance." The name may also be thought of as suggesting the *trans*fer of signals through a var*istor*, a varistor being a semiconductor diode whose electrical resistance decreases substantially with a moderate increase in applied voltage. (Varistors are often used as buffers to protect delicate components from voltage surges.)

The first transistors produced in quantity in the laboratory contained a tiny chunk of slightly impure germanium on which two "catwhiskers" converged, *contacting* the surface at *points* less than a hair's breadth apart.

William Shockley, meanwhile, continued to pursue his own ideas on how best to make a semiconductor amplify. His quest led to the invention, later in 1948, of the *junction* transistor in which transistor action was achieved by the sandwiching together of *p*-type (electron deficiency) and *n*-type (electron surplus) semiconductors. Shockley's design, although at first more difficult to fabricate, proved more predictable in its properties and less fragile than its "point contact" predecessor, and was therefore soon to supersede it. The junction transistor was introduced early in 1951.

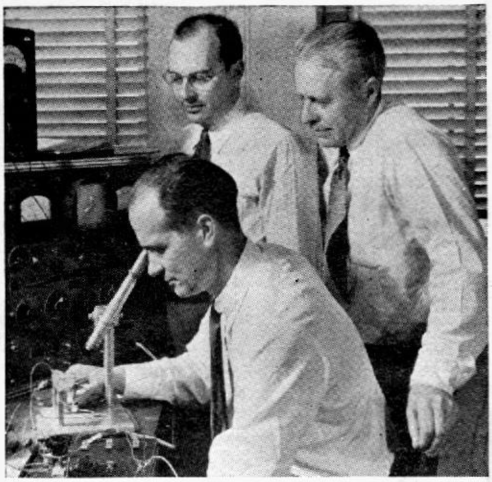
Overcoming Obstacles. A major obstacle to mass production was the requirement that semiconductor materials contain carefully controlled degrees of impurities to insure the proper electrical imbalance. This meant starting with a nearly pure substance and then adding adulterants (such as arsenic or gallium) by a carefully controlled doping process. The introduction of zone refining in 1955 was the first big breakthrough in high volume production of the basic materials.

In recognition of the magnitude of the revolution they had kindled, the transistor's trio of inventors—Shockley, Brattain, and Bardeen—were awarded the 1956 Nobel Prize in Physics.

But, during the middle fifties, the widely acclaimed little device still suffered a number of serious shortcomings. For one thing, it was critically temperature-sensitive and therefore unable to handle power beyond a fraction of a watt. What's more, it was noisy and unstable, had ridiculously low input impedance, and was a sluggish device whose switching speed and frequency response left much to be desired.

These shortcomings, however, were gradually overcome as new manufacturing processes were introduced and semiconductor materials with improved electrical characteristics were developed. By the late fifties, the reliability of the device had already begun to exceed that of vacuum tubes.

The year 1957 was the best ever for the sale of vacuum tubes. Unit for unit, they were still outselling transistors by thirteen to one. But the gap was rapidly narrowing, with the turning point due in the early sixties. (In 1959, 77.5 million germanium transistors were sold for a total of 151.8 million dollars, at an average price of $1.96 per unit. By 1966, the picture was considerably changed: 368.7 million units were sold for a total of 164.5 million dollars, an average price of 45 cents each!)



William Shockley, John Bardeen, and Walter H. Brattain, co-discoverers of the transistor, received the 1956 Nobel Physics Award for their invention.

Further Improvements. New developments followed in rapid succession, and with them came a whole new electronics vocabulary: *p*-type, *n*-type, bipolar, diffused junction, epitaxial growth. The grown junction gave way to the alloy junction, which, along with the introduction of the diffusion process, resulted in improved frequency response and switching speeds. It was now feasible to use transistors in computers—a marriage which, in turn, was to enhance the evolution of still faster and more reliable semiconductor devices.

The diffusion process also broke the transistor's power-handling and temperature barriers by facilitating the use of silicon in place of germanium. Mesa, planar, and epitaxial devices emerged as some of the more prominent offshoots of the diffusion technique.

The field-effect transistor, which had continued to lie dormant in the laboratories, seemed to hold the key to some of the improvements still needed—higher input impedance, for example, and lower levels of noise and distortion. Of all semiconductor devices, it came closest to a vacuum tube in characteristics. But the electrical surface properties of the semiconductor material used in its fabrication were critical, and it was not until recently that FET's finally became competitive with other semiconductors.

Similarly, the unijunction transistor, with its single *p-n* junction, was originally developed in the early fifties, but is just now beginning to emerge as one of the less expensive, more stable, and temperature-resistant devices.

The late fifties saw the introduction of miniature circuit modules, silicon-controlled rectifiers (SCR's), and Esaki's remarkable tunnel diode, with which amplification was possible without the traditional "third element." SCR's shrunk the gap between tube and semiconductor capabilities by providing a highly efficient solid-state replacement for thryatrons and mercury-arc rectifier tubes in power control equipment.

What Does The Future Hold? The pace of development of new transistor types has been absolutely staggering. The list now numbers in the thousands, and it continues to grow as the mighty midget celebrates its 20th birthday.

Apart from its having reshaped an entire industry and opened many new doors, perhaps the most fascinating offshoot of the whole solid-state technology to date has been the subordinate art of microelectronics. Already in the making are integrated circuits so minute that an entire amplifier could hide behind a single transistor.

Solid-state technology has been growing and changing at such a dizzying pace that it is difficult to predict what lies ahead even in the next year or so. Perhaps at this very moment, somewhere in the world, a small but persistent group of experimenters is exploring a radically new concept that may someday render the present technology obsolete. —30—

A Question Of Semantics

WHO DID INVENT RADIO?

BY FRED SHUNAMAN

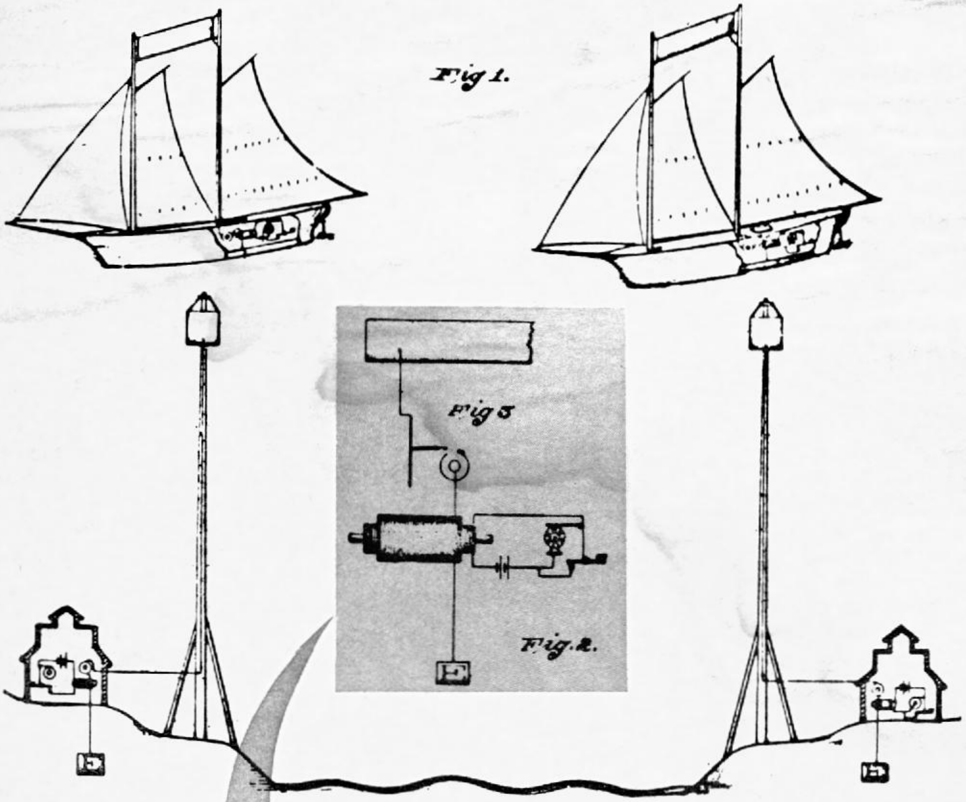
IN ALL PROBABILITY there will never be total agreement on the question of who actually discovered radio. In fact, the word "radio" itself does not stand up to a strict historical interpretation. Does the "first radio" mean the first two-way wireless communication? Or a one-way wireless transmission? Or would a minor laboratory demonstration and a patent establish the precedency of the discoverer/inventor?

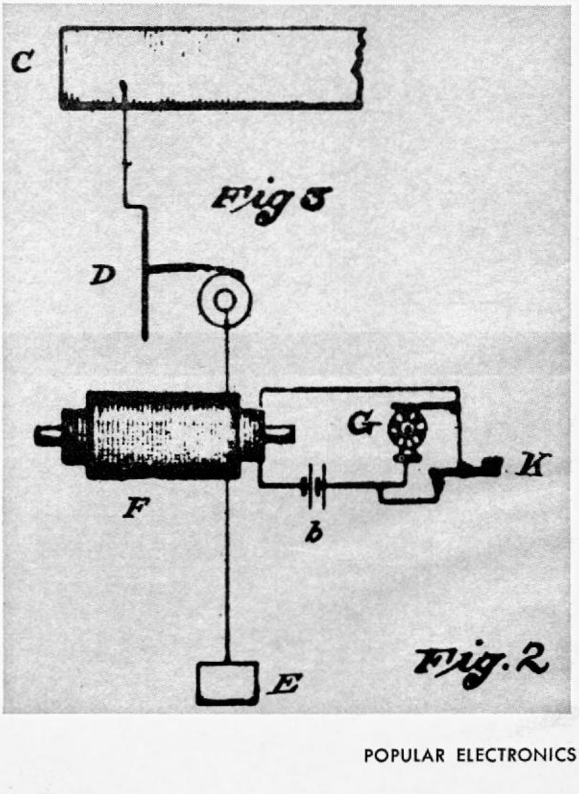
In one way or another, Marconi, Popov, Loomis, Butterfield, Lodge, Hertz and Tesla all qualify as discoverers of radio. However, history now shows that none of these men has the supporting evidence of discovery that belongs to Thomas Alva Edison—to whom the honor may rightfully belong.

A simple language difficulty may have cost Edison the credit for first discovering and using radio as a means of communication. He announced the discovery of "etheric force" when Marconi was only a year old and while Tesla was still attending school. And, in 1885, two years before Hertz announced the discovery of electromagnetic waves, Edison applied for a patent on a complete wireless system. Submitted with his application were patent drawings of radio towers and antennas on the masts of ships.

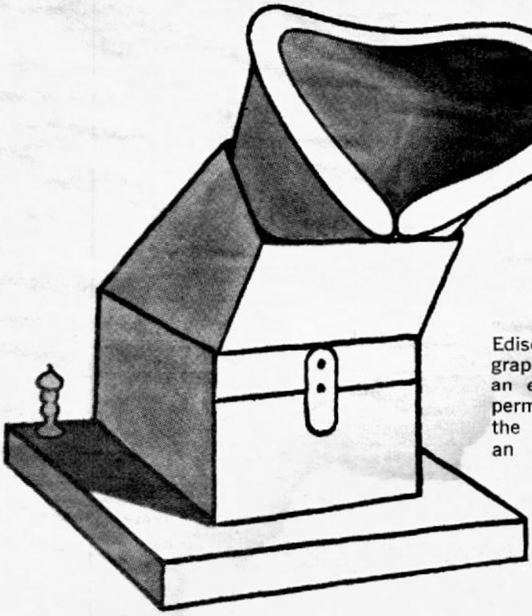
How It All Began. During the evening of November 22, 1875, Edison was studying the action of a magnetic vibrator. He noticed a tiny spark between the armature and core of the vibrator as the armature approached the core. Suspecting faulty insulation, he checked the coil but found everything in order.

However, Edison reported that: "If we touched any part of the vibrator we got the spark," and that "the larger the body of iron touched to the vibrator, the larger the spark." If a wire was connected between the vibrator





Above is one of the drawings from Edison's Patent No. 465,971, Dec. 29, 1891, describing a "Means for Transmitting Signals Electrically." Particularly interested in transmitting across bodies of water, he showed high towers and ships carrying "condensing surfaces" (which we would call antennas). At the right is an enlargement of the insert, in which Edison described how signal was generated and transmitted to antenna.



Edison's "black box" 1881 demonstration had graphite points which could be connected to an external circuit. The extension eye-shade permitted viewer to see, jumping between the contacts, sparks unlike any known to an electrical phenomenon at that period.

and a gas jet on the wall, a spark could be drawn from the gas pipes anywhere in the room.

Then Edison performed the experiment that Hertz was to do 17 years later; he found that "if you turn the wire round on itself and let the point of the wire touch any part of itself, you get a spark. . . . This is simply wonderful and a good proof that the cause of the spark is not *now known force.*"

Next, Edison constructed a demonstration apparatus and revealed his new setheric force" to the Polyclinic Club of the American Institute. Many of the members seemed upset by the name he had chosen for the new effect. But Edison was undaunted, and he predicted (in the January 1876 issue of the *Operator,* a telegrapher's magazine) that the new force might become the telegraphic medium of the future. He is quoted as having stated: "The cumbersome appliances of transmitting ordinary electricity, such as telegraph poles, insulating knobs, cable sheathings, and so on, may be left out of the problem of quick and easy telegraphic transmission, and a great saving of time and labor accomplished."

The *Scientific American* of December 1875 stated: "By this simple means signals have been sent [by wire] for long distances, as from Mr. Edison's laboratory to his dwelling house in another part of the town. Mr. Edison states that signals have also been sent the distance of 75 miles on an open circuit, by attaching a conducting wire to the Western Union telegraph line."

As It Developed. A "black box," used by Edison to demonstrate etheric force was sent to Paris where Edison's assistant, Charles Batchelor, lectured on the etheric force. (The black box detector consisted of a pair of adjustable graphite points in a shaded enclosure, with terminals to attach it to an external circuit.) There is a bare possibility that Heinrich Hertz might have heard about Edison's experiments, for his spark points with the micrometer adjustment are virtually identical to those in the black box, and he repeated the experiment of turning the wire back upon itself.

Work on the telephone took Edison's attention away from etheric force for some time. But in 1885 he applied for a patent for a wireless telegraph system based on his etheric force. The patent drawings show towers that are easily recognizable as radio masts, and two ships with broad ribbon-like antennas hung between their masts! The text of the patent application goes into detail about the equipment shown in the drawings.

"The wire (from the 'condensing surface' C) extends through an electromotograph telephone receiver D (Fig. 2) or other suitable receiver, and also includes the secondary circuit of an induction coil F. In the primary of this coil is a battery *b* and a revolving circuit-

Thomas A. Edison, from a print dated 1877, about the time he was working on his "etheric force" invention. This and other illustrations in this article are adapted from those appearing in "Menlo Park Reminiscences," Vol. I, by F. Jehl, Edison Institute, Dearborn Park, Mich.

breaker G. This circuit-breaker . . . is short-circuited normally by a backpoint key K, by depressing which . . . the circuit-breaker makes and breaks the primary circuit of the induction coil with great rapidity," Edison wrote.

Explaining the phenomenon as he saw it, Edison went on to state: "These electric impulses are transmitted inductively to the elevated condensing surface at the distant point . . ."

Here is where the confusion in language occurred. At the time, the term *induction*, unless otherwise explained, meant *electrostatic induction* (a tendency that still lingers on in some elementary physics textbooks). The transformer had just been invented, and magnetic induction was a laboratory curiosity. The term "electrostatic" drifted into obscurity as the art progressed, and later writers referring to the "induction telegraph" unquestioningly accepted the term to mean *magnetic* induction.

The confusion was increased because the only commercial use Edison made of his invention was the "grasshopper telegraph," a system of telegraphing from moving trains to the telegraph wires alongside the tracks. This was a distance that could be covered easily by electromagnetic induction, and historians who believe that radio communication started with Tesla, Lodge, and Marconi assumed that this was the case. Yet, in explaining the "grasshopper telegraph" to a reporter, Edison said, "The system works by electrostatic induction."

So, a change in the generally accepted meaning of a word with the changing times buried the fact that Edison invented, described, patented, and *operated* a radiotelegraph system in 1886—a year before Hertz explained the cause of the etheric force, which he called electric force.

What other "firsts" may lay buried or attributed to other discoverers because semantics denied the original inventor or discoverer his due? At least now Thomas Alva Edison's long list of achievements will have numbered among them the discovery of radio waves—even if he did not title them as such. —30—

Editor's Note: We are given to understand that the graphic-points "black box" is still in existence and has been exhibited on the second floor of the restored Edison Laboratory.

In his book, "Menlo Park Reminiscences" (now believed to be out of print and unobtainable), author Jehl says that Edison was intrigued by the spark and performed many experiments to seek an explanation of its nature. Edison did find that the spark was unpolarized; had no respect for the usual types of insulation; would not discharge a Leyden jar; and had no effect on his electroscopes.

Unquestionably, Edison had stumbled onto radio-wave transmission, but the fact that energy could be propagated through the atmosphere and not via wires was alien to all of his telegraphy experiments.

BY FRANK ATLEE,
K[illegible]

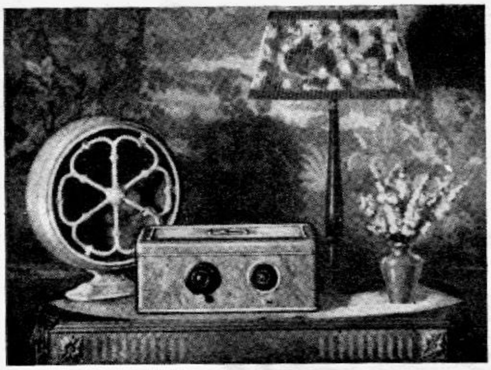
What ever Happened to Atwater Kent?

WORLD RENOWN . . . MANUFACTURER OF 5,000,000 RECEIVERS . . . FAMOUS FOR QUALITY . . . BUT HE CLOSED THE DOORS AND WALKED AWAY

ALTHOUGH more than 40 years have elapsed since the name Atwater Kent was a household word, the radio receivers he manufactured were so well made that thousands are still in existence and in operating condition. Many more Atwater Kent receivers are unearthed daily from cellars and attics to be restored by antique-radio collectors and made conversation pieces for modern living rooms.

The story of this unusual man and his company in many ways parallels the heyday of mass production ascribed to the Ford Motor Company. At one time, Atwater Kent was a company known the world over and even the most conservative estimate of its manufacturing facilities indicates that it produced well over 5,000,000 radio receivers.

The Atwater Kent Company was a well-established manufacturing business



The A-K Model 37 was a 7-tube a.c. operated receiver with the popular 2 r.f., detector, 2 audio circuit.

nearly 20 years before the first radio broadcast. Starting with the making of voltmeters for telephone linemen, the company gradually expanded to include the manufacture of ignition systems, starters and generators for pre-World War I automobiles.

Residing on the "Main Line," then the home of many wealthy Philadelphians able to purchase the fine cars of the day, Kent observed that ignition systems and electric starters (if any) were usually under-designed and subject to frequent failures. Kent purchased several dozen used cars on which to work toward developing improved electrical systems. In a short time, he had invented the "Unisparker" and in 1914 received a medal from the Franklin Institute of Philadelphia. He also developed his type "LA" ignition system for the Model T Ford. Having worked closely with 4- and 6-cylinder engines, Kent predicted that eventually the 4-cylinder engine would be a thing of the past.

First Expansion. Sensing that the market for his automotive products was rapidly expanding, in 1914 Kent purchased a large tract of ground north of the Wayne Junction branch of the Reading Railroad in Germantown, Philadelphia. As soon as this factory was completed, he partially switched over production during World War I to the manufacture of gunsights.

Kent's long-range plans for the post-war economic boom did not materialize and in 1920-21 Kent found himself in a temporary business depression. Scouting around with his usual keen vision for products to manufacture, he decided to look into the new craze of radio b[illegible]cast listening. Kent hired two well-known Philadelphia radio engineers and from a modest start in making transformers he rapidly branched out into the manufacture of tuning units, detectors, and one-to three-tube amplifiers.

Kent even assembled a five-tube radio receiver with all transformers sealed in tar in a metal container about the size of a one pound coffee can.

Labelled the Model 5, 100 of these "breadboard" receivers were sent to each of Kent's nationwide auto parts distributors. A somewhat similar experimental receiver had been presented to President Harding in August, 1921. This was the first radio receiver installed in the White House and it was this type of publicity which Kent used more and more during the "Roaring 20's." Until late 1923, Kent concentrated on the manufacture of individual radio parts, all of beautiful appearance and fine construction. At the same time Kent conducted a vigorous advertising campaign in consumer magazines such as *The Saturday Evening Post,* plus hobby magazines like *Radio News* (now *Electronics World*).

To avoid becoming entangled in the complicated patent situation that existed regarding radio circuits, Kent purchased, for a moderate sum, the rights to a number of inventions of his previous patent attorney and hired a new attorney to help plan for future developments.

Mass Production. Quick to watch for business opportunities and to consider suggestions from his nationwide distributors, Kent announced, for the Christmas buying season of 1923, his famous Model 10 radio. This was a five-tube receiver with all parts mounted on an attractive wooden board and the wiring channeled out of sight beneath the board. The immediate demand for this receiver was tremendous and some months later, Kent modified and improved the original Model 10 and added a four-tube Model 9 receiver to his line.

In late 1924 at the insistence of his distributors and in view of the competition from the growing number of makers of console-style receivers, Kent announced the Model 20—a five-tube TRF receiver in an attractive mahogany cabinet with a gold-color nameplate. By the spring of 1925, his engineers had designed an almost identical receiver about half the physical size, which Kent personally named the "20 Compact." Kent felt that this name was a concession and an attraction to the growing number of women who had become fascinated by listening to radio broadcasts.

Kent now envisioned an unlimited increase in demand for radio receivers and decided to enlarge his manufacturing facilities. He purchased a large vacant parcel of ground on Wissahickon Avenue in Germantown. The new factory was a single-story modern (then) building with good lighting for both factory and office employees. There were imposing entrances and when one passed through the reception area, practically the entire office force was visible and the heads of departments were located so that they could keep an eye on the lower echelons of office workers. This is not to say that the arrangement was designed to encourage staff heads to spy on employees; as a matter of fact, all desks were well separated and office employees were treated with more consideration than those of competitive radio manufacturers.

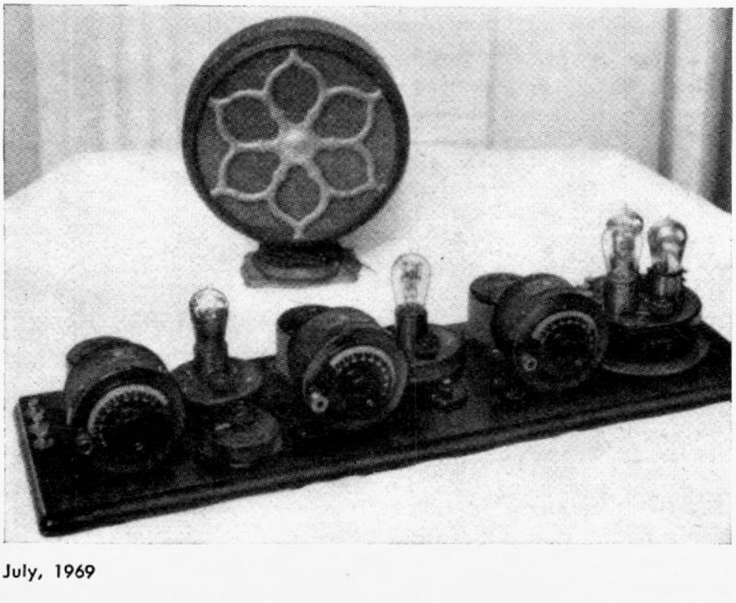
Kent himself occupied a complete suite of offices including a dining room, kitchen and dressing room. This arrangement was used to great advantage since every day Kent invited to lunch a number of his company executives. Many of the important future plans were announced over the luncheon table with Mr. Kent speaking in a semi-New England accent with the intermittent broad *a*.

The Peak Years. From the time of his move into the larger new factory until the depression of late 1929, the Atwater Kent business expanded by leaps and bounds. While progress was being made in the design of radio receivers, Kent continued to manufacture ignition systems for the Model T Ford, which itself remained in mass production until late 1928.

The small three-dial console receiver was replaced in early 1926 by the single-dial Model 30, plus variations of the latter such as the Model 33 with a tuned antenna circuit and, later in 1926, the Model 32 with four stages of tuned r.f.

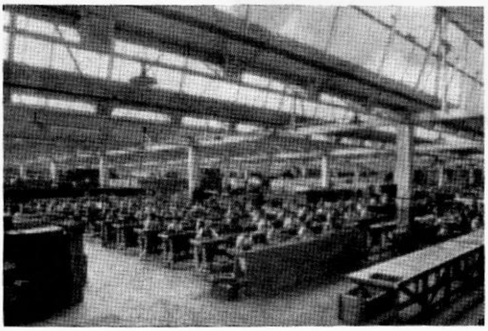
In 1927 Kent turned out a battery eliminator of pleasing appearance to replace the unsightly B batteries, but it was not until RCA developed tubes in which the filaments could operate on alternating current that the true all-household electric radio receivers became a reality at a moderate price. In 1928, Atwater Kent sold nearly 1,000,000 a.c.-operated radio receivers, mostly table models, in metal cabinets with a single tuning dial.

In the early 20's, while still located in the Stenton Avenue plant, Atwater Kent did not make a loudspeaker, only an attachment used to play the output of the



Model 10 was next to the top of the A-K line in 1923 selling for $80. Open breadboard design with the connecting wires hidden under the fine wooden finish was a particular trademark of A-K. Speaker in background is from another A-K era around 1927 when Kent recognized the importance of selling loudspeakers. (Author's collection) radio receiver through the horn of a phonograph. These attachments did not do justice to the audio quality of the receiver and in 1924 Kent had his engineers trying to develop a loudspeaker with quality equal to that of the receiver.

At that time, the Timmons Company was doing a brisk business selling a large "Music Master" horn loudspeaker with a wooden bell. The Kent engineers concluded that an all-metal horn loudspeaker could give better performance. A variety of sizes of metal horn loudspeakers was made and they sold in large quantities until the magnetic cone loudspeaker with more pleasing and decorative appearance—as well as excellent reproduction—replaced horn speakers. Many different sizes and finishes of cone speakers were made in 1927-28. Advertisements showing the Atwater Kent receiver and loudspeaker appeared around the world in newspaper, magazine and catalog advertising.



Kent followed the Henry Ford thinking and manufactured receivers on an assembly line. Factory conditions were better than most companies of the day.

Competition and the Depression. Competitors to Atwater Kent were not sitting on the sidelines while such enormous inroads were being made in the volume sales of radio receivers. By 1928 the Majestic Corporation had developed a high-quality dynamic speaker that was capable of reproducing a much lower range of musical notes and in 1929 Kent designed a table model for use with a separate dynamic speaker. The distinctive mark of all of these 1928-29 radio receivers was a goldplated emblem of a full rigged sailing ship secured to the top or lid of the unit. Meanwhile, Kent used up the remainder of his magnetic speakers by manufacturing a limited quantity of "End Table" metal receivers using the 1928 chassis.

At the annual sales convention in August, 1929, the Kent wholesalers had placed enormous orders in anticipation of a continuing sales boom in radio receivers. After the stock market crash however, orders were cut substantially and Kent was obliged to trim his sails. In early 1930, he had concluded that new aggressive sales techniques and advertising methods were called for.

Meanwhile, his engineers were furiously designing a console-type receiver chassis that would surpass in appearance and performance that of his competitors. At the August, 1930 sales convention in Atlantic City, Kent announced and displayed the famous Model 70 and showed samples of a console cabinet which Kent was not going to manufacture. He informed his distributors at the convention that installation of the chassis into the console was to be made either by the wholesaler or retailer. The entire receiver, which was called the "Radio with the Golden Voice," was promoted in national magazine ads and billboards throughout the country. The dial, in the shape of a large illuminated arc, soon became well-known in the trade and to the general public. The price of this receiver was $275!

Meantime, a local competitor announced a four-tube table model radio receiver with a rounded top selling at the attractive price of $59.50. While there was probably little profit in this small receiver, it was intended as a lever for retail salesmen to talk the buyer up to the price level of a console. But, as the depression worsened and it became clear that prosperity was not around the corner, Kent's wholesalers insisted that he make a competitive model. Unfortunately, he held off doing so until the spring of 1931 with the result that receiver sales in 1930-31 were drastically reduced.

Although it had become painfully evident that the boom sales of the early and mid-1920's could no longer be expected, Atwater Kent continued to turn out high-class models, both table and consoles, as well as radio phonographs. In the 30's, Kent also turned out several radios for use in automobiles and to satisfy the public's interest in shortwave listening, Kent announced various models with two, three or four bands. Later, in 1935, Kent conceived the idea of adding some home appliances to his line of products. The company designed and sold 6000 electric refrigerators. However, the venture was not as successful as had been expected and was abruptly discontinued.

Big Government and Big Labor. Atwater Kent treated his employees exceptionally well. Although he paid no bonuses and sold no stock in his company, he realized that public generosity could benefit the image of a multi-millionaire manufacturer. Insofar as his employees were concerned, as early as 1925 Kent had established a "Welfare Fund" and had made sizable contributions to it. When seasonal layoffs were required, this fund was used to tide over his unemployed personnel until full manufacturing production was resumed. Such an arrangement was unique in the days before Social Security and Unemployment Compensation.

Possibly because Atwater Kent was such a staunch Republican and strictly a self-made millionaire, the New Deal programs of President Franklin D. Roosevelt seemed an invasion of his personal rights. The very idea of enforced Social Security and Unemployment Compensation rubbed Kent the wrong way.

In the fall of 1933, union organizers began to muscle in on the radio manufacturers in the Philadelphia area. This resulted in a short strike at the Atwater Kent Company and it was settled by an agreement involving a 10% pay increase. At the time of the settlement, Kent informed the union leaders that any future attempt to interfere with his management of the business would result in his shutting down the manufacturing plant for good. From then, until June, 1936, the Atwater Kent Company continued to produce new models to conform with the trend of the times, but as sales gradually decreased and profits became marginal, it was abundantly clear that the time left for the company was growing shorter.

Arthur Atwater Kent was then 62 and there was no individual, or group, he felt he could trust to maintain the good name he had built up over the years. Consequently, when union organizers approached Kent in the late spring of 1936, he bluntly informed them that, rather than grant any of their demands, he would close down the manufacturing plant and put the business up for sale. To the several thousands of employees

This is a corner of the author's fine collection of Atwater-Kent and other antique radio receivers, microphones and keys of 1920-25. Author worked at the A-K factory.

still working, this announcement was a tremendous shock. The engineering and production departments had been planning for a vigorous fall selling season and his employees undoubtedly assumed that Kent would make a settlement. When it became clear that Kent was as good as his word, a group of about 20 of his top men pleaded with him to allow them to take over the business. To their mutual dismay, Kent refused and in June, 1936, the doors of the plant were closed for good.

Those employees that had been working for Kent for 20 years were given three months salary as severance pay, but most of the others were fortunate if they could find employment either with competitive radio manufacturers or in the now well-established appliance business.

Kent himself immediately headed for California, bought a palatial estate in the Bel Air section of Los Angeles and proceeded to enjoy the fruits of his many years of highly profitable enterprise. He became well acquainted with many of the celebrities of Hollywood and was noted for the extravagant parties that he gave on his estate. In the spring of 1949 he became hospitalized with a virus infection and passed away at the age of 75.

At the time of the closing of the Atwater Kent manufacturing plant, the building had been put up for sale and was to include his past advertising, name, trade outlets, and good will—all for a price of $11,000,000. However, 1936 was not a propitious year for such a sale and it wasn't until 1939 that the Bendix Corporation occupied half of the plant to manufacture war materials. The other half of the plant (the 1929 addition) was soon occupied by the U.S. Signal Corp. as a training school for radio inspectors and a depot for accumulating the amateur radio equipment used by the Armed Forces in 1942-43. After the war, the entire plant building was taken over by the Veterans Administration and is still occupied by that organization. –30–

Some Highlights in the A-K History

In late 1926, Atwater Kent announced that he had manufactured his one millionth a.c. operated radio receiver. The original of this receiver was allegedly donated to the then King of Spain. However, a sufficient number of these sets (the Model 35) all in a gold-plated finish and all with serial numbers starting at 1,000,000 were shipped to his wholesalers for display.

In 1927, Kent was visited by Helen Keller and her companion. Miss Keller was personally conducted on a tour of the plant and was presented with a special radio receiver and magnetic cone speaker. By pressing her fingers lightly on the speaker cone she was able to enjoy music through the delicate vibrations of the cone.

In the next year, the famous Russian inventor, Leon Theremin, visited the Kent factory with the intention of selling the patent rights to the manufacture of his electrical musical instrument. A working model of the Theremin was in the Atwater Kent laboratories for several months when it was finally decided that the instrument was too much of a novelty. A year later, RCA bought the patent rights, but at a selling price of $300 per Theremin, the project was a financial failure and gladly forgotten.

In August, 1928, the two millionth radio receiver was given to Mrs. Thomas A. Edison.

Atwater Kent, the Philanthropist

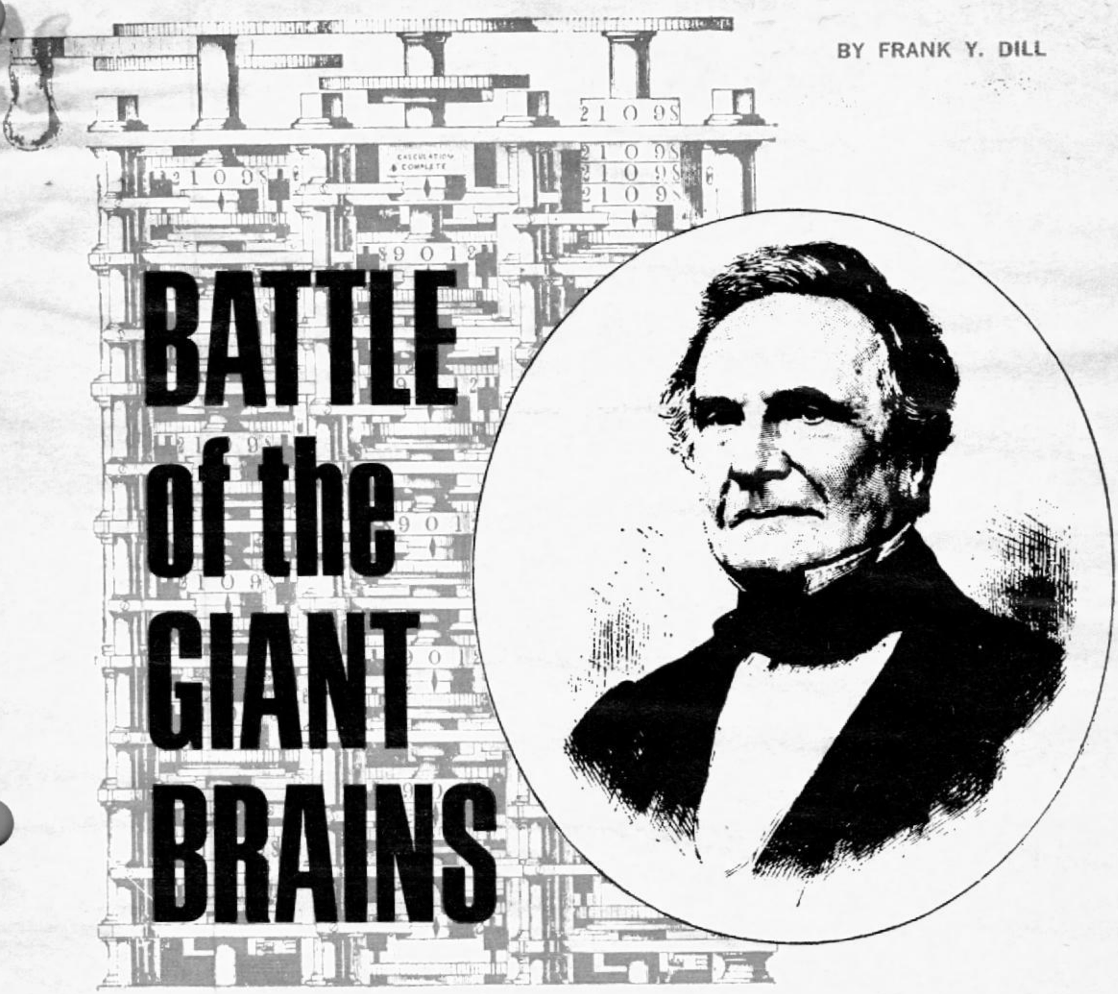
Always very publicity conscious, Kent's most notable contribution was in promoting the public's interest in music. In particular, he sponsored opera broadcasts on the radio networks. The first of these broadcasts was in October, 1925. In addition, Kent supported local schools of music in Philadelphia and provided scholarships in music to promising local singers, including Philadelphia's Wilbur Evans, who later became nationally famous.

Through his original connections with New England, he contributed liberally to the Perkins School for the Blind; and, toward the end of the manufacturing period for battery-operated radio receivers, he ordered the donation of a large quantity of these receivers to the merchant fishing fleet sailing out of Boston Harbor.

Another step taken by Atwater Kent to prevent his name from becoming forgotten was the establishment of the Atwater Kent museum in a small building on South 6th Street in downtown Philadelphia, not far from his original place of business. The museum does not display his manufactured products but is devoted primarily to historical items of Philadelphia.

His many philanthropic and charitable contributions were not tax deductible since there was no applicable income tax in those days. Considering that the Atwater Kent Manufacturing Company, Inc. was owned and controlled by Mr. Kent himself, with only one other minority stockholder, one can scarcely imagine the profits that were made during the free-spending boom years of 1924-1929.

BY FRANK Y. DILL



BATTLE of the GIANT BRAINS

or Electronics Conquers All

A STARTLING REVELATION OF THE EARLY DAYS OF DIGITAL COMPUTERS

CONSIDER for a moment the hardware that goes to make up a digital computer. Could any way of implementing digital functions be better or more natural than the use of electronic components? Our first reaction is to say "no"—conditioned as we are by a quarter of a century of electronic computers and an $8 billion (annually) computer manufacturing industry. It happens, however, that this has not always been the case. In the late 1930's, the question of how to design a digital computer was very much up in the air.

For more than a century after its theoretical invention, the digital computer was an idea in search of realization through suitable technology. Electronics, while it was used in some limited precision analog devices, was

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Frank Y. Dill is a freelance writer specializing in computers and electronics. Above are copies of old engravings of Charles Babbage and his plans for the Difference Engine.

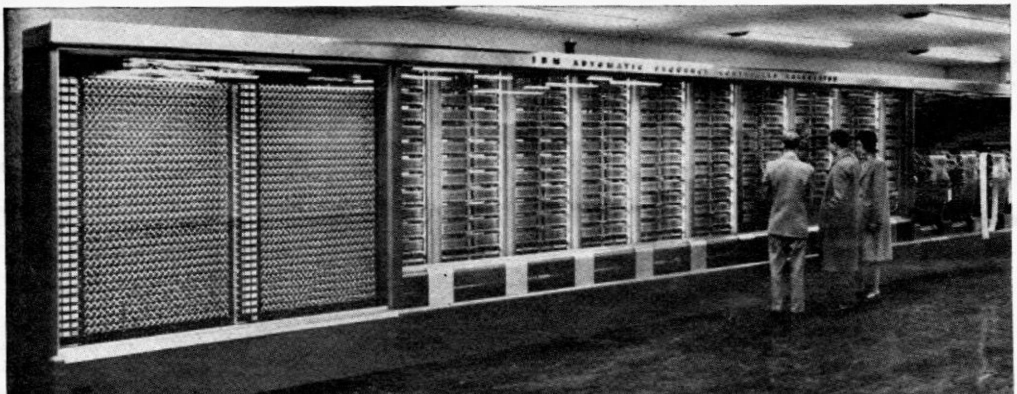
generally overlooked for digital applications. Designers were still thinking of representing discrete quantities in terms of rotating wheels, punched cards, and relays. These devices had shown great promise as far as reliability was concerned and had proven workable in small-scale digital machines. Thus, when the first large-scale digital computers were being designed over 40 years ago, they used non-electronic devices.

Unchallenged success of these non-electronic "giant brains" would have set important design precedents. Fortunately, however, before this could happen construction of an electronic digital computer was begun. Actually, a three-way contest developed between two electromechanical designs and one electronic. The electronic project was at a disadvantage due to the head start enjoyed by its rivals. However, the fate of electronics in computers rested on the success of this project. If this machine were to fail to operate at all or to be not competitive in reliability and overall cost, the future of electronics would be greatly damaged.

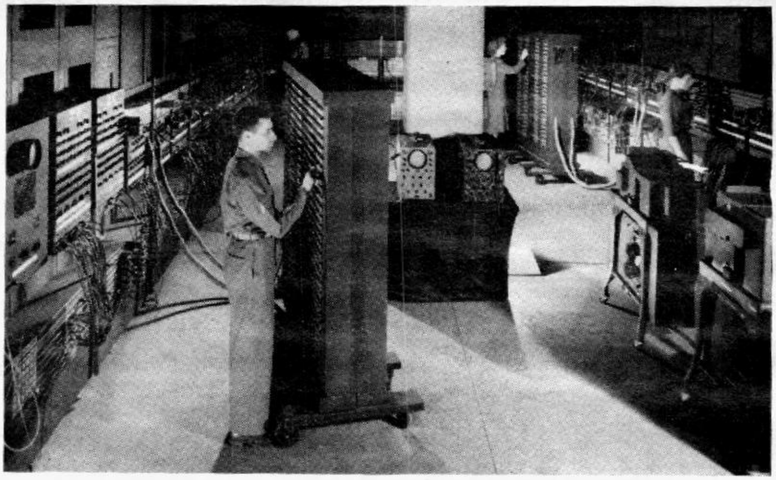
Where It All Began. Before witnessing this three-way design race, let's see where the idea of digital computation began. In September 1834, an Englishman named Charles Babbage, hoping to free mathematicians from the drudgery of calculating tables and to rid the tables of the mathematicians' errors, made the first drawings for what he called an "Analytical Engine." These plans contain many of the basic modern computing principles: punched card input, multiple registers to store intermediate results, automatic sequencing of control, sequencing based on both calculated results and original instructions, and direct mechanical printout of results.

Babbage's device was an extension of the then two-century-old adding and multiplying machines in that it included multiple step calculations whose sequence was controlled by the machine itself. The older machines used a wheel with teeth to advance an adjacent wheel for an arithmetic carry. Similar wheels were to be used in the Analytical Engine to store one thousand numbers of fifty decimal digits each. Calculations and control were to be accomplished by a combination of metal cams, rods, shafts, and levers capable of coupling and decoupling as the program demanded.

Unfortunately, the Analytical Engine was never built. Its construction—like that of twentieth century digital computers—required considerable financial support. The most likely sponsor, the British Government, had already spent £17,000 on an uncompleted, 10-year project of Babbage's called the "Difference Engine." This project had encountered unexpected delays since the machinist's art, lacking modern alloys and mechanical drawing conventions, was unable to fashion Babbage's ideas into metal. So, when Babbage asked the government whether he should continue work on the older project or begin the more powerful and complex Analytical Engine, they, in typical bureaucratic fashion, deliberated for nine years and then said, "neither."



The IBM Automatic Sequence Controlled Calculator, also called the Harvard Mark I, was the first electromechanical, general-purpose digital computer. Neat in appearance, it used counter wheels and relays, had relatively small size, required little maintenance, but computations were slow. (Photo courtesy IBM)



First electronic general-purpose computer was developed by University of Pennsylvania for the Army Ballistic Research Lab. Not mini in size, it solved the speed problem and was predecessor of many electronic computers. (Photo courtesy U. of Penn.)

Unable to obtain financial support, Charles Babbage spent the remainder of his life (until 1871) trying to improve the mechanical technology of the period. The general purpose digital computer remained unbuilt for more than a century after Babbage conceived his plans. However, it was a fruitful period for electromechanical technology and the advances obtained led to the design in the twentieth century of the first large-scale computer.

Babbage Is Vindicated. In 1937, Howard H. Aiken, of Harvard University, aware of the school's need for computational facilities, wrote a paper describing the connection between Babbage's ideas and machines then being produced by International Business Machines.[1] It turned out that IBM was willing to build such a machine, believing that many of their existing mechanisms could be used with little or no modification.

The project was begun in 1939 at Endicott, N.Y., and was officially called the IBM Automatic Sequence Controlled Calculator. Computer jargon was not tolerant of such long names, of course, so it is now usually referred to as the IBM A.S.C.C. or the Harvard Mark I, depending on the speaker's industrial or academic background.

In this first electromechanical project (as in Babbage's machine), variable numbers were stored on ten-position metal wheels. They were rotated by a shaft connected to a 4-hp motor and were engaged by a magnetically controlled clutch. Unlike the Analytical Engine, numbers were not transferred mechanically, but electrically through a buss. Relays controlled access to the buss and provided for arithmetic carries and borrows. Mechanical wheels and relays were used to implement the mathematical functions.

The Second Project. Proceeding concurrently with the IBM-Harvard effort was a computer design originated by George R. Stibitz of Bell Telephone Laboratories. Not surprisingly, this design relied heavily on existing telephone and teletype devices. The fundamental computing device was the ordinary telephone relay, which was so reliable that it could be expected to operate continually for years without failure. An added advantage was that standard telephone practice already included design and maintenance procedures necessary to keep the computer in order.

A series of six computer models was eventually built by Bell Labs. The success of each provided incentive and design experience which contributed to the next. The Model I, called the Complex Computer, was put into operation in January 1940. It contained 450 relays and was used to perform the arithmetic of complex numbers for the Labs. In the Models II, III, and IV, which followed, 440, 1400, and 1425 relays were used, respectively. Finally in 1944, Bell Labs had gained enough experience to attempt to build a 9000-relay general-purpose computer—the Model V.

Electromechanical technology was used in both of the projects just described. The main difference was that the IBM-Harvard computer used some purely mechanical devices for number storage and for implementing the arithmetic operations. The need for a mechanical drive system however placed severe spatial restrictions on the design. The Bell Labs machines, using only relays, eliminated these space problems, but speed was not greatly improved. This problem was a fundamental one, involving the inertial mass of the moving parts. Even the short time required to close the relay contacts was an important factor.

Solving the Speed Problem. Events leading to a solution of the speed problem were taking place at the same time. Soon after the start of World War II, the Army's Ballistic Research Laboratory needed more capacity for handling ballistic tables. It had been using a differential analyzer (an analog computer) designed by the Moore School of Electrical Engineering, University of Pennsylvania. Since the Moore School had a larger analyzer, the BRL contracted to use it and the combination developed into what was prabably the largest scientific computing group in the world.

Unfortunately, the results were still unsatisfactory. More than a hundred desk calculators were needed to supplement the analog computers. The Army needed, as soon as possible, a better way of producing firing tables, each of which involved 250,000 to 500,000 mathematical operations.

In the spring of 1943, Dr. John W. Mauchly, a professor at the U. of Pennsylvania, circulated a report which offered a solution to the Army's computing problem. In 1941, he had visited Iowa State College to study the Atanasoff-Berry computer.[2] This 300-tube electronic computer was being built to solve algebraic equations. It was never finished but it reinforced Mauchly's belief that electronic high-speed computing devices were feasible. His report advocated building such a machine. An appendix to the report by J. Presper Eckert, Jr., gave explicit suggestions for implementing Mauchly's ideas in electronic hardware.

The Army's need at that time justified taking a chance on the project and $61,700 was allocated in 1943 for six months of research and development on Project PX, Mauchly's electronic digital computer. The project later became known as ENIAC, an acronym which originally stood for Electronic Numerical Integrator and Computer, though the last word has since been incorrectly reported as Calculator.

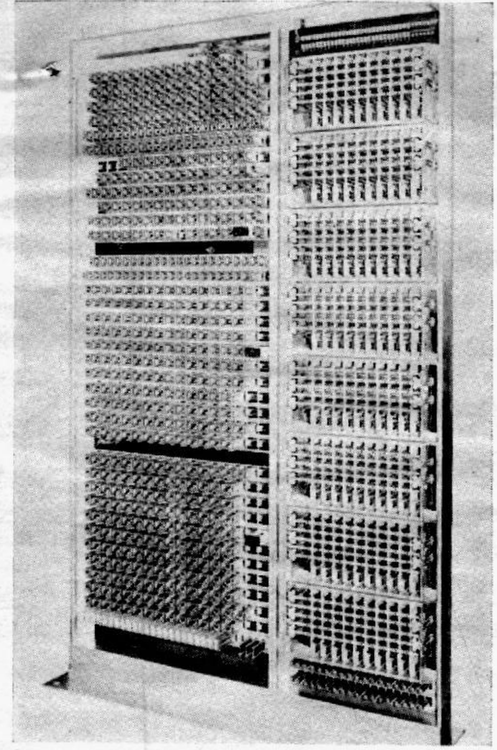
During those six developmental months, the most challenging electronic problems ever encountered in a single design were tackled. Since the reliability of a computer is all-important and since the reliability of the whole is no better than that of its individual parts, component reliability was the first major technical consideration.

The most likely component to fail was the vacuum tube. While a single tube had a life expectancy of many thousands of hours, a total of 18,000 tubes were to be used. This meant that the probability of a single tube failure at any particular time was rather high. Prior to this, the largest electronic system was a radar set with 400 tubes, and the problem was important even then.

The solution was to use proven standard tubes and to operate them well below their normal ratings. Filaments were run at 5.7 volts instead of 6.3 and they were rarely

COMPARISON OF EARLY COMPUTERS[7]

	IBM A.S.C.C. Harvard Mark I	Bell Labs Model V	ENIAC
Construction	Electromechanical	Relay	Electronic
Major Components	2200 Counter wheels 3300 Relays	9000 Relays	18,000 vacuum tubes
Floor space	240 sq. ft.	1150 sq. ft.	1800 sq. ft.
Weight	5 tons	10 tons	30 tons
Percentage of time needed for repair	8%	3%	25.6%
Maintenance staff	3 men	1 man	11 men
Addition time	1/3 sec.	1/3 sec.	1/5000 sec.
Multiplication time	6 sec.	1 sec.	1/350 sec.



Relay panel from Bell Labs Model I Complex Computer, first of series of 6 relay computers using standard telephone apparatus. (Photo courtesy Bell Labs.)

turned off to increase their life.[3] Plate and screen powers were limited to 25% of rated values.

It is easy to see how the heat generated by all those tubes provided another problem. There were 70,000 resistors and 10,000 capacitors in the system which could be damaged by excessive heat. Of the 150 kW of power consumed by the ENIAC, 80 kW was dissipated by the tubes and another 20 kW was used to drive cooling fans. In addition, each panel of the machine was protected by a thermostat which would shut off that panel if the temperature got over 115°F.

Another problem encountered in the design of the computer was synchronization. Control pulses of two to five microseconds were repeated in cycles. Still other pulses were generated by the computing process. Although the idea of gating is now fundamental to computer design, one of the first applications of a "gating tube" was in the ENIAC computer.[4]

For storage, the ENIAC used the Eccles-Jordan trigger circuit commonly called a flip-flop. The arrangement of the flip-flops to represent decimal digits was rather unusual in terms of modern design. Ten flip-flops were used to represent a single digit. This resulted in a very expensive main memory. Eckert estimated that the average cost of storage was $15.00 per decimal digit. By comparison if the largest main memory of a modern computer like the IBM System 370 Model 165 used such a memory, the 3 million bits would cost in excess of one hundred million dollars.

The Race Quickens. When the ENIAC project was just a year old, the complete electromechanical Mark I was unveiled in a public dedication ceremony on August 7, 1944. Its impressive 51-foot, neatly encased exterior was in sharp contrast to the jumble of wire and panels that were to comprise the ENIAC. Actually the Mark I had been tested prior to the start of ENIAC and it had undergone a complete debugging while operating in secret. The age of digital computers had arrived and the Mark I operated around the clock with a down-time record that was impressive by modern standards.

Thus the Mark I posed a real threat to electronic computers. The total need for computers had been greatly underestimated. In fact, a prediction had been made that the entire computing requirements of the U. S. could be satisfied by six computers.[5] So the Army might have been justified in cancelling the ENIAC in favor of a Mark I type of machine, especially if unexpected delays or expenses were encountered. Such loss of sponsorship had happened to Babbage a century before.

An even more direct challenge to ENIAC came from the Bell Labs Model V. The same Army group that had contracted for ENIAC, hedging on its gamble, had also ordered one of the two Model V's being built. However, the hedge was not needed since ENIAC was completed and shown to the public in February 1946, after 30 months and $486,804.22 in the making.

(*Continued on page* 99)

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GIANT BRAINS

(*Continued from page 33*)

Now the time had come to decide which design was best—the Mark I, the Model V, or the ENIAC. The direction computer design was to take lay in the balance. Debate was based on arguments of component reliability, problem set-up time, error-free operation, self-checking ability, and maintenance costs. The builders of ENIAC based their stand on the fundamental advantage of speed, which really meant decreased cost of computing—and this attribute far outweighed ENIAC's disadvantages.

The deciding argument was given by Dr. Mauchly when he said that the life of a computing device should not be based on time alone but on the number of operations it can be expected to perform before failure.[6] A good relay may average 100,000,000 operations before failure. A vacuum tube may be expected to operate reliably at a pulse rate of one operation per microsecond for 5,000 to 10,000 hours. Thus the tube may perform more than 10^{12} operations compared to 10^8 for the relay.

Not only did great speed mean cheaper computing, it also offered hope of fulfillment of the cybernetist's dream of real-time control of complicated events. The ENIAC could calculate the trajectory of an artillery shell in half the time of the shell's flight.

The strength of ENIAC's success can be seen in changes made by other builders of digital computers. Harvard followed the electromechanical Mark I with a relay Mark II. A twelve-fold increase in speed was achieved. Since this was still no serious challenge to the ENIAC, there followed the Mark III, which got on the electronic bandwagon. The interest of Bell Labs in computer manufacturing was too heavily tied to the use of telephone equipment to convert to electronics. Their contribution to computer technology was to be with the invention of the transistor, not by the direct manufacture of computers.

The Eckert-Mauchly team went commercial and designed the Binac and their small company was absorbed to form the basis of Univac. And what of IBM, the builder of Harvard's Mark I? Suffice it to say that they too recognized the potential of electronic digital computers. —30—

Ampere's Law

BY DAVID L. HEISERMAN

AMPERE'S Law states that a pair of conductors carrying electrical currents exert magnetic forces upon one another. Furthermore, the amount of that force depends upon the amount of current flowing in each conductor, and the distance and angle between them. Andre Marie Ampere, a French physicist and mathematician, announced this new law of nature on September 18, 1820. As if discovering such a law weren't enough, Ampere used it to lay the theoretical foundations for a whole new branch of electricity and physics called electro-dynamics—and he did it in just seven years.

Early Years. Looking back at Ampere's work from our present-day point of view, it appears that the man spent the first forty-five years of his life preparing for his seven years of discovery. Born into a moderately well-to-do and educated family, young Ampere had most of the advantages available to French children reared during the Great Revolution. Moreover, he was a child prodigy who learned geometry and calculus at the age of twelve by reading texts that were written in their original Latin.

When Ampere was eighteen, his father was executed during the bloody "Reign of Terror" that swept France. The sights and sounds of the revolution, topped off by his father's violent death, shocked Ampere's mind. He spent the following six years of his life wandering aimlessly about the countryside, building sand castles by the sea and composing nonsense poetry.

At the end of that lost period of time, Ampere married and settled down to a more conventional style of living. His brilliant mind had returned, but the family money was gone. So, Ampere took his first job as a professor at the University of Bourgen-Bresses. Barely three years passed before his wife died, shocking Ampere's mind into a stupor for another year.

Napoleon had heard about the talents of this unfortunate young genius, and he offered Ampere a teaching position at a school in Paris. Discouraged with life, but anxious to return to his work, Ampere accepted the position and he remained there for the rest of his professional life.

Ampere began contributing papers on a wide variety of subjects, including chemistry, mathematics, molecular physics and biology. At the time, his special interest was in the theory of games. These papers were important to other scientists, but they were not the sort that fall into the category of special greatness.

A New Discovery. On September 11, 1820, Ampere happened to attend a demonstration of Oersted's new discovery. The demonstration showed that a current flowing through a straight piece of wire makes a compass needle turn to a position at right angles to the conductor. Even while this demonstration was still in progress, Ampere must have thought, "Since one conductor carrying an electrical current can exert a force upon a compass needle, why can't two current-carrying conductors exert forces upon one another?"

Excited by the notion that current-carrying wires produce exactly the same kind of magnetic forces as loadstones and permanent magnets, Ampere immediately dropped all his other work and began investigating this "artificial" source of magnetism. In seven days, Ampere developed the fundamental theories of electrodynamics, designed and built the experimental setups, performed the necessary experiments, and presented his findings to the scientific world. No other major scientific discovery has ever been conceived and tested in such a short period of time. Ampere was, indeed, fully primed for this week of great discoveries.

Two highly significant ideas emerged from Ampere's mind and experiments that week. For one thing, he developed what we now commonly call the "right-hand rule." According to this rule, with the thumb of the right hand pointing in the direction of conventional current flow (positive to negative) through a wire, the curled fingers of that hand indicate the direction of the resulting magnetic field. Oersted had already concluded that magnetic lines of force emerge at right angles from the conductor. Ampere, however, perfected the notion by making it possible to predict the sense, or polarity, of that field.

The other important idea in Ampere's first paper concerned the attraction and repulsion of two parallel wires carrying an electrical current. Ampere showed that currents flowing through the wires in the same direction made them attract one another, while currents flowing in opposite directions made the wires repel.

Ampere's discoveries about the direction of magnetic fields around a conductor and the forces acting upon a pair of current-carrying wires are just as important today as they were 150 years ago. What is perhaps even more remarkable is the almost unbelievable simplicity of the lab equipment he used. He managed to open a whole new technology using nothing more than a few lengths of copper wire, a compass, and a couple of Volta batteries.

During the seven years after his preliminary announcement, Ampere's papers became increasingly spiked with complicated equations. His early studies of geometry and calculus were paying off. Other researchers in Europe had picked up some good ideas from Oersted's work, too; but most of these people lacked the high level of mathematical sophistication and creative insight Ampere possessed.

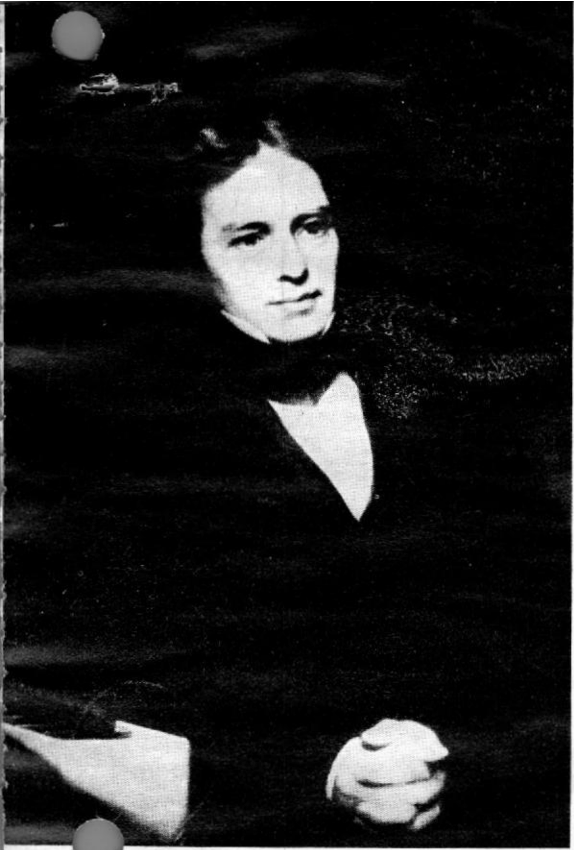
Back to the Laboratory. His work soon reached a point where he had to return to the laboratory to confirm his equations. This time he had to obtain precise figures for the amounts of current flow and forces between the conductors. Using what was then a revolutionary new measuring instrument, the galvanometer, Ampere was able to measure the amount of current flowing through the wires. His own original work with coils of wire and solenoids, by the way, was directly responsible for the invention of the very galvanometer he used.

Since he also had to know the exact amount of force two conductors exerted upon one another, Ampere devised a couple of specialized instruments. One of them was an ordinary laboratory balance that had a solenoid attached to one side of the beam. This solenoid fit inside a larger one fixed to the bottom of the balance. Current flowing through the two solenoids made the smaller one move inside the larger. By placing calibrated weights upon a weighing pan on the opposite end of the beam, Ampere could determine the exact amount of force the two sets of conductors exerted upon one another.

According to the famous scientist, James Clerk Maxwell, Ampere's fundamental equations had "leaped full grown and fully armed from the brain of the Newton of electricity." Ampere's equations were practically complete even before he set out to demonstrate their validity in the laboratory. Making up equations before running the experiments was contrary to the accepted scientific procedure of the time, but one simple fact silenced all critics—the equations and laboratory experiments always agreed. And to honor this "Newton of Electricity," the International Congress of Electricians named the basic unit of current, the ampere, after him.

Ampere was a hard worker as well as a scientific genius. Even while he was concentrating on the job of building the foundations of electrodynamics, he taught classes at the university. Perhaps this was a mistake. Ampere was noted for stopping his lectures in the middle of a sentence while his mind wandered off onto some new idea or equation. He also had a habit of letting his work at the blackboard meander into some new line of mathematical reasoning, leaving his students to puzzle over the jumble of incomprehensible figures related to some new idea in electrodynamics.

Ampere was, indeed, a classic example of an absent-minded professor. There can be no doubt, though, that he was one of the most successful absent-minded professors of all time. Unlike the blackboards that carried his ideas off into oblivion, Ampere's basic equations stand essentially unchanged to this day. ◆



FARADAY AND ELECTROSTATIC LINES OF FORCE

By David L. Heiserman

AS A BOY in the early 1800's, Michael Faraday hardly looked the part of someone destined to grow up to become one of the world's most productive scientific geniuses. The son of a poor London blacksmith, Faraday spent much of his boyhood standing in welfare lines waiting for food. Out of sheer desperation, his family permitted him to drop out of school at age 13 to earn his own way as an errand boy in a bookstore. For young Michael, leaving school was no great loss since he had no fondness for school.

Faraday soon found that he had a liking for books, especially the ones about popularized science. Fortunately, his employer was an understanding man who allowed the boy to read between errands and janitorial duties.

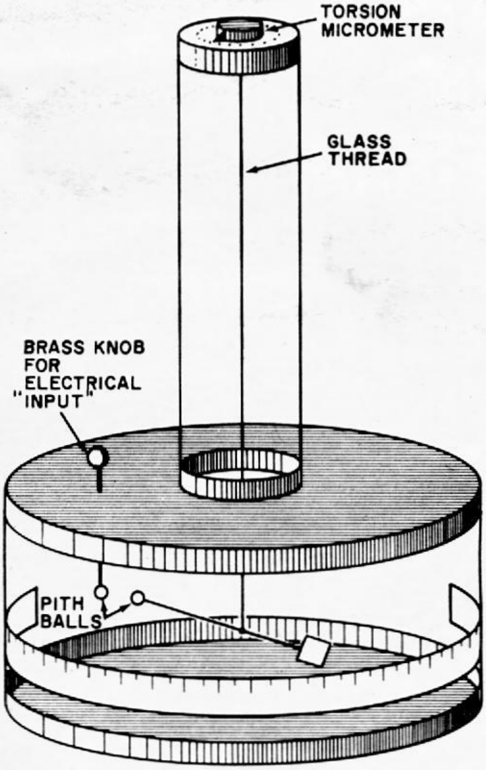
One day a customer gave Faraday a ticket to a lecture that was to be given by the eminent British scientist, Sir Humphrey Davy. Owing to his reading, Faraday understood most of what Davy said at the lecture. He also managed to take down an incredably complete and accurate set of lecture notes. A few days later, he copied the notes into a booklet and mailed them to Davy, along with a request for any kind of a job in the scientist's laboratory. Davy was impressed and flattered and offered Faraday a job as bottle washer in his chemistry lab.

The Scientist Emerges. Faraday's abilities and enthusiasm soon prompted Davy to promote him to research assistant. After that, Faraday's list of accomplishments makes most success stories seem uneventful. By the time he was 30, he had worked his way up to being one of Europe's most popular experimenters and lecturers. Almost entirely self-taught, Faraday conducted his own experiments in chemistry and electricity with a genius and precision that surpassed that of most scientists of his time. He had no liking for mathematics, but he made up for the deficiency by drawing elaborate analogies between everyday situations and his abstract theories.

In 1831, Faraday began his famous series of experiments that eventually led to his discovery of electromagnetic induction and the invention of the first electric motors and generators. It was only his lack of mathematical sophistication that prevented

Faraday from becoming the discoverer of radio. Clerk Maxwell, a more mathematically minded investigator, later used Faraday's principles to formulate the basic equations for electromagnetic waves.

Ever in search of new knowledge, Faraday by 1836 returned to the electrolysis experiments he had once shared with Davy. By placing sheets of metallic foil on opposite faces of a block of ice, he demonstrating that no current could flow through the ice until it melted. To the contrary; the ice seemed to gather and store an electrical charge. But once the ice melted, current began to flow and decompose the water into its fundamental elements of oxygen and hydrogen. While this experiment was popular among professional and amateur experimenters of the time, Faraday saw some important features in it that others had overlooked.



The Coulomb Torsion Balance. The instrument is initially calibrated by turning the torsion micrometer so that it reads zero when the two pith balls just touch. Placing an electrical charge onto the pith balls makes the suspended ball rotate away from the fixed one. Faraday rotated the torsion micrometer until the charged pith balls were exactly 20° apart, then he recorded the number of degrees and minutes he turned the micrometer knob. By knowing the torsion constant of the glass thread, it was possible to calculate the amount of force and, hence, the amount of the electrical charge that was on the balls.

The idea that current-carrying conductors produce a magnetic field had served him quite well in his work with induction; so, he proposed the existence of another kind of field—an electric field—to explain the storage quality of ice and all other kinds of nonconductors. In his laboratory notes dated December 23, 1836, Faraday describes a new kind of apparatus for studying the relationships between different types of insulating materials and their "inductive capacity."

Faraday built devices made of two hollow airtight brass spheres. One of the spheres was small enough to fit inside the other, leaving ½ inch of space all around for inserting different types of insulating gases or solids. He suspended the smaller sphere inside the larger by means of a glass tube. A wire running through the glass tube provided electrical connection to the inne sphere.

The outer sphere was mounted on a stand equipped with a valve that let him evacuate the space between the spheres or fill the space with different kinds of gases. He also fashioned a mold for forming solid materials that would perfectly fit into the space.

With this apparatus, Faraday was able to construct a "spherical" capacitor whose plates he could separate with any type of dielectric material of his choosing. His main idea was to compare the "inductive capacities" (a term now known as "dielectric constant") of different insulating materials by charging the spheres with a static potential and measuring the amount of charge they acquired.

To measure the stored charges, Faraday used a sensitive torsion balance invented by Coulomb. This apparatus consisted of a thin lacquered straw about the size of a toothpick suspended at right angles from a length of fine glass thread. Minute forces applied in the proper direction to one end of the straw made the straw twist about the thread. By measuring the angle of the twist, an experimenter could calculate the actual amount of applied force.

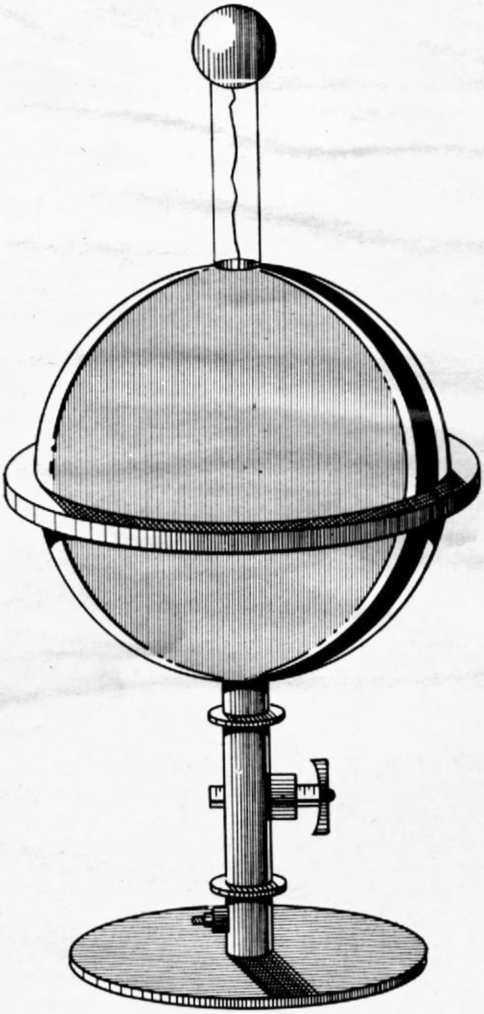
To make the torsion balance sensitive to electrostatic charges, Faraday attached a small pith ball to one end of the straw. He attached a piece of paper to the opposite end to serve as a damper for the mechanical oscillations and act as a counterweight. Another pith ball, fixed to the frame of the balance, carried test charges to the space around the ball on the straw. Charging the fixed pith ball made the movable one rotate through an arc Faraday measured by means of a piece of paper scribed with units of arc in degrees and minutes.

In his experiments, Faraday would place a dielectric material between the spheres, charge them with a static voltage, and measure the amount of charge with the torsion balance. He also kept track of how fast the charges leaked off the spheres, discovering that different materials took on different amounts of charge. Spheres separated by glass, for example, took on larger charges and held them longer than did spheres separated by air or hydrogen. This confirmed his suspicion that different insulating materials have different "specific inductive capacities."

What is more important, these experiments backed up his theory of electrostatic lines of force and cleared up a longstanding problem concerning charged insulators. Other researchers believed that the metallic plates and not the dielectric between them held the stored charges. By demonstrating that electrostatic lines of force within the dielectric—not the plates—held the stored charge, Faraday cleared up a prevalent misconception.

The Perfectionist. Since Faraday did not like to bother with mathematics, he was content to explain his findings in terms of pictures which showed lines of force more concentrated in some materials than in others. His data was so accurate and complete that other scientists incorporated his notion of "specific inductive capacity" into formal equations that stand to this day.

Faraday's notes indicate that he often mistrusted the readings he obtained from the torsion balance. To convince himself, and many critics as well, that the amount of charge stored within different types of materials was really different, he frequently used two identical sets of hollow spheres. He would charge one set, measure the charge with the torsion balance, and then touch the charged set of spheres to an uncharged set. Whenever the two sets contained the same type of dielectric, they divided the original charge equally. But when one set of spheres contained a better dielectric than the other, the set with the better dielectric took on a large percentage of the original charge.



A Faraday Sphere. Faraday used this piece of equipment to determine the "specific inductive capacity" (which we now call the dielectric constant) of different types of insulating materials.

The scientific community accepted Faraday's theories and experimental results with enthusiasm. As a result of his work with dielectric lines of force and dielectric materials, the 1891 International Electrical Congress voted to name the electrical unit of capacitance, the "Farad," in honor of Michael Faraday. ◆

The Origin of

Ohm's Law

TODAY, Ohm's Law stands as one of the most powerful and commonly used laws of electricity and electronics. It states that the amount of current flowing through a conductor (or resistor) is equal to the applied voltage divided by the resistance of the conducting material. In mathematical terms, the equation generally reads $I=E/R$. What seems simple and obvious today, however, took a great deal of genius, courage and effort to propose for the first time in 1825. Georg Simon Ohm, a German physicist and mathematician, was a man who had the right kind of genius and courage.

BY DAVID L. HEISERMAN

Scientists were aware of a "galvanic fluid" (electrical current) that played some mysterious role in their studies; but the elusive and short-lived nature of currents in static electricity made them a difficult subject for any kind of meaningful study.

Alessandro Volta completely changed all this in the early months of 1800 when he formally announced the discovery of his electric generating cell. His "hydro-electric battery," forerunner of modern wet-cell batteries, gave scientists their first source of current that could flow continuously. For nearly twenty years, however, all the studies of galvanic currents suffered from one serious disadvantage—there was no way to measure the amount of current flow.

The breakthrough came in 1820 when Oersted showed that a current passing through a wire produces a magnetic field. A year later, Schweigger and Poggendorff used Oersted's findings to invent the galvanoscope—a crude sort of galvanometer made of hundreds of turns of wire wrapped around an ordinary compass. Current flowing through the wire produced a magnetic field that deflected the compass needle by a proportional amount.

Georg Ohm, then a high school mathematics and physics teacher in Cologne, saw the possibility of combining Volta's hydro-electric battery with a galvanoscope to study the nature of electrical current flow.

Using equipment he constructed himself, Ohm set out to find the exact relationship between applied potential, the length of a conductor, and the amount of deflection of the needle in a galvanoscope. His procedure was to connect the galvanoscope directly to the battery and carefully note the position of the compass needle. This gave him a reference reading. He then inserted a wire of known composition and length into the circuit and noted the new position of the needle. This was his experimental reading. Of course, the resistance of the test wire made the needle show a smaller amount of deflection in the experimental condition.

In 1825, Ohm reported his first findings in a paper titled "Preliminary Notice of the Law Accordng to which Metals Conduct Contact Electricity." Publishing this paper turned out to be a mistake that plagued Ohm for the next sixteen years.

Technically speaking, the equation Ohm

presented in the paper was incorrect. It stated that $v=m \log(1+x/r)$; where v was the decrease in the needle's deflection, x represented the length of the conductor, r represented the resistivity of the conducting material, and m stood for the amount of applied potential.

Just before his paper was scheduled to appear in print, Ohm repeated a few of his experiments using a different kind of power source. The results didn't agree with his original findings, and Ohm immediately saw he could develop a much simpler equation that didn't contain a logarithmic term. By the time he contacted the publisher, however, the paper was already in print; and the best he could do was publish a short letter promising to run a new series of experiments. Ohm stated he would show that the amount of current flowing through a circuit goes to zero as the length of the conductor approaches infinity. This bit of mathematical talk constituted his second mistake—a political one in this case. His letter infuriated most scientists of the time because they firmly believed the only proper scientific procedure was to gather mountains of data before playing with any kind of equation.

Ohm's incorrect equation was the result of a widespread lack of knowledge about the basic theory of batteries. After it was too late to stop publication of his paper, Ohm realized he had used an unstable power source—one whose output voltage varied with the amount of loading.

Poggendorff, one of Ohm's few allies in the scientific community, suggested he use a Seebeck thermoelectric battery rather than Volta's hydro-electric battery.

The thermoelectric battery was the first practical device to take advantage of the thermoelectric effect discovered by Seebeck in 1821. The Seebeck effect makes two unlike, tightly bonded conductors produce an electrical potential when one of them is heated. The output voltage is small, but so is the internal resistance. So, Ohm repeated all his experiments using the stable thermoelectric battery and galvanoscope. The equation we now know as Ohm's Law fit the data from his new series of experiments.

In 1826, Ohm was ready to show the world he knew what he was talking about. His second paper was entitled "Determination of the Law According to which Metals Conduct Contact Electricity, Together with the Outlines of a Theory of Volta's Apparatus and the Schweigger Galvanoscope." The corrected equation read, $X=a/(b+x)$; where X represents the amount of current flow through the conductor, a stands for the exciting voltage, x is the resistance of the conductor under test, and b is the combined internal resistance of the power source and galvanoscope.

In the early part of 1827, Ohm published yet a third milestone paper in the history of science called "The Galvanic Battery Treated Mathematically." He then believed he had completely vindicated himself for proposing an incorrect equation and was confident that his colleagues would finally accept his law of electrical conduction.

The scientific community, however, was still not ready to accept Ohm and his works. For one thing, the equation seemed too simple—far too simple to explain a phenomenon that had been challenging the best minds of Europe and America for nearly thirty years. Then, of course, there was Ohm's widely misunderstood statements in the letter following his first paper. Most reputable scientists still considered Ohm a quack. Bitter and disappointed, Ohm returned to his teaching profession.

Six years passed before a few influential scientists began taking serious looks at Ohm's work. The incident that touched off this mild renewal of interest was a paper published by Pouillet in 1831. Pouillet had unwittingly repeated Ohm's work, and he had arrived at exactly the same results. Pouillet believed he was the founder of the law of electrical conduction, and so did most of the scientists of the time. Several scientists, however, noted a strong similarity between Ohm's work and Pouillet's paper.

In 1841, sixteen years after Ohm announced his law of electrical conduction, the British Royal Society presented him the Coply gold medal for "the most conspicuous discovery in the domain of exact investigation." Ohm thus received proper credit for his work, a formal apology for the delay, and a well-deserved round of applause from his peers.

Ohm died in 1854; and, exactly ten years later, the British Association for the Advancement of Science adopted the ohm as the unit of measure for electrical resistance. Thus Ohm (like Ampere and Volta) is now immortalized in the everyday language of modern electrical engineers and technicians everywhere. ◆

THE WALL STREET JOURNAL, Monday, November 11, 1968

Current Electronics

New Materia' ... v Lead to an Inexpensive

Glass V- ... ms Such as Transistors

Memory Cell May Start Electronics Revolution

Glassy Electronic Device May Surpass Transistor

By WILLIAM K. STEVENS

Ovshinsky Effect: A Big Bang

OF ATOMS AND MEN

'News' Is Old-Hat but Still Market Jumps

Components

Transistors face an invisible foe

OVSHINSKY EFFECT

The Tumult and the Shouting Die

An Electronic Breakthrough

Amazing New Transistor

The Threshold Switch

New Component for Ac Control

The Incredible Ovshinsky Affair

Wave the magic wand of electronics and Wall Street comes running

By JAMES LYDON

IF YOU'VE got it, flaunt it. So say the ads. Stanford R. Ovshinsky isn't the most humble person around in the scientific community today, but why should he be? He may have one of the best things going in semiconductor electronics. Then again, he may not. Even the professionals are undecided at this moment.

Mr. Ovshinsky is the author of several papers on glassy semiconductors—also called Ovonic devices—that exhibit what he has termed the Ovshinsky Effect. The big guns in the semiconductor industry (Bell Labs, RCA, Texas Instruments, etc.) have been working on glass devices off and on since the early sixties but Ovshinsky seems to be the first to have made a full-time thing of it. Now that he has announced the Ovshinsky Effect and its future applications, many people in the scientific and technical-press communities are mad at him for *not* telling it like they think it really is.

Glass semiconductors differ from the silicon and germanium materials you are familiar with. Silicon and germanium are crystalline substances which provide an abundance or lack of electrons at positive-negative junctions. Current flows according to the bias placed on the junction. Glass semiconductors, however, are *amorphous* (disordered) materials. They exhibit a high resistance to

Ovshinsky Affair

applied signals until a critical voltage (dependent on the design) appears at the two terminals of the glass layer; at this point resistance practically disappears. Thus, an Ovonic device acts like a semiconductor switch. You turn it on or off by applying the correct voltage. Also, the devices are said to be unaffected by radiation—a possible point of interest for the military.

Problem is, glass semiconductors work according to little known principles so the whole thing is highly theoretical. The technology of amorphous materials is not fully understood (crystal growers, take note!) and it is impossible to reproduce stable devices with any uniformity. This puts the Ovshinsky Effect back in time to when the transistor was still suffering growing pains. At the moment many experts are disenchanted with Ovonics. Its sudden presentation to the press on Friday, Nov. 8, 1968, had a lot to do with this state of affairs.

Presentation is the key word. These days, how you sell an item is just as important as the worth of your product. Part of this hectic scene is the press kit. Between pieces of glossy cardboard bearing a company's name, reams of data sheets, photographs and other miscellaneous and sundry items are stuffed until the folder will hold no more.

Such was the package that greeted a few technically unprepared reporters at the November 8 press conference sponsored by Energy Conversion Devices, Inc., the company headed by Mr. Ovshinsky. Since only 11 of 25 reporters invited from the consumer press showed up, remaining press kits were mailed to publications selected with great care.

When scientists at Bell Telephone Labs picked up a copy of the *New York Times* on the following Monday (Veteran's Day), they were probably mesmerized by a three-column headline on the front page which heralded a new era in physics.

According to the *Times* story, the phenomenon whereby glass becomes a semiconductor was called the Ovshinsky Effect; and it had thus far yielded switches, computer memories and thin-film semiconductors, the latter having been heretofore considered impossible in the industry. These Ovonic devices were termed a breakthrough in a new branch of physics that would make possible a whole new line of ultra-miniature gizmos—desk top computers, flat TV sets you can hang on your wall, ultra-fast switches, everything for a better world.

Shades of Shockley! The Bell scientists probably recalled that the announcement of their transistor some 20 years ago got a mere four in. of space on the inside pages of the *Times*. And the transistor effect was hot news at the time.

In Washington, one could imagine Russian diplomats scanning the front page of the *Washington Post* for news of the Paris peace talks. You guessed it! They read still another angle on the same story—a glass mini-switch had been announced at a press conference in Troy, Michigan. This story implied that the new device was a forerunner of a revolution in electronics similar to that started by the transistor. It probably appeared to the Russians and some other foreign diplomats that the Americans had again widened the technology gap.

On Wall Street the quiet of the holiday was shattered by a banner headline in the esteemed *Wall Street Journal* which pulled readers into a story announcing cheap, easy-to-make glass versions of transistors. Investment brokers, mutual fund managers, bank clerks and elevator operators underlined the name of Energy Conversion Devices and started a telephone marathon that would last well into the week. Indeed, the one-two punch of the *Times* and *WSJ* stories was enough to drop the stock values of virtually every major semiconductor manufacturer when the exchanges opened the following day.

Throughout the country the story of the new science was told by the 11 odd reporters who had been among the select group at the Troy press parley. The *Boston Globe*, aiming for the egghead community of MIT and Harvard, proclaimed that Ovshinsky had made a discovery "missed by the world's great industrial laboratories and university physicists." Filled with pride, the *Detroit News* sounded off with "Troy Ovonics Inventor Eyed for Nobel Prize." Finally, Sub urban America was filled in by the Associated Press which put the story on its wire.

Only a monetary crisis in France could knock the story off the front pages of the Paris *Herald*; yet it had no trouble biting a good swatch of newsprint inside. The *Herald* picked up the *Times* story and ran it whole—the Ovshinsky effect had become a snowball effect, adhering to a little known law of

Headed for a Nobel Prize? Stanford Ovshinsky was so photographed on Nov. 11, 1968 after his company, Energy Conversion Devices (located at Troy, Mich.), held a press conference to announce the development of Ovonic devices. After initial fever hit Wall Street and certain members of the press, Ovonics soon cooled down to a point where a deep freeze finally set in. Just what the outcome will be is anyone's guess.

UPI Photo

Newton that publicity begets more publicity unless acted upon by an external fact. Feedback from the tidal wave was not long in coming.

Phones rang all day at Energy Conversion Devices in Troy. Ovshinsky—overwhelmed by sudden fame—had a tough time handling the calls. A Milan magazine called about an interview, an Australian News service asked for a taped report, radio reporters from CBS sought material, and invitations to speak at universities poured in. Was impresario Sol Hurok waiting in the wings?

The Dow Jones News Service (in a frenzy of activity after the *Times* and *WSJ* stories) began to record the scramble for Energy Conversion stock that occurred when the Street opened for business Tuesday. Traded over-the-counter ECD shares opened at 105 from a low of 58 on the previous Friday. The asking price soared to 150 before trading ended; small fortunes were won and lost almost instantaneously before some Tuesday afternoon quarterbacking knocked the price of ECD down to 75—still much higher than the pre-press conference price.

The first of the more cautious quarterbacks was Bache & Co., which issued a caveat to its investors on the basis of a dubious attitude that its investigators found among experts in the electronics industry.

Meanwhile, financial reporters for the *Times* (who not too willingly inherited the follow-up assignments from the Science desk) started a probe but were unable to come up with much support for the enthusiasm of the Monday story. Ovonic devices, they found, were apparently not up to snuff, and a licensing agreement between ECD and ITT (cited in the initial story) had gone a little sour. If there were red faces around the Science desk they were to get redder still.

The *Wall Street Journal*, homing in on fiscal aspects, reported in its follow-up that Energy Conversion was up tight, having sustained sizable losses during the last two years. Most of the firm's income, the *Journal* said, was derived from private investors and contracts. The company had only one profitable year in its eight years of operation, the *WSJ* noted dryly.

As the Times and WSJ continued to examine and meditate upon the Ovonic Wonder, *Newsweek* magazine, with more lead time, checked with its own inputs and discovered that the technical press had not been invited to the Troy press conference. For some reason, a subject as abstruse as amorphous semiconductors was restricted to the lay press. It was almost like inviting *Better Homes and Gardens* to speed trials at Indy.

Why trade and technical reporters were snubbed was soon to emerge much to the discomfort of the national press. For what had been brought back from Troy as hot copy had actually been circulating for years in the staid pages of trade magazines. Over the past five years Ovshinsky had been plying trade journals with reports of his efforts in glassy materials, explaining their potential use as semiconductors. He had examined hundreds of compositions and had worked relentlessly to build practical devices since founding the company in 1960.

An in-depth piece on the Ovonic switch ran four years ago in *Control Engineering Magazine*. About this time, Ovshinsky began an advertising campaign in several trade journals wherein he described his devices and invited readers to send for a brochure on basic Ovonic principles. To reach a broader audience, the advertisement also ran in *Scientific American* in December 1964.

Two years later, *Electronics*, another industry magazine, carried a detailed feature on Ovshinsky's new science and its alleged promise. The term Ovshinsky Effect was used here for the first time. The article emphasized the fact that Ovshinsky was far from alone in the field and that research at Bell Labs had created a rather volatile patent situation.

Despite this publicity, much of which he generated himself at seminars and meetings of professional societies, Ovshinsky was unable to get a rise out of the electronics industry. There was no backlog of orders at Troy. No one was knocking down his doors.

Confident, and still trying to get Energy Conversion into the black, the 46-year old, self-educated inventor renewed his advertising campaign in the fall of 1967 by running three full-page display ads in *Electronics*, *Control Engineering* and *Scientific American*. The copy this time stated the speeds of his switches and proclaimed the new field of Ovonic physics and technology. A photo of the switch in the advertisement was later handed out at the press conference—a cardinal sin in any press agent's book.

It is not an unfair assumption that if trade and technical reporters had been present at the Troy briefing they would have tempered much of the hysteria that appeared in Monday's newspapers. Indeed, the more journalists studied the circumstances of the press conference, the more it took on the guise of a vacuum. To begin with, it had been held on the eve of a three-day holiday weekend; there was no opportunity for the reporters to check out the claims with leading industrial organizations. Since only 11 reporters had the story none of them could afford to sit on it without risk of being scooped. It was a case of mass psychology, par excellence.

Ovshinsky claims to have had a good reason for choosing Friday. On the following Monday the details of his Ovonic theory (explaining the materials he was working with and had recently patented) were to appear in the *Physical Review Letters*, a highly respected organ of the American Physical Society. Being published in the *Letters*, for a non-physicist, was no mean accomplishment and Ovshinsky felt some chest-pounding was justified.

The only snag was that while a copy of the *PRL* paper was in the press kit, its jargon was beyond the grasp of the reporters. Anticipating this, a ten-page explanation of the treatise was also in the kit and in plainer language it unfolded the story of Ovonics, much of which was by now old hat. Probably an all-time record for length, it was lifted almost bodily into newspaper stories. No one took the time to examine the copy.

If Ovshinsky had anything going for him that Friday, it was undoubtedly the all-star cast of physicists, including a Nobel laureate, which endorsed his work. Three of them briefed reporters at the conference and it appeared to bother no one that one was an officer of the company and the others, consultants to ECD (one a shareholder).

Though Ovshinsky was stunned by the magnitude of the press coverage—"I had expected a blurb in the Sunday papers," he said afterward—he did not help his cause any by refusing to say who was buying his Ovonic devices, reportedly being turned out at the rate of 150,000 a day at Troy. This prompted *Newsweek* to ask in its weekend story, "Did Ovshinsky have anything or didn't he?"

Top brass at some of our country's leading daily papers, a trifle anxious over the stock market reaction, undoubtedly put the same question to their science editors.

The *New York Times* Science desk, however, stuck to its guns. "In my opinion, the Ovshinsky story merited page one on the basis of his paper in the *Physical Review letters*, said Henry Lieberman, chief of the *Times* science desk. "My reporter tried to check it out at Bell Labs but they gave him a lot of double talk. I called them myself and they were afraid to say anything for publication." Mr. Lieberman added that the *Times* "was only interested in the scientific aspects of Ovshinsky's work and not the technology, and if 20 physicists think it's great stuff, that's good enough for me."

George Trigg, senior editor at *Physical Review Letters*, noted that when the Ovshinsky manuscript was submitted it was assumed the work had no previous history, at least not on the scale that was later discovered. "If we had known that some of it had appeared in advertisements we would have turned it down," said Trigg. Apparently the referees at *PRL* were caught napping.

In any event, there emerged out of it all an exuberant inventor—a high school dropout—whose name and company were catapulted around the world in no more time than it takes to write a headline. ◆