The Research State:
A History of Science in New Jersey

THE NEW JERSEY HISTORICAL SERIES

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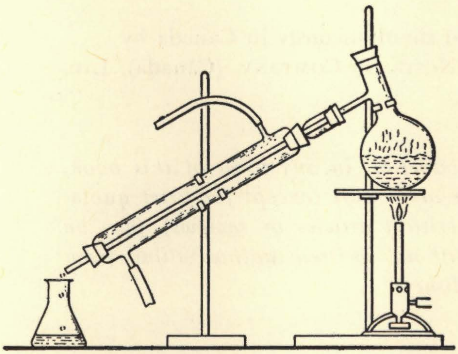
Volume 15
The New Jersey Historical Series

The Research State:

A History of Science in New Jersey



JOHN R. PIERCE
ARTHUR G. TRESSLER

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FOREWORD

Many tracks will be left by the New Jersey Tercentenary celebration, but few will be larger than those made by the New Jersey Historical Series. The Series is a monumental publishing project—the product of a remarkable collaborative effort between public and private enterprise.

New Jersey has needed a series of books about itself. The 300th anniversary of the State is a fitting time to publish such a series. It is to the credit of the State's Tercentenary Commission that this series has been created.

In an enterprise of such scope, there must be many contributors. Each of these must give considerably of himself if the enterprise is to succeed. The New Jersey Historical Series, the most ambitious publishing venture ever undertaken about a state, was conceived by a committee of Jerseymen—Julian P. Boyd, Wesley Frank Craven, John T. Cunningham, David S. Davies, and Richard P. McCormick. Not only did these men outline the need for such an historic venture; they also aided in the selection of the editors of the series.

Both jobs were well done. The volumes speak for themselves. The devoted and scholarly services of Richard M. Huber and Wheaton J. Lane, the editors, are a part of every book in the series. The editors have been aided in their work by two fine assistants, Elizabeth Jackson Holland and Bertha DeGraw Miller.

To D. Van Nostrand Company, Inc. my special thanks for recognizing New Jersey's need and for bringing their skills and publishing wisdom to bear upon the printing and distributing of the New Jersey Historical Series.

My final and most heartfelt thanks must go to John R. Pierce and Arthur G. Tressler, who accepted my invitation to write *The Research State: A History of Science in New Jersey,* doing so at great personal sacrifice and without thought of material gain. We are richer by their scholarship. We welcome this important contribution to an understanding of our State.

RICHARD J. HUGHES
Governor of the
State of New Jersey

January, 1964

PREFACE

Like most words, research has many meanings. In this book we are not concerned with the sort of library research that scenarists do before writing a movie script, or historians do before writing a history. And we will not dwell on important areas such as population studies, research on local, state, and world politics, the studies of public opinion polls or work in educational testing. We will concentrate instead on the science and technology that have evolved in the areas in which New Jersey's contributions have been greatest—agriculture, chemicals, electronics—and study briefly present trends in research in all fields which are represented in New Jersey.

Even with this restriction, we may still wonder just what the word research means. Science, invention, and technology progress together. For example, the invention of the steam engine led to the development of the science of thermodynamics, and this science in turn has had wide technological applications. The technology of a time inspires its inventions and makes possible the experiments necessary to its scientific discoveries. In turn, scientific discovery brings to us new forces and substances, such as electricity, high-polymer plastics, and nuclear energy, and these inspire invention, and broaden and strengthen technology.

Somehow, then, we must think of research as that which brings about the process of change and advance, and include in it all that is novel in invention and scientific discovery. We should also include the first demonstration of the usefulness of any new technological product, device, or process.

Several things are necessary if the interrelated process of scientific discovery, invention, and technological exploitation is to succeed, and all these things concern the welfare of men of science. First, we must find men with original and vigorous minds. Then we must give them a society with technological resources, one which is open to invention and discovery. These men must receive an adequate education, which may come to them in a variety of ways. And they must have financial support for the experiments which lead to the realization of their ideas, and for the successful introduction of the new things they devise into the life of the times.

Today research is so complex that it is hard to understand all the ways in which its needs are provided for. Perhaps we can learn best from history; from the original and enterprising man in the context of an earlier time who had an idea and found support to realize it and to make it a part of the world about him.

We will find examples in the history of New Jersey of the inventor seeking both money and the exclusive right to use his invention from State and Federal governments. We will see the inventor seeking private financial backing. We will find apt illustrations of the difficult relations among new technology, franchises or monopolies, and business practices. We will see the inventor who uses the profits of his invention to break new ground. In Thomas Edison, we will see the inventor who establishes a research laboratory which is supported by the profits of its work. If research is to change and improve our lives many obstacles must be overcome, and these are not all the mere cussedness of nature.

All of this gives us some background for understanding the organization and support of research we find in the world of today, and we can find examples of all sorts of research in New Jersey's present economy. John Cunningham wrote a decade ago in his industrial history of New Jersey, "No other state tops New Jersey in the magnitude and diversity of research carried on within the state." One can hardly dispute this, for there are about six hundred and twenty-five research laboratories in the state, and these employ over twenty-three thousand scientists and engineers—the highest per capita of any state in the nation. These laboratories spend between 9 and 15 per cent of the annual twenty billion dollars the federal government and private industry spends on research and development. Over fourteen thousand industrial plants turn out about seven hundred product classifications and this places the state seventh in rank of value added by manufacture. And the trend is up, for between 1950 and 1960, New Jersey was second only to California in the number of new industrial concerns established.

A great deal of research in universities and other institutions is done with no conscious or immediate thought of its practical and direct impact on our lives. We will encounter this sort of research in our survey. But research is important in a practical way, and much of it is directly associated with general or specific aims and purposes. The evolution of research in New Jersey illustrates three major areas of this type which we see in the world about us.

Two of these areas, industrial and agricultural, are related directly to the advancement of the nation's economy and to the improvement of the everyday life of us all. Agricultural research has helped to supply us with food, and in a measure to protect us against pests and disease. Industrial research supplies us all with improved products, whether they be antibiotics, paints, or telephones, and supplies industry itself with better raw materials.

Perhaps because the farmer is persistently the small businessman, many improvements in agriculture have been supported by the state and federal governments, and carried out at universities and experiment stations. We will see, however, that private enterprise has also made important contributions.

Industrial research arises from the strength and needs of new and enterprising industries. It is in this field that New Jersey particularly excels today. We shall see that some of its chief strengths are in the pharmaceutical, the chemical, and the communications industries.

A third area of research is that which, during and since World War II, has been associated with defense and, more recently, with space. Nationally, expenditures in these fields substantially exceed those for all other research, though the patents that come from space and defense activities are fewer and their economic value is far less than those which come from industrial discoveries. Defense and space activities are constantly in the public eye. But their direct effects on our lives and our prosperity are fewer than that of other industries and of agriculture, and their indirect effects are problematical.

New Jersey is fortunate to have substantial strengths in most fields of research. But we cannot deny that there are areas of weakness, too. For example, medical education is inadequate in New Jersey. Publicly supported higher education is weaker than in many states. Much of New Jersey's prosperity is based on research. Yet we may fairly ask if its public life is as well geared as it might be to foster research in the fact of competition from other states.

It is difficult, if not impossible, to produce a useful book on any subject without talking to people who are experts in the field. Thus, conversation formed an important part of the information-gathering process for *The Research State*. The authors are indebted to many people involved in the science and technology of New Jersey who were generous with their knowledge.

Providing major contributions via discussion were: Drs. Ordway Starnes, Frederick Main, Donald F. Cameron, Rutgers University; Drs. Glenn Weaver, Joseph Notterman, Henry Smyth, Princeton University; Dr. Roscoe P. Kandle, Commissioner of Health of the State of New Jersey; Dr. Robert Davis, American Institute of Physics; Drs. K. Bullington, J. K. Galt, S. O. Morgan, S. Millman, J. H. Scaff, R. N. Shepard, and J. C. Schelling (retired), Bell Telephone Laboratories.

In addition, the various corporations and universities mentioned in this book were extremely helpful in providing written material and the answers to specific questions.

We would also like to thank those who reviewed the book through the auspices of the Tercentenary Commission: Mr. Howard E. Orem, Dr. James Hillier, Dr. W. J. Sparks, and Dr. W. O. Teeters, as well as the Editors of the New Jersey Historical Series.

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I

THE STEAM MERCHANTS

MOST SCIENTIFIC EXPERIMENTS, even successful ones, have little value. It is the few great and lastingly important experiments that become a part of history. Most inventions, even if they are original and realizable within the technology of their times, are of no practical worth. And many potentially valuable inventions fail to be commercially successful because technology has not caught up with them. In this sense, New Jersey's first notable inventor was a failure.

When metalsmith John Fitch tried to promote steamboat travel in 1785, he met disinterest. Americans were barely recovering from the devastation of the Revolutionary War. They had yet to realize, and yet to care, that the growth of their new country lay to the west, where much of the travel was to take place over the inland water routes.

But the primary reason Fitch failed was his inability to show that steam travel could be commercially advantageous. It is not certain that he was able, or even tried, to produce figures demonstrating economies of the steamboat over other modes of movement. Certainly, he was unable to get lasting financial support, and this in itself was enough to prevent either commercial success or his being recognized as the inventor of the steamboat.

John Fitch was born in Hartford, Connecticut, in 1743. He was a spindly, narrow-chested, weak member of a robust family, unable as a youngster to do his share of the farm work. He read geography, astronomy, and mathematics avidly. Apparently unhappy, with little taste for home, he began to wander, eventually settling in Trenton, New Jersey, where he established a successful brass and silversmith business.

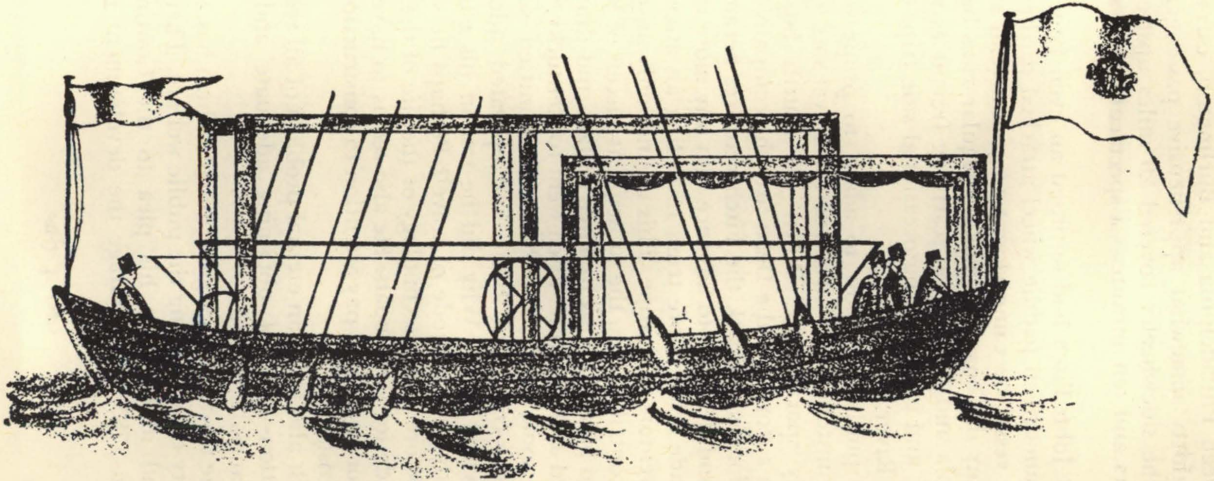
Along with British domination of the Colonies, the Revolutionary War disposed of Fitch's business, and he spent the next few years as a surveyor of lands to the west of New Jersey.

In the spring of 1782 he was captured on the Ohio River by a group of Delaware Indians who marched him and his companions to Detroit and turned him over to the British. They in turn sent him across southern Canada to an island in the St. Lawrence; he was exchanged the next year. It was probably this exposure to the rivers of the West that enabled Fitch to visualize the part steamboats could play in settling America. Unfortunately, interest in the West came much later, following the land grant acts of 1800 and 1804.

When Fitch first considered using steam power for propelling a boat, stationary steam engines had been in use for many years for pumping, and in 1782 James Watt had devised a double-acting engine capable of rotary motion. It was not until Fitch had shown his plans to a friend that he learned of the work already done in harnessing steam power. But the novelty of his idea really lay in his proposed application.

A mere idea does not constitute successful research or invention; something must be proved or demonstrated. In the summer of 1785 John Fitch built a small boat and placed it on a stream in Bucks County, Pennsylvania. The craft, about 45 feet long, had on each side endless chains to which paddles were attached. The chains were connected to a cross shaft which was powered by the steam engine.

Inventors learn by doing. The chain arrangement proved to have drawbacks, and on the second model, launched the following year on the Delaware River, the paddles were moved to a drum, making the boat a side-



Early version of the steamboat by John Fitch, around 1785 wheeler. This slightly larger vessel made a number of trips between Philadelphia and Burlington, carrying as many as thirty somewhat apprehensive passengers. On one trip the sidewheeler covered 20 miles upstream in three hours and ten minutes—a spectacular feat at that time.

By 1788 John Fitch had outfitted an even larger boat with a steam-driven paddle wheel attached to the stern. With this vessel he came closest to commercial success. In two years the boat was making regular runs between Philadelphia and Burlington, carrying freight as well as passengers, and even making occasional side trips on the Schuylkill River.

But the public was slow to adapt to propulsion by fire and brimstone and patronized this novel sort of river travel only sporadically. When the fourth boat was wrecked in a storm on the Delaware, the company which had been formed to back the Fitch ventures became discouraged and declined to advance him any more money.

Fitch made a few more tries, including an attempt to interest inventors in Europe. This was not only unsuccessful, but it contributed to the subsequent success of Robert Fulton who gained access to Fitch's plans and drawings. Discouraged and destitute, Fitch went to Kentucky, where he owned some land. In 1798 he committed suicide.

John Fitch conceived, built, and operated sidewheel and sternwheel boats. Why did he fail in his effort to introduce them as a mode of travel? Perhaps he started too soon, before either technology or the life of the country was ready for steamboats. He also seems to have been unwilling, or unable, to pay attention to construction and operating costs.

But, Fitch also faced an eternal problem of all research and invention—that of obtaining adequate and continuing financial support.

At first he turned to the government, which has always had the duty of promoting the public welfare. There was honesty and idealism in his plea to the Continental Congress in 1785 to encourage the development of his inventions for the benefit of everyone. But what he felt he needed to have to do this (and did not get) were subsidies and an exclusive right to develop the boat for naval and civilian use. He also tried unsuccessfully to obtain money from several scientific societies.

Besides the positive action of granting funds, governments can also forbid all but a selected individual or company from engaging in a particular enterprise, with a view to encouraging the expenditure of effort and funds toward the establishment of a useful service. While it is rare in America to establish perpetual monopolies by law (the postal service and the Communication Satellite Corporation are examples), monopolies or franchises for a stated period are common. It appears that Fitch was opposed to monopolies of this sort. Yet he petitioned the State of New Jersey in 1786 for exclusive privileges to build and operate steamboats on all waters of that state. This was granted—for a period of 14 years—and in the following year Pennsylvania, New York, Delaware, and Virginia granted him similar prerogatives. This had enabled Fitch to organize a group of prominent Philadelphians into a company which provided him with money but deserted him after his fourth boat was wrecked.

Although Fitch failed commercially, he stands high as a prophet and an inventor. His boats worked, and he had a clear view of the future importance of steamboat transportation in opening up the American West and expanding its trade.

Stevens and Steam Propulsion

A New Jersey inventor of better fortune was John Stevens of Castle Point (now Hoboken), whose interest stemmed from the work of Fitch and James Ramsey, a Virginian with claims to the invention of the steamboat. First applying himself to improving steam boilers, Stevens soon turned to the improvement of steamboats and ultimately to what became his greatest contribution—the steam railroad.

Born in 1749 in New York City, Stevens grew up in Perth Amboy, then returned to New York to attend the forerunner of Columbia University, where he studied law and practical politics. He was commissioned at the start of the Revolutionary War, was assigned mainly financial duties, and served as treasurer of the Colony of New Jersey. In considering a practical transportation system, this training and experience in financial matters gave Stevens an advantage over John Fitch.

In 1788 Stevens stood on the banks of the Delaware River and watched Fitch demonstrate his sternwheeler. Convinced that his own future lay in pursuing the advantages of steam transportation, Stevens returned to Hoboken and began to set down on paper his ideas for improvements in steam transportation, especially in the boilers and engines. He too, turned to the federal government. But he sought protection of his inventions through the grant of an exclusive right of manufacture for a limited period, rather than through a subsidy. Stevens had friends in Congress. The government listened to him. The result was a federal act of 1790 that has had an overwhelming influence on the course of research and invention in the United States—the establishment of the federal Patent Laws. New Jersey's John Stevens was not only one of those responsible for this act, he was also one of the first to profit by it. In 1791 he received a patent on his steam boiler.

Apparently Stevens had good general ideas of how to make existing steam boilers and engines more efficient. But he was trained as a lawyer, not as a mechanic. As a result, by 1797 he found it necessary to seek the services of Nicholas Roosevelt, who owned a foundry in Belleville. Stevens, Roosevelt, and Robert R. Livingston thus formed a partnership to build and operate steamboats. This is an early instance of the sort of pooling of talents and resources that has become increasingly important in science and technology.

In the first few years of the firm's operation there was much tinkering but little success. An experimental boat, the sternwheeler *Polacca,* was built, but many trials on the Passaic River showed that excessive vibration opened the piping and seams. Not until 1804 was a workable boat, the *Little Juliana,* constructed. It included a multitubular boiler (patented in 1803) and the first twin-screw propeller.

Stevens' sons, Robert and Edwin, tried to set up a successful ferry service across the Hudson River with the *Little Juliana* but failed because the screw arrangement caused excessive vibration. It was not until 1839 that this type of propulsion came into general use.

In 1806 Stevens launched a larger boat on the Hudson River, the 100-foot *Phoenix.* This was a mechanical success but a legal failure. The boat was designed to carry both freight and passengers from New Brunswick down the Raritan River and across the bay into New York City. However, Stevens was prohibited from setting up a regular service. His ex-partner Robert Livingston, who had joined Robert Fulton, had been granted a monopoly in New York State waters. When Fulton's *Clermont* became successful in the latter part of 1807, Stevens wisely decided to leave that part of the eastern waterways.

Thus, in 1809, the *Phoenix* found a new home on the Delaware. On the way she became the first steamboat to travel the open seas. The boat eventually became a commercial success on a run between Philadelphia and Trenton.

The granting of transportation monopolies remained anathema to Stevens for many years. When invited to join the Fulton-Livingston partnership, he turned down the offer primarily because of his belief that monopoly was unconstitutional. In 1811 he tried once more to set up a ferry service across the Hudson but was threatened with a lawsuit. That boat eventually was taken to Connecticut whence it operated on Long Island Sound.

The Switch to Land

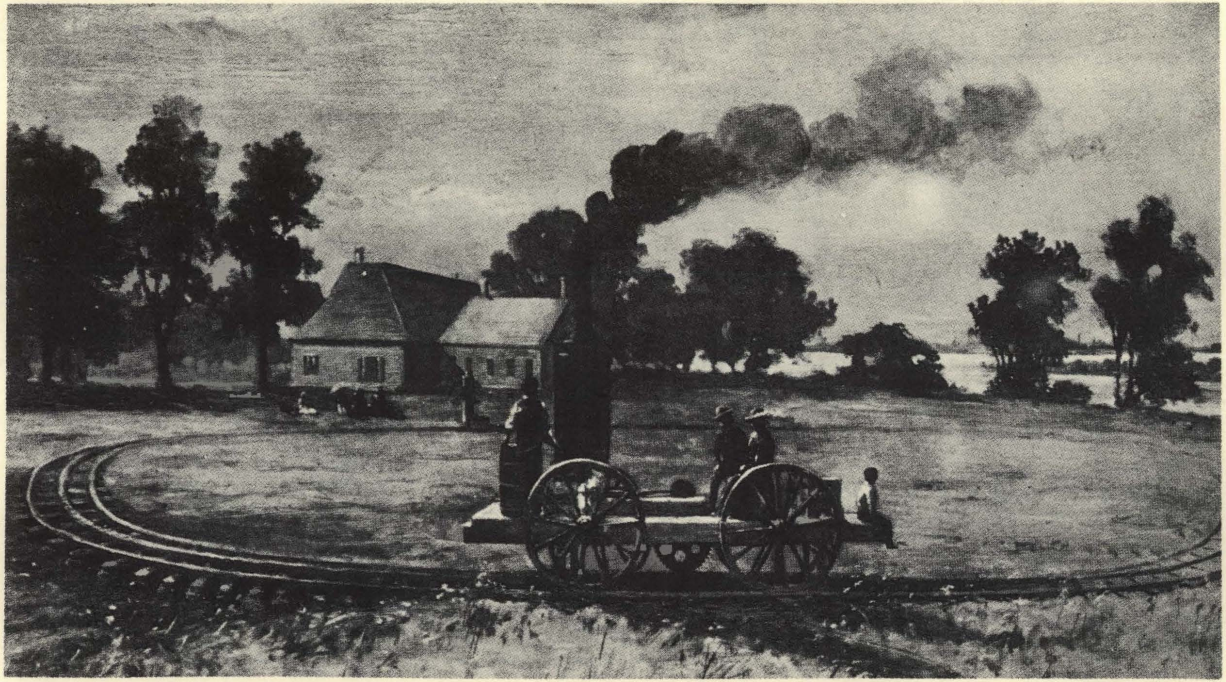
About 1810 John Stevens became interested in applying his steam engine to overland travel. This was only two years after Trevithick in England had demonstrated a locomotive and carriage on a circular track and two years before Bleinkinsop, also in England, made the first practical locomotive. The following year Stevens turned over the remainder of the steamboat business to his sons and went to work in earnest to develop steam-driven rail transportation. His first act was to petition the State of New Jersey for a franchise to build and operate a railroad across the "waist" of the state from Trenton to New Brunswick. The request was turned down as "impractical."

The New Jersey Legislature of 1815 had more vision, however. That year, when Stevens made essentially the same application, he was granted the franchise. The New Jersey Assembly created the New Jersey Railroad Company to build a road from Bordentown, near Trenton, to a place on the banks of the Raritan near New Brunswick. This first "railroad act" in the United States provided for connecting the steamboat lines on the two rivers, thereby connecting New York City and the Northeast with Philadelphia and the West.

New Jersey granted permission but not financial backing for the venture. Stevens wrote letters and argued orally for years before various state legislatures, citing the advantages of speed (he predicted 50 miles per hour standard speed, 100 miles per hour maximum) and efficiency of rail travel over canal systems. But Stevens was unable to give the country a working railroad. Potential investors were unmoved by arguments. They were convinced that the canal systems would be adequate for transporting people and freight.

Thinking that Pennsylvania might harbor more adventuresome investors, Stevens gained permission from the Pennsylvania Legislature to form a company to build and operate a railroad between Philadelphia and Columbia, Pennsylvania. But he could not raise funds for this venture.

It was not until 1825, when he actually built a locomotive and operated it on a circular track 200 feet in diameter at his Castle Point estate, that the public be-



The first American locomotive on rails at Castle Point, Hoboken, 1825 came interested. The locomotive consisted of a vertical 20-tube boiler and a one-cylinder engine which applied power to a gear that meshed into a rack-rail between the tracks. The boiler and engine were mounted on a platform carried on four large wheels.

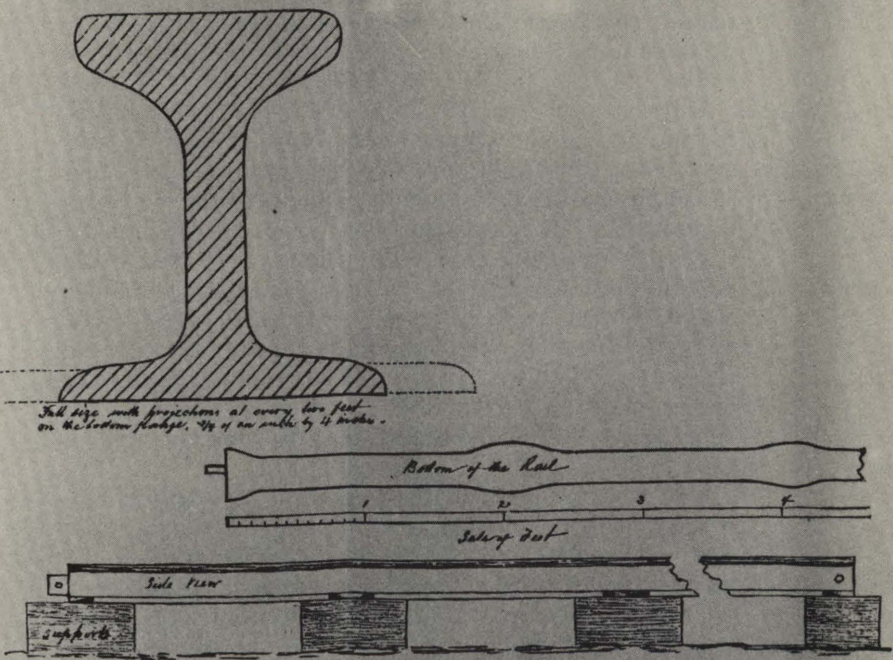
A story published by the *New York Evening Post* in May, 1825, drew attention to what Stevens was trying to show. This, together with reports of success by railroad companies in England, fired the public's imagination. In 1830, when New Jersey chartered the Camden and Amboy Railroad at Stevens' behest, it was quickly and easily financed.

Accouterments to Railroading

New Jersey had thrown away her chance to be the first state to have a commercial railroad, for several other states chartered lines before 1830. But Stevens' experiments at Castle Point did give the state the first working locomotive in America. Furthermore, Robert Stevens, who with his brother Edwin headed the new Camden and Amboy Railroad, was to give New Jersey some more firsts with his inventions and developments for the roadbed.

As first president of the C.&A., Robert Stevens commenced a survey for the new line from South Amboy to Bordentown. He then left for England to buy rails and a locomotive. During the journey, he was inspired to design, by whittling a chunk of wood, the famous "T-rail," cheaper than the "U-rails" then in use, which used more iron. Stevens found an iron foundry in Wales which overcame some of the manufacturing problems of this design; the Welsh firm subsequently made all the T-rails for the Camden and Amboy. But it was not until 1846 that the advantages of the Stevens-designed rails became obvious to American railroad men, and an iron works in Trenton began to manufacture them. It was another ten years before T-rails came into general use in the United States.

Robert Stevens' other contributions to the roadbed



Liverpool November 26 1830.

Gentlemen

At what rate will you contract to deliver at Liverpool; say from five to six hundred tons of Railway, of the best quality Iron rolled to the above pattern in twelve or sixteen feet lengths, to lap as shown in the drawing, with one hole at each end, and the projections on the lower flange at every two feet. Cash on delivery.. How soon could you make the first delivery, and at what rate per month until the whole is complete— Should the terms suit and the work give satisfaction a more extended order is likely to follow, as this is but about one-sixth part of the quantity required— Please to address your answer (as soon as convenient) to the care of Francis B Ogden, Consul of the United States at Liverpool—

I am

Your obedient Servant

Robt L Stevens

President & Engineer of the Camden & South Amboy Rail Road & transportation Company

Specifications of T-rail designed by Robert Stevens included the "hook-headed" spike and the dependable rail joint made by a riveted "fishplate." With good reason, the development of the modern rail has been declared to be "almost solely the product of his inventive genius." *

Following the practice of their English counterparts, the builders of the Camden and Amboy laid their rails onto hewn stone. The rails were spiked to wooden plugs in chiseled holes. Because Robert Stevens was in a hurry to finish the line before the winter of 1832-1833 and the stone ties were slow in arriving from upstate New York, he fashioned wooden ties from logs, around which he packed broken rocks. The new rail bed proved to be more flexible and therefore more comfortable for the passengers. Moreover, it speeded up the laying of rail. Spikes could be driven into the wooden ties with less effort and with less likelihood of disturbing the aligned rails.

One other innovation in railroading is attributed to Robert Stevens. The locomotive he had brought from England, called the *John Bull,* sometimes ran off the track when rounding sharp curves. To solve this problem, Stevens designed and attached to the front axle of the locomotive a "pilot" consisting of an oak frame led by two guiding wheels. This later acquired the name "cowcatcher."

Early in 1833 the Camden and Amboy was completed. It ran from South Amboy on Raritan Bay to Bordentown on the Delaware. Service was started with horse drawn coaches, but by that fall the *John Bull* was put in operation. Early in 1834 the Bordentown-Camden section was completed. The link by steam-propelled vehicles was now complete between Philadelphia and New York City, across the heart of New Jersey.

* Wheaton J. Lane, *From Indian Trail to Iron Horse* (Princeton, 1939), 287.

II

FACTORIES, FARMS, AND A TELEGRAPH KEY

IN 1813 A twenty-five-year-old mechanic from Massachusetts named Seth Boyden came to Newark with a leather-splitting machine he had developed. He immediately set up a business supplying split sheepskins and leathers for bookbindings to the many leather-using industries in the city. Boyden had little formal education, but both his father and grandfather were inventors and he had a great deal of mechanical skill. The variety of products that came from his fertile mind led Thomas Edison to call him "one of America's greatest inventors." *

Boyden helped to free American industry from dependence on European manufactured products. In 1819 he successfully duplicated the European process of lacquering hides and established the first American factory to turn out patent leather. He inaugurated an important New Jersey industry which until the Civil War made 85 per cent of the country's patent leather and still manufactures more than half of it.

Another closely guarded European manufacturing secret was the production of malleable cast iron. For six years Boyden tried by means of various additives to produce a pig iron that could be beaten or pressed into shape. In 1826 he found he could produce malleable iron by baking pig iron of the right carbon content at a high

* New Jersey Writers' Project, *Stories of New Jersey*, Bulletin 10, 1939-1940 Series (NPN).

temperature for nine days. He thus freed the United States from dependence on England for malleable castings. He received a patent on the process in 1831, sold his leather business, and began to devote full time to iron manufacturing.

The Uncommercial Inventor

But this soon bored Boyden, and in 1837 he sold the cast iron business and began to build improved steam engines. An important contribution to stationary engines was a cut-off governor that he invented to economize on steam. In a major improvement in rail transportation, he designed a locomotive whose driving rod stood outside the engine and whose rear wheels served as a crank; this was a step toward coupling several wheels together to serve as drivers.

Boyden's talents were broad. He designed locomotives and a machine for forming hats. He developed, through metallurgical feats, an inexpensive process for making sheet iron and the preparation of a goldlike alloy for ornamentation. He improved Daguerre's photomaking process with a reflector to increase the available sunlight, and he is credited with having introduced daguerreotypes into the United States. In his later years he even produced a giant strawberry—the result of his experiments in hybridization.

Seth Boyden gives the impression of having been an industrial vagabond. As soon as one business became a commercial success, he sold it and directed his talents to something quite different. This apparent disinclination to reap the financial benefits of his ideas earned him the title of "the uncommercial inventor," * but his behavior illustrates one important means of financing research or invention. He retained enough of the profits from each venture to enable him to start the next. Furthermore, though his developments may seem un-

* New Jersey Writers' Project, *Stories of New Jersey,* Bulletin 10, 1939-1940 Series (NPN).

related, they had one important thing in common—they met a real need and were accepted by the public. Choosing to solve problems that are both important and amenable to solution is of the highest importance in research. Seth Boyden had the good sense, or the inspiration, to make wise choices.

Another Versatile Inventor

When the Hyatt brothers came to Newark in 1882, they brought with them a genius close to that of Seth Boyden. John Wesley Hyatt's ideas ranged many spheres. His experiments with celluloid, which led the way to an important plastics industry, were of an entirely different sort from his experiments in machine design.

Hyatt's celluloid factory was founded on his discovery (in Albany, New York) that a mixture of nitrocellulose, camphor, and a small amount of alcohol can be made soft enough to mold when heated under pressure but will retain its shape when cooled and unpressurized. In Newark, Hyatt developed the technique, and the necessary machinery, for turning out everything from buttons to billiard balls.

In 1881 John and his brother Isaiah patented a water filtration process. They made use of a coagulant (1/3 grain of alum per gallon) added to the water on its way to the filter. This made a settling basin unnecessary and cut down the time required for purification. The Hyatt Pure Water Company sold its filter process to many paper and woolen mills as well as to the towns and cities of northern New Jersey.

Hyatt's success with celluloid-making machinery whetted his appetite for other projects, and over the next decade he designed machines that could make anything from a cold-rolled steel shaft to a school slate. His design of a superior roller bearing led to the establishment of the Hyatt Roller Bearing Company in 1891. The company in Harrison stands today as a living memorial to this versatile inventor.

A Developer of Instruments

Another immigrant to Newark, Edward Weston, came all the way from England. He set up a laboratory there and added his name to the list of New Jersey inventors. In 1875 Weston produced an improved dynamo for electroplating, and by 1877 he had formed the Weston Dynamo Electric Machine Company. Soon he was the United States' leading manufacturer of electroplating dynamos.

Weston became interested in electric lighting, and he entered the arc-lighting field with his Weston Electric Light Company. This company was soon absorbed, with Weston as chief electrical engineer, into the United States Electric Lighting Company. Weston continued his experiments on incandescent bulbs. Although his bulbs never approached the perfection of Thomas Edison's, Weston is considered to have made important technological contributions to the field.

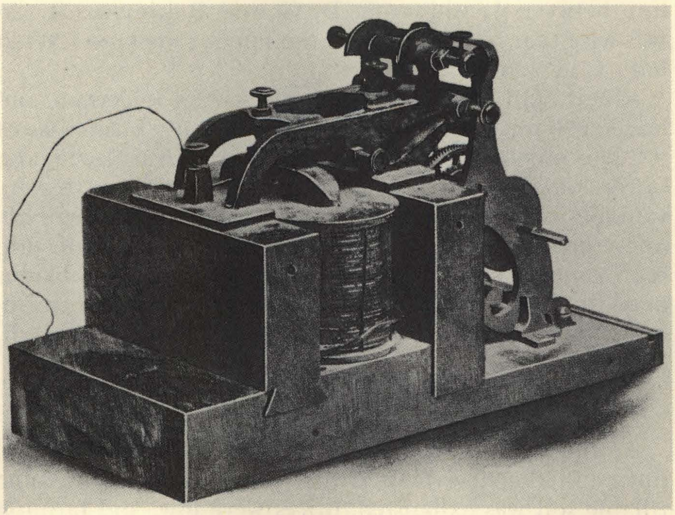
Weston left the lighting business in 1886, and in 1888 he founded the Weston Electric Instrument Company. It was this business and its products which brought him world acclaim—as a designer of measuring instruments renowned for their dependability and precision.

The First Telegraph

Alfred Vail was a Jerseyman whose mechanical expertise brought another man's invention to fruition. In 1837, in New York City, Samuel F. B. Morse demonstrated a device in which an electrical signal caused an electromagnet to actuate a pen, which marked lines on a continuously moving paper tape. Vail sat fascinated in the audience. He immediately saw ways to improve the mechanics of the device, and he hastened to tell Morse so.

Morse had been a fine-arts professor at New York University before he turned to invention. Aware of his mechanical limitations, and even more so of his financial ones, he happily accepted Vail, along with Leonard Gale, a scientist, as partners. Vail's father and brother consented to finance the operation, and the three men went to work at the senior Vail's ironworks on Speedwell Avenue in Morristown.

Vail made several improvements in Morse's primitive telegraph. He changed the motion of the armature of the receiving electromagnet from horizontal to vertical, so that the recording pen wrote a series of dots and dashes instead of a zig-zag line. He improved the sending contact, and eventually designed the standard telegraph key. It was while Morse was working with Vail that the unwieldy scheme of assigning numbers to words in a dictionary and transmitting the numbers in a coded form was replaced by the Morse code. In this code short patterns of dots and dashes represent commonly occurring letters such as *e,* and longer patterns represent infrequently occurring letters such as *z.* Various degrees of credit for this extremely effective and highly ingenious invention have been assigned to Vail.



Telegraph receiver designed and built by Alfred Vail

Leonard Gale's major contribution was the application of his understanding of the scientific principles of Joseph Henry's electromagnet. This led to using many turns of wire on the armature of the electromagnet and to wiring several battery cells in series. These modifications were necessary if signals were to be transmited over long distances.

The new telegraph was demonstrated for the first time on January 6, 1838, in an upper room of one of the Morristown factory buildings. Over the three miles of wire looped around the room, Vail transmitted and Morse received the message, "A patient waiter is no loser."

Other demonstrations soon followed, including one before the United States Congress. From the first, the inventors felt that the federal government should take over and operate the telegraph system. Initially the United States Congress showed little interest, and Morse spent four years trying to drum up support in Europe. In 1843 Congress finally did approve an experimental line between Washington, D. C. and Baltimore. It was this wire that in 1844 carried the famous message, "What hath God wrought?"

Alfred Vail finally lost interest in the telegraph and had no share in one of the most lucrative businesses of the late nineteenth century. Together with Gale, he also lost popular credit for his part in developing this invaluable communication system. This seems particularly unfortunate because the Morse-Vail-Gale partnership represented what was becoming an increasingly obvious need in science and technology—an association of inventive genius, scientific understanding, and mechanical skill.

Revolution on the Farm

At the close of the Revolutionary War the farm industry in the new United States was at its nadir. The tillable soil was exhausted, prices were low, and farming methods were inefficient. Farmers were depressed not only financially but mentally as well. But in New Jersey the situation was soon to change. The state lay between the two most important markets in America—New York City and Philadelphia. Moreover, as the nineteenth century proceeded, New Jersey's growing industries began to draw manpower from the farms to the factories. The increase in demand for food and diminution in the labor force made it imperative for the farmers to increase their efficiency.

One way in which inventive Jerseymen attacked this problem was by improving farm implements. A number of advances, particularly in plows, came from New Jersey. A first step was taken by Charles Newbold of Burlington County, who designed and had cast at a furnace in Hanover a plow whose moldboard, share, and landside were all in one piece. Although Newbold received a patent in 1797, both technology and superstition were against him. The soft iron point broke. And he ran into a peculiar prejudice; people believed that iron poisoned the land, drained its richness, and encouraged weeds.

It was not until 1807, when Burlington County's David Peacock patented an improved plow, that the farmers of New Jersey (and New York and Pennsylvania) could enjoy a superior tool. Peacock's plow was cast in three pieces; any one could be replaced if it broke. The next advance was made in 1828 by John Deats, a Stockton blacksmith. His improved plow was a potpourri of many ideas. Its chief feature was interchangeable moldboards, which permitted the plowing and cultivating of crops planted in rows of varying widths.

A varied assortment of new farm implements came from New Jersey during the nineteenth century. In 1813 Richard French and J. T. Hawkins patented a mowing machine, and in 1831 William Manning of Plainfield was issued a patent for a mowing machine which was, in a sense, a reaper pushed in front of the horse. It antedated the more famous McCormick reaper by three years. The

Manning machine and one called the "Ketchum" made up the total of about five thousand mowing machines manufactured in the United States prior to 1850. A Keyport farmer named Thomas Stout invented a potato-digger in 1853. Oliver Kugler of Three Bridges patented a corn-cultivator in 1873, and Reuben Niece of Frenchtown a similar machine five years later. Patent rights to Kugler's cultivator were sold to manufacturers as far west as Illinois.

Science in Agriculture

Tool improvements solved only one part of the problem of New Jersey farmers of the nineteenth century. The soil needed attention, and James Jay Mapes was one of the first to recognize it. Mapes was a self-educated "professor" with a reputation as an analytical chemist. This was backed to some degree by his acknowledged work in pigments and his post as professor of chemistry at the National Academy of Design in New York City.

Mapes' lack of formal education in no way detracted from his influence on the agriculture, and to some degree on the chemical industry, of modern New Jersey. In 1847 he bought a worn-out piece of land in Newark and turned it into a model farm by applying the techniques of subsoil draining, rotation of crops, and the judicious use of fertilizer. He devised a formula for nitrogenized superphosphate, which is considered to be the first complete plant food developed in the United States.

One of the chief means by which the results of research become known and used is through publication. James Mapes deserves much credit for founding, in 1846, and editing, until 1863, *The Working Farmer,* an agricultural journal in which he published the results of his farm experiments and explained their scientific principles. Under his editorship the journal attained a circulation of ten thousand.

The overriding consideration in Mapes' contributions to agricultural science was his recognition that indeed it was a science. He accepted pupils at his experimental farm, delivered lectures, and gave demonstrations, continually expounding the value of fertile soil. He insisted that agricultural science could be understood and advantageously used by the average farmer. And, he forecast the agricultural extension services that have been such an important part of modern scientific agriculture.

III

THE COLUMBUS OF NEW JERSEY

THE TITLE ABOVE, "The Wizard of Menlo Park," and similar hyperboles were conceived by newspaper reporters—a manifestation of competition by the press in creating fantastic stories about Thomas Alva Edison and his world. The man simply overwhelmed people with the number and variety of his inventions.

Edison was "good copy" partly because of the age he lived in. By the latter half of the nineteenth century, "science" had captured the public's imagination, and naturally the newspapers were quick to exploit the situation. As a result, while Edison lived he had the aura of a conjurer, of a man with the Midas-touch. He himself professed that the role both confused and annoyed him. Yet he used this reputation to secure financial support. Edison was a man of genius, and it is not surprising that he was more complicated and interesting than his legend.

In 1932, shortly after Edison's death, Frank B. Jewett wrote, "Because Edison's name has been a household word throughout the world for nearly a century . . . one runs the risk of overvaluing Edison's real achievements." * But his achievements were real and important, and more than thirty years later we can see how they have set a pattern for industrial research and technology.

There was a "needle in the haystack" aspect to some of Edison's work, but he understood and made wise use of more science than many people realize. His experimental

* F. B. Jewett, R. A. Millikan, et al., *Science,* January 15, 1932.

procedures were often scientific in nature, and he was well aware of the inventor's need for men with varied technical skills. Mathematician Norbert Wiener has called Edison "a transitional figure in late 19th century science . . . linking the crude ways of mechanical inventors to the systematic experiment and research now being done by men of skill and speciality."

A Beginning in Telegraphy

What brought America's best known inventor to New Jersey was partly an accident of residence. In 1869 Thomas Edison and Franklin L. Pope formed a partnership as consulting engineers on telegraphic problems. Pope and his wife lived in Elizabeth, and they invited Edison to live with them so he could save money. He happily accepted the offer and set up shop in an old building in Jersey City where he worked on engineering problems involving the telegraph.

It was the telegraph that had brought Edison from the Middle West, where he had grown up. The Western Union Telegraph Company had hired him as a telegraph operator. In 1867 the company sent the twenty-year-old telegrapher to Boston. Edison handled the job of operator exceedingly well, but it bored him and he spent a great deal of time searching for ways to improve the communication system. It was in Boston that he started work on multiplex telegraphy—the sending of a number of messages simultaneously over a single circuit.

In June, 1869, he moved to New York where he was moderately successful in selling an improved mechanism for stock market tickers. These devices launched him on his first successful commercial venture. By 1871 Edison, who had left the partnership with Pope because he found that he was doing all the work, had rented the third floor of a Ward Street, Newark, warehouse. There he began to manufacture stock tickers on order from Western Union.

The company which had hired this resourceful young telegraph operator in 1864 had been interested in his tinkerings from the start. Western Union was quick to subsidize any promising young inventor and take over his patents. In Edison's case this corporate policy was to pay high dividends. Western Union joined capital investment to inventive ability by establishing the firm of Edison and Unger. The second member of the new company, William Unger, was a professional of the business mold, as Edison was of the scientific.

Edison found the arrangement somewhat distasteful but accepted it as necessary if he was to be rid of financial problems. The union of capitalist and inventor had the petty disagreements, the rocks and shoals, of a loveless marriage. Nevertheless, during the early 1870's many important engineering developments in telegraphy came from the partnership. The patents, of course, went to Western Union.

Simultaneously, Edison was trying to develop a high-speed automatic telegraph through another firm, Edison and Murray, in another Newark shop and under the aegis of another corporate patron. Working on a sending apparatus originally designed in England by George Little, Edison found a way to increase its speed to 1000 words per minute over long distances. He applied Joseph Henry's principle of electromagnetic induction in a single circuit to produce a momentary reversal of current when the power was turned on or off. A soft-iron core shunt gave a high-speed, sharply defined signal in the receiver. Edison also improved the chemical composition of the paper tape used in the receiver. When perfected, the "automatic" had a speed far above that of other contemporary communications devices.

The automatic telegraph was sponsored by the Automatic Telegraph Company, which was in competition with Western Union. But while the product worked satisfactorily in the shop, it never came into commercial use. This has been blamed on the machinations of Jay Gould who stepped from behind the scenes and took control of Automatic Telegraph, and with it, the patents on Edison's invention. His intention was to remove Edison's developments from the technological scene in order to harass Western Union and prevent it from going into automatic telegraphy.

In 1873 Edison went to England to try to sell the automatic equipment to the British Post Office. Unfortunately, some serious equipment failures accompanied his demonstrations there. The British thanked him kindly and bought another system. Back in the United States, Edison found that the Western Union Company was not impressed enough with the device to even try to get around the patents. Thus, although the Gould-backed company had publicly demonstrated the high-speed automatic telegraph, it was soon abandoned.

While Edison's automatic telegraph did transmit signals rapidly, there were some major drawbacks to the system. The message first had to be punched out as holes in a paper tape by means of a typewriter-like device—a slow process. And at the receiving end, dots and dashes had to be read from a paper tape at a speed certainly no greater than a telegraph operator could read them on manual equipment. Of course, a tape could be prepared and read in sections by several operators to take full advantage of the system's speed.

It appears that automatic operation was tried for a few years in several large cities, but abandoned. The industry stayed with hand operation for three or four decades. When automatic telegraphy did become common, it made use of automatic alphabetic printing rather than the translation of dots and dashes by an operator.

During the depression years of 1873-1874 Edison worked alternately for the Western Union Telegraph Company and the Automatic Telegraph Company. For Western Union he worked on an old favorite, the multiplex telegraph. In 1866 J. B. Stearns had devised a duplex system in which two messages could be sent simultaneously over the same wire, but only in opposite directions. Edison felt he could increase this traffic and was so certain of the commercial advantages that he used his own money to finance further experiments.

He devised a system that used a polarized relay, which responded according to which pole of the battery was connected to the wire. The system interleaved two messages traveling simultaneously in the same direction over one wire; this he called "diplexing." Added to the Stearns system, this transmission method became the renowned "quadruplex system," and when introduced in 1874 it greatly increased the transmission capabilities of telegraph lines.

Hardly was this completed when Edison again found himself working for Western Union's rival. The Automatic Telegraph Company had been using on its lines a relay (essentially an amplifier of telegraph signals) constructed under patents held by Western Union. In the summer of 1874 Western Union brought an infringement suit against Automatic Telegraph. The latter turned to Edison in the hope that he could invent a device sufficiently different from the one Western Union used so that Automatic Telegraph could continue in the business of long-distance telegraphy.

Out of this corporate battle came the chalk relay—a drum-shaped, motor-driven piece of moistened chalk replacing the conventional electromagnet. A metallic finger pressed against the drum, and a difference in friction caused by the telegraph signal acted to make or break the contact. Edison received a patent for his "electromotograph" in 1875.

Edison had gone to work on the quadruplex telegraph for Western Union under an arrangement which made George B. Prescott, chief engineer for Western Union, his partner. The invention was ultimately credited to this partnership, leaving Edison with only half the patents, and to his lasting chagrin, only half the accolades.

Western Union had been quick to encourage the aspiring inventor but was less quick to reimburse him. Edison got a five-thousand-dollar advance from Western

Union for the quadruplex, but after delivering the completed device could draw no more. As a result, when approached by the Automatic Telegraph Company, he agreed to sell his half of the patents to them.

During this period it became clear to Thomas Edison that his inventive mind was being used as a weapon in battles between the financial generals. But though the development of complicated adjuncts to the telegraph did play a large part in late nineteenth-century financial warfare, they also helped establish Edison as a scientist. Technical journals joined the popular news media in recognizing the young inventor. The reputation he established became valuable in bringing him adequate financial support.

And adequate help was necessary if Edison was to succeed in his work. The intricacies of his devices illustrated an inexorable trend in scientific research. Edison himself was at a disadvantage in not having the mathematical background necessary to analyze his electrical circuits. In the case of the quadruplex telegraph, for example, he could not cope with the abstract concept of current flowing in two directions at once over a single wire. He found it necessary to construct a hydraulic analogue—a structure of pipes and valves with water flowing through them—before he could picture what was going on in the electric circuit. Thus, of necessity, Edison began to surround himself with trained scientists and technicians.

Menlo Park

Tired of the manufacturing business (he had at least three operating in Newark), Edison sought a pleasant setting where he could pursue his business of inventing. He decided upon Menlo Park, an isolated village about twenty-five miles southwest of New York City. By 1876 he had put up a group of buildings which became his invention factory. There he employed a conglomeration of chemists, mathematicians, model-makers, skilled mechanics, and even a few theorists. Many people today believe that Edison's greatest contribution to science and technology was his conception of a highly organized research and development laboratory, embodied in his Menlo Park establishment. There a diverse, well-directed staff worked and learned, supported by the proceeds of those projects which became commercially successful. Menlo Park was certainly the first institution of its kind in America if not in the world.

The Telephone

One of the first important projects pursued at Menlo Park was the telephone. In 1876 Western Union, sensing fierce competition for its communications world, sent for Edison, soothed his injured pride, and put him to work (at five hundred dollars a month) doing research on the "speaking telegraphs" of Elisha Gray and Alexander Graham Bell. The following year he began to experiment with a crude device that had been invented in Germany in 1861 by Jacob P. Reis. Edison soon had a patent filed on a device with a separate transmitter and receiver, using an in-series battery for increased power. He also adapted the induction coil to telephony; this sent a higher-voltage, lower-current signal over the line and reduced transmission loss.

Edison's greatest contribution to telephony, however, was the carbon transmitter, which ultimately replaced Bell's magnetic transmitter and made telephony commercially practicable. Before this device became accepted, Edison once again found himself in the midst of corporate fights and patent suits. The litigation over the telegraphic devices and the hours of testimony he had to give led Edison to feel that the patent laws he favored were taking an intolerable amount of his time. He once wrote, with some exasperation, "A lawsuit is the suicide of time." * Eventually Western Union withdrew from

* D. D. Runes (ed.), *The Diary and Sundry Observations of Thomas Alva Edison* (New York, 1948), 12.

telephony, leaving the field to the rapdily growing telephone companies.

Edison made one more effort before he too retired from telephone research by dealing successfully with the Bell people in England. To go with his carbon transmitter, Edison adapted the chalk-drum idea he had used as a telegraph relay in order to produce a new sort of telephone receiver. Although awkward, the contrivance produced a louder sound than the Bell receiver and was successful enough to lead to a settlement with the Bell contingent. More important, the search for a telephone receiver led almost directly to one of Edison's best known inventions, the phonograph.

Early Work on the Phonograph

In 1877 Edison described in *Scientific American* a method for mechanically recording the human voice on a strip of paper. By the fall of 1877 he had produced the first crude machine, using tinfoil wrapped around a hand-cranked cylinder. Two diaphragms, each with a stylus, served as recorder and reproducer. The success of the first trial of the machine astonished even its inventor. In December Edison was ready for a public demonstration which was held in New York City. Those gathered were astounded with the reproduction of sound, and the next day the press devoted an enormous amount of space to the anouncement.

It was a newspaper story about the phonograph which gave Edison the nickname of the "Columbus of New Jersey," and similar stories brought an intensely curious public to Menlo Park to see what made an inventor tick. Edison was pleased. He threw open the doors to his "science village" and stood about explaining everything to the crowds.

In 1878 the newly organized Edison Speaking Phonograph Company began to manufacture the still-crude devices. After a short time, however, the novelty of the phonograph wore off. It did not work well enough to serve as mass entertainment; that was to come some years later.

The newspaper coverage of and the public enthusiasm for the phonograph taught Edison a valuable lesson. Any venture with a little glamour and his name attached would command attention. This in turn would attract the capital he knew to be so vital to the development of his ideas. He put this lesson to deliberate use for the first time in developing the electric light.

The Incandescent Light

Today, many people argue whether or not Edison really invented the electric light. Experiments in electrical illumination were done as far back as 1840, and in 1860 Sir William Swan in England had introduced the carbon filament.

Such thinking misses the point of Edison's achievement, which was to create a useful device and to bring it into use. His work led him to an understanding of problems which even astute scientists failed to recognize completely, let alone to solve. Once he understood the various problems he had to meet to make a practical lighting system, he set about to solve them by whatever means, empirical or mathematical, he could muster.

Edison became interested in electric lighting in 1878 after he had had an opportunity to study arc-light systems in Connecticut. He saw at once that a different approach was needed for practical internal lighting and that the first step would be to subdivide the circuit for efficiency and safety. Thus he proposed multiple, or "parallel," circuits. But if many lights were to be connected across a circuit, and if the current was to be supplied with wires of reasonable diameter and cost, the filaments of the lamps would have to be very thin and long, so as to draw power at a much higher voltage and lower current than had been contemplated.

The development of the electric light had many facets.

The circuit system Edison proposed required an efficient constant-voltage source, and for this he developed an improved dynamo. Here he had to overcome a popular superstition dear to the hearts of contemporary physicists (and based on a misapplication of mathematics) that the internal resistance of a dynamo should be equal to the resistance of the load to which it supplied power. Edison knew better and made the resistance of his machines very small compared with that of the load. This was necessary to attain high efficiency and a constant voltage.

Another important problem was that of making accurate measurements. Edison realized that this was necessary to do useful experiments and also to operate a practical electric supply system. He had fairly satisfactory voltmeters but lacked a useful ammeter. To measure current he used devices involving electroplating and tried to devise a reliable instrument using the torque between two coils carrying the same current. It is interesting to note that the idea of measuring current by measuring the voltage drop across a resistor carrying the current escaped not only Edison but, for many years, the whole scientific world.

Edison also needed a meter to measure the amount of electricity a customer would use. For this he devised an instrument which electrodeposited silver according to the amount of current used. Relative weight of the deposited silver determined the bill.

Finding a suitable filament for an incandescent bulb drove Edison, and many others, to the limit of knowledge of chemistry at that time. And the need to completely remove the air from the bulb forced him to improve the evacuating equipment—a development for which he eventually received a patent.

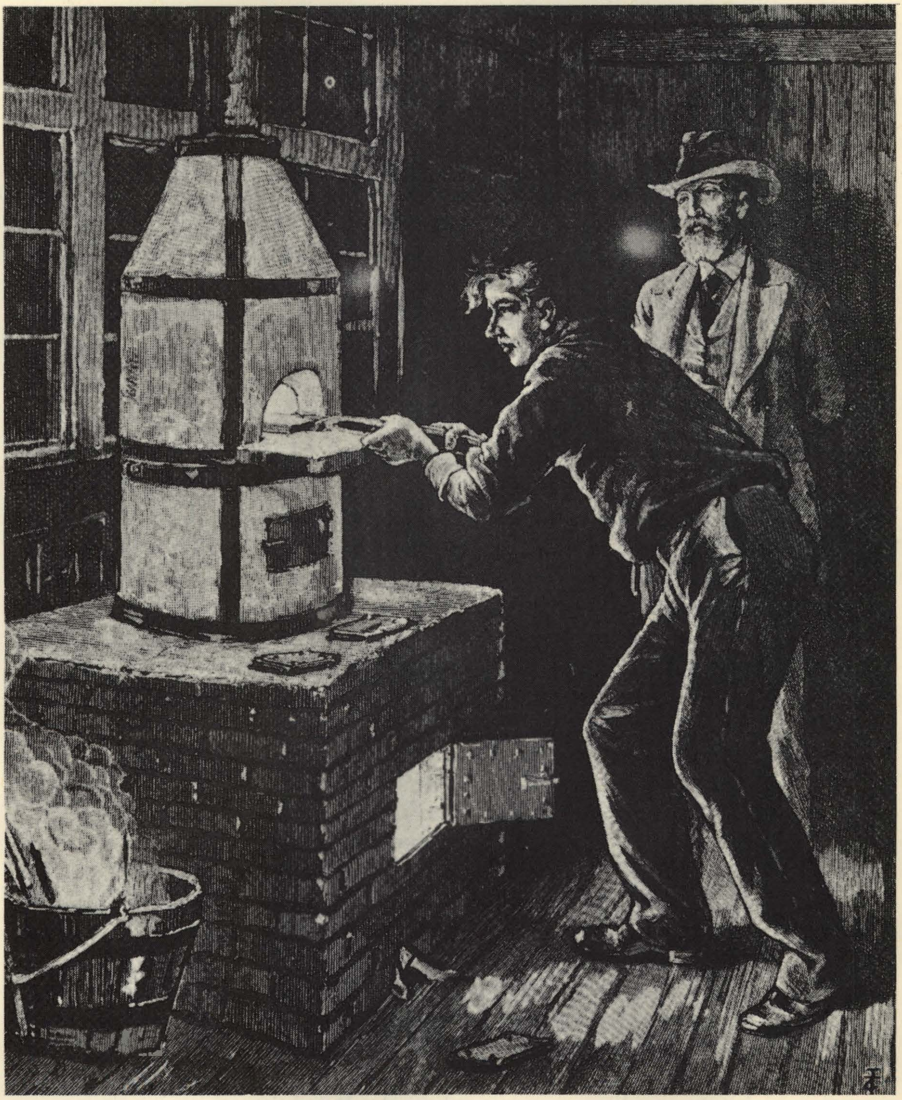
In carrying through such a program, Edison found it necessary to supplement his retinue with more university-trained scientists. One of the most valuable of the new men was Francis Upton, a graduate of Princeton who had studied a year with Hermann von Helmholtz in Germany. Edison hired Upton as chief scientific assistant and mathematician at Menlo Park. We noted before that, in the face of alleged contradictions of electrical laws, Edison had proposed connecting high-resistance lamps in parallel across a low-current circuit. It was Upton's calculations that ultimately proved Edison's ideas to be sound. And it was Upton who figured the resistance requirements for the filament of the bulb and so gave Edison guidance in selecting materials.

Off to a late start in the race for a successful lamp, Edison looked upon this as a challenge and said so publicly. Only time, he insisted, stood between him and success. This attitude was more than simple boasting. It served to alert men with money. Grosvenor Lowrey, the general counsel for Western Union, took over the financing arrangements (with Edison's permission) and formed a syndicate of important capitalists—Vanderbilt, Drexel, certain directors of Western Union, and, behind the scenes, J. P. Morgan. The arrangement between Edison and this syndicate was unique in capital-technology relationships. The Edison Electric Light Company was formed in October, 1878, not to manufacture an existing product, but to invent one to manufacture.

The difficulty in devising a practical electric light surprised even Edison. The right filament material eluded him as had nothing else before. First he tried wires, giving especial attention to platinum. The range of voltage over which platinum wire would supply light, and yet not melt, was too narrow. Edison invented a device to control the current; this resulted in a "flicker" light. In January, 1879, his first high-resistance lamp, using a platinum wire spiral as a filament, burned for an hour.

Both practical and theoretical research surrounded the project and Edison drove his men at a desperate pace. Months passed with no significant progress. The public began to display its impatience with the man who usually delivered something spectacular in a few weeks. Moreover, the financial backers were being asked for more money and their impatience became more pointed.

But progress was being made. It became clear that the



Edison carbonizing his paper lamp filament

filament must have a small cross section as well as a high resistance, and so the researchers began to prepare very thin carbonized threads. In October they had a bulb that burned 13½ hours. By then Edison knew the filament must have a fibrous structure but be made of something stronger than the carbonized cotton he had been using. Nevertheless, the October experiment was the turning point, and when it was supplemented by a 170-hour test of a carbonized paper filament in December, the *New York Herald* ran a front-page story on the success. Investors' faith was restored and Edison rose to new heights in the public eye.

A Systems Approach

Unlike the rest of the electric light "inventors," Edison saw his lamp as only part of a whole electrical network. His approach proved this when he decided first what would be a practical network and then designed a lamp to fit it. As soon as the light bulb itself was assured, he began to plan a complete electric light and power system. He proposed a "feeder and main" system, using parallel heavy main circuits and smaller branch circuits. This idea reduced the amount of expensive copper wire needed in an installation.

In February, 1881, Edison moved to New York City to supervise the building of a central power station in lower Manhattan. His aim was to design everything from the dynamos right down to the sockets and switches. Starting with the generator station on Pearl Street, he and his crew began to fan out a network of underground cables. Much electrical matching and balancing attended the process. Edison was constantly plagued with "patch up" problems—adding makeshift improvements to steam engines or repairing occasional electrical leaks that threatened to incinerate passers-by.

Persistence was rewarded, however, and in the fall of 1882 a small area surrounding the Pearl Street station was wired for electric illumination. Eventually central-station electricity would replace the self-contained units operating in a few buildings around the city, but in the meantime these units were to bring in most of the revenue to the Edison Lamp Company.

As with most products, an electric light bulb went down in cost as the use went up. In 1880 a bulb cost $1.21; by 1890 it was down to $.22 when about a million were being made annually. In 1886 there were over five hundred isolated power plants—in factories, department stores, hotels—and 58 central stations in the United States. Europe, where Edison had had representatives selling his ideas for years, and even South America and Japan were beginning to "go electric."

West Orange

Edison's companies, the Edison Electric Lamp Company, the Edison Illuminating Company, the Edison Machine Works, prospered in the boom times of the late 1880's. In 1887 Edison moved to West Orange and built a laboratory near by. The new facility was ten times the size of the one in Menlo Park and, in fact, was the largest and most complete research laboratory in the world. Here the inventor maintained a research team of from forty-five to sixty members, varying in vocations from unskilled laborer to scientific specialist.

One of the first projects pursued in the new West Orange laboratory was the revitalizing of the phonograph. In 1885 Edison had been spurred to go back to work on this device because others, a cousin of Alexander Bell and Bell's partner C. S. Tainter, were trying to improve and capitalize on it. Strictly speaking, Chichester Bell and Tainter were willing to keep Edison's name in the invention and offered him a half interest in the improvement. The offer only infuriated him.

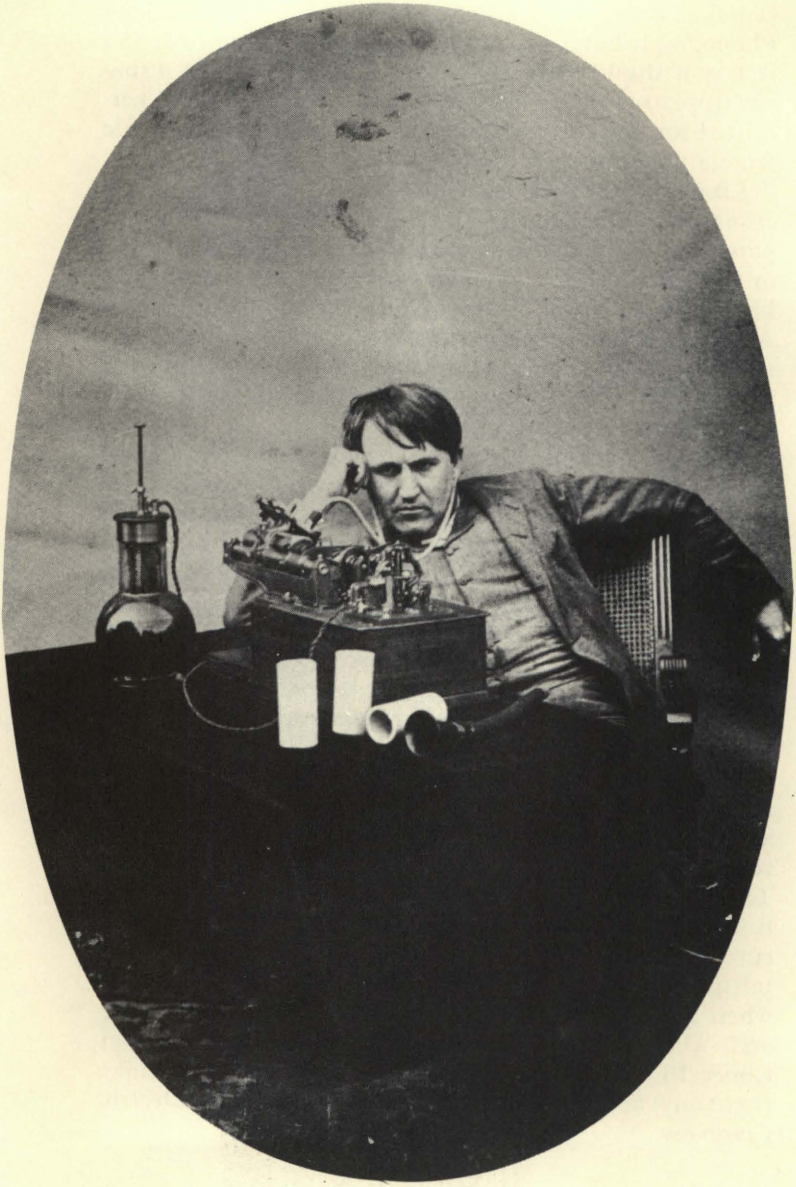
At West Orange the crude tinfoil sheet of the original phonograph was replaced by a wax cylinder. Then a hard cutting stylus was devised in a flexible pickup head for recording. A similarly sensitive arrangement became the reproducing head. Through successive refinements Edison finally produced a device capable of producing ac-

Edison at work in Chemical Dept.—Orange Lab—after 1887 ceptable commercial entertainment. The old Speaking Phonograph Company of 1878 had been reorganized, and it began duplicating records in large volume by using electroplating on a "negative" mold. The technique permitted an unlimited number of wax records to be made from a metal master.

Like other Edison developments, the phonograph was ensnarled with legal red tape, the buying and selling of patents, and, in this case, the rather involved cupidity of one of the inventor's close friends. Moreover, Edison was burdened with the inept management of the North American Phonograph Company which had been set up to distribute the new phonograph. He had to wait several years until that company went bankrupt before the phonograph became profitable.

By 1888 Thomas Alva Edison had become an important New Jersey industrialist employing two to three thousand people in a wide variety of enterprises. He had the industrialist's headaches too—from labor troubles to patent infringements. About this time he also exhibited a blindness to the value of long-distance transmission of electric power through the use of alternating current. Edison's original plan of using direct current stemmed partly from safety aspects—the high voltage alternating-current arc lights of the time were electrocuting craftsmen (and occasional customers) at an alarming rate.

As methods of grounding and shielding improved, and as the possibility of using such natural sources of power as Niagara Falls became evident, the electric industry, represented by firms such as Westinghouse Electric and Thompson-Hamilton, pushed for alternating-current transmission. In insisting that the dangers of alternating current were insurmountable Edison was being uncharacteristically dogmatic. The problem was finally solved when Edison left the power-generating business in 1892 and when Thompson-Hamilton took over the Edison General Electric Company (née the Edison Electric Light Company) and formed what is today the General Electric Company.



Motion Pictures

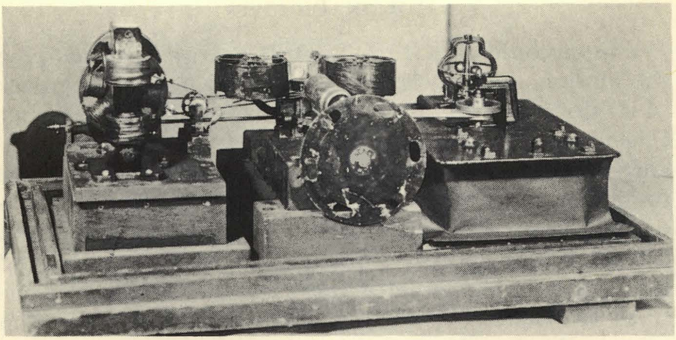
Edison could now turn his full energy to developing the motion picture camera, which had been in the back of his mind for several years. The stage had been set when Edison read about experiments showing the eye's persistence of vision—the fact that the brain retains an image for a fraction of a second after the stimulus itself has disappeared. This, plus Edison's own idea of a chain of film on which successive pictures could be exposed and later displayed, completed the basic idea of motion pictures. On October 8, 1888, he filed notice of the invention—basically the photographing of a series of pictures at intervals in a continuous spiral on a cylinder or plate. It showed strong overtones of his phonograph technique.

The need for radical improvements was immediately obvious. In 1889 Edison and W. K. L. Dickson decided on a film "strip" passing through the focal plane of the camera and periodically exposed by a shutter. They experimented with celluloid to support the emulsion. When George Eastman devised an improved film, Edison encouraged him to make it still better. Meanwhile, he continued to make mechanical improvements to the camera.

Viewing the films was another problem. Edison's kinetoscope, a one-viewer-at-a-time device, was clearly limited as an entertainment medium. Some sort of projector was needed similar to ones already being developed in Europe. In 1895 Otway and Grey Latham built a workable projector using reels of film. When Thomas Armat devised an improved gear the projector took a giant step toward commercial reality.

The patents of Edison, Armat, and the Lathams were eventually banded together and by 1907 they had become a trust: the Motion Picture Patents Corporation. Many looked with disfavor on Edison for attaching his name to something he didn't invent. But when one understands Edison's belief that the value of an invention lay primarily in its use, he realizes that Edison was not primarily

Thomas Edison after long work on the phonograph



Kinetograph—prototype of the motion picture camera

trying to take credit but rather was trying to assure the success of motion pictures.

Edison foresaw for motion pictures an important role in education. He felt that, coupled with the phonograph, they would provide a sight-and-sound method of instruction that would replace textbooks.* Books have remained the basic medium of education, but Edison's vision of audio-visual aids to education has been realized.

Around 1900 Edison entered the auto business, or rather he entered the battery business, which he thought of as a first step toward producing a car. The development of the Edison storage battery was a tremendous project involving over ninety men, including many accomplished chemists and physicists. In seeking a light, noncorrosive electrolyte, this research team performed tens of thousands of experiments. It was the greatest of all of Edison's "cut and try" programs. The seemingly nonscientific search for a good combination of electrodes and electrolyte was perhaps the only way to attack the problem. There was no area of established chemistry from which to seek guidance. And the sheer number of trained men at work made a solution to the problem at least statistically more probable. Edison himself said, "the

* D. D. Runes (ed.), *The Diary and Sundry Observations of Thomas Alva Edison* (New York, 1948), 65.

experiments of a laboratory consist mostly in finding something won't work." *

Ultimately something did work, as it nearly always did, and in 1904 Edison was manufacturing batteries with electrodes of nickel-hydrate and iron-oxide. However, these did not hold up under use. It was not until 1909 that, by adding lithium to the electrolyte, Edison had a commercial product. The following year he started a new production line and the Edison Storage Battery Company finally became a success—not, curiously, as a supplier of automotive batteries, but as a supplier of dependable, long-life power for remote railway signals, or for coal miners caps. Later this battery generated power for submarines and army field radios.

Edison was a highly ingenious individual whose interests ranged far beyond the practical. In 1880 he noticed and properly explained a flow of current through the vacuum of an electric light; this "Edison effect" was to reappear in a useful form in De Forest's vacuum tube. In 1875 he noticed an "etheric" force which seems to have been the first conscious observation of electromagnetic or radio waves, though at that time no one recognized it as such. He devised a phonometer or vocal engine which used the power of the voice to turn a wheel. He invented the tasimeter, which responded to extremely minute changes of temperature, and tried, unsuccessfully, to use it to make scientific experiments during the solar eclipse of 1878.

Beyond this, Edison's ingenious inventions ranged from an electric pen to a process for magnetic separation of iron ore. Circumstances rendered these obsolete.

Edison's most novel contribution to the growth of science and technology was that of maintaining, through the profits of his successes, a group of specialists. Throughout his entire career he depended on the faithful master mechanics, the skilled fingers of John Ott and Charles Batchelor and the machinery expertise of John

* D. D. Runes (ed.), *The Diary and Sundry Observations of Thomas Alva Edison* (New York, 1948), 74.

Kruesi. He made much fun of college-trained scientists but hired the best of them. He despaired of the time and money and personal effort he had to expend in countless patent litigations, yet he knew and respected the laws that protected his ideas and hired the best patent lawyers he could find. He often railed against the "Wall Street interests," the money brokers, but he also knew the engine of invention was fueled by finance, and in later years he employed an expert to handle his financial affairs.

Many call his Menlo Park laboratory the first industrial research laboratory in the world. It has been much imitated. Alexander Graham Bell set up a laboratory in Washington, D.C. which was patterned after it. The General Electric Research laboratory was a direct descendant. And many modern laboratories have features which are reminiscent of Menlo Park. Edison's integrating of several sciences—mechanics, electricity, chemistry, mathematics—and the placing of their specialists under one roof and maintaining them from year to year, made him the world's first "research director."

IV

SCIENCE AND THE SOIL

IT'S DIFFICULT TO PICTURE how the fifth smallest and the most densely populated state (slightly over eight hundred people per square mile) in the Union can afford to spare 40 per cent of its acreage to farmland. Yet it does. Moreover, New Jersey leads the nation in gross farm income per acre. This bespeaks an efficiency which comes to New Jersey farmers from having access to a "soil science."

In New Jersey, as elsewhere, improvement in agriculture shows how effective university research supported by state and federal funds can be. The nucleus of agricultural research in New Jersey is the Agricultural Experiment Station at Rutgers University in New Brunswick. In 1880 New Jersey, then the third state in the Union to have an agricultural college, became the fifth to establish an experiment station "for the benefit of practical and scientific agriculture." * George H. Cook, a Rutgers professor whose exhortations had convinced the State Legislature that it should furnish the necessary money, was appointed the Station's first director. Cook was also instrumental in bringing about the Hatch Act of 1887, which authorized the federal government to establish state agricultural stations.

New Jersey's "garden farm" economy has shaped the agricultural research carried out at the Station. In the middle of the nineteenth century, the big crops—wheat

* Ingrid Nelson Waller, *Where There is Vision* (New Brunswick, 1955).

and beef cattle, for example—moved to the plentiful and fertile land and the great farms of the Middle West, and New Jersey farmers became more and more concerned with truck crops. This was essential, for the total amount of land in New Jersey which is given over to agriculture is relatively small. Yet the state has had to feed not only itself but also a good portion of the northeastern section of the nation. New Jersey has continued to do this even while her farmland has been encroached upon by spreading industrial and residential areas.

Thus, it has become imperative for New Jersey farmers to make the most of the soil they have–an important reason for the Experiment Station's efforts in soil science. Toward the end of the nineteenth century Edward B. Voorhees, the second director of the Experiment Station, established a program of long-range research intended to yield fundamental information about soils.

Particularly, he initiated a research project to determine the effect of animal manures on denitrification processes in the soil. Voorhees and the Station's soil chemist, J. B. Street, subsequently presented a paper entitled "Studies in Denitrification" to the American Chemical Society and were awarded the Society's first Nichol Gold Medal.

In 1907 Voorhees, recognizing the important role that bacteria play in soil fertility, organized the Department of Soil Chemistry and Bacteriology—the first of its kind in the United States. Jacob G. Lipman, who was completing his graduate work at Cornell University, was appointed to the staff.

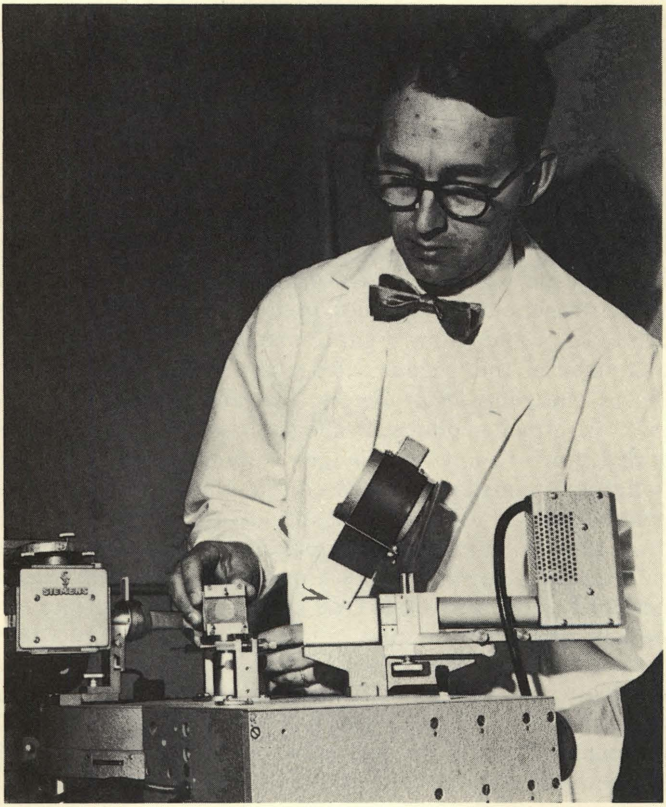
When Voorhees died in 1911, Lipman took over as director of the Station while continuing to serve as head of the Department of Soil Chemistry and Bacteriology. In 1915 he was appointed the first dean of the Agricultural College. Lipman began to add new departments–seed analysis, plant pathology, agronomy and farm management, poultry husbandry, and the extension service. After World War I he added departments of plant physiology, agricultural biochemistry, agricultural economics, sewage investigation, agricultural engineering, ornamental horticulture—departments that implied the need to treat agriculture as an industry and to assure that it could and would take advantage of technological advances. An outstanding journal, *Soil Science,* was established in 1916 and Lipman remained editor-in-chief throughout his life.

Lipman and his associates, notably Percy E. Brown, devoted themselves to problems on the relation of bacteria to soil fertility. Principal among these were studies on the influence of bacteria on the transformation of nitrogen and nitrogenous compounds in the soil and on the loss of nitrogen and other organic materials. A special study was made of the various nitrogen-fixing bacteria belonging to the genus *Azotobacter.* Research included a program of growing plants in chemical solutions which has added much to our knowledge of plant growth.

Better understanding of soil and plant life has led to better understanding of how animals use plants for their own growth. Biochemists working in this area have gained knowledge of what animals and human beings need for good nutrition. One of the most important results of these studies came from the field of soil microbes —microbiology—which led to pursuit of knowledge of antibiotics and the discovery of streptomycin at Rutgers by Selman A. Waksman (see page 56).

Lipman bridged the gap between the old farmer and the new. He pointed out the folly of the hit-or-miss farming methods of the early twentieth century and convinced the farmer that success in agriculture was intimately tied to science. The Experiment Station at Rutgers has done this in the way calculated to attract the most disciples—by example. Experiments are carried out on land belonging to the College of Agriculture, thus avoiding the need for the farmer to experiment on his own limited acres.

The proper balance of a "rich" soil depends on just the right amount of certain elements. Many of these elements, boron, copper, zinc, iron, iodine, are needed in minute quantities. In a five-year study completed in 1956



Dr. Lowell A. Douglas of Rutgers University sets up soil sample in x-ray diffractometer

Courtesy of Rutgers University

Rutgers research workers took samples of soils from all parts of the state and analyzed them in a spectrograph, which had been purchased for Rutgers by two dozen industrial firms and farmers' cooperatives. The study determined the exact effects on plants, and the animals who ate the plants, of too much or too little of these "trace" elements. The study also ascertained the effects of adding new elements, such as lime, and the effects of a change in atmospheric conditions on the soil.

While federal and state support of university agricultural research has been of primary importance, funds have come from private sources as well. As a collateral part of the soil science studies, the Sloan-Kettering Cancer Institute has granted money to the Experiment Station to seek clues linking the amount of trace elements in the soil to the condition of the blood in animals and human beings who eat plants grown in the soil. There may be some key here to the differences between normal blood and blood which has elements indicating a cancerous or precancerous condition. A number of similar experiments conducted by Rutgers graduate students in the Soils Department are financed by various foundations, cooperatives, and industries.

Lipman's era at Rutgers came to an end with his death in 1939, and he was succeeded by William H. Martin. Martin had joined the Station in 1919 as an associate plant pathologist and in 1935 was appointed to the post of Director of Research. He became the fourth director of the Experiment Station and the second dean of the College of Agriculture.

The present director of the Station is Ordway Starnes. In eighty-three years there have been only five directors and, until the selection of Starnes, the pupil always succeeded the teacher. The present Dean of the College of Agriculture is Leland J. Merrill, Jr.

During the Depression of the Thirties the Station tried to keep New Jersey farmers in business by helping them to increase their productivity. But many of the farmers, conservative in thought and poor as well, did not take advantage of new discoveries. Thus there was a "backlog of knowledge" to be put to work during and after World War II in helping to raise agricultural output.

In 1944 Martin took over the duties of Director of the Extension Service. After the war he realigned some of the departments at the Experiment Station. One of his most important administrative actions was to encourage specialists from all departments to work on the same problem at once—for example, discovering the cause and cure of a tomato fungus. This approach has served to illuminate each problem, to find out exactly what kind of investigation is needed to improve a crop or eradicate a blight.

Improving stock is part of the job of agricultural research. Selective breeding of both plants and animals results in bigger, hardier, and tastier plants and animals. The Agricultural Experiment Station at Rutgers has a long record in this field. Research workers there established the first program in America for the artificial insemination of dairy cattle.

A notable example of plant improvement is the Rutgers tomato introduced in 1934 after eight years of hybridization experiments. The canning industry was looking for a tomato that would ripen from the inside out. A group at the Station under the direction of Lyman Schermerhorn selected two likely "parents" and from the cross-bred seeds put out many thousands of plants. Seventy-five likely offspring were culled from this mass, studied and bred and whittled down to four plants, which were further studied and bred. Finally, one plant was picked. At one point more than 70 per cent of the tomatoes grown in the United States were descended from that one plant. A few years later a similar hybridization process resulted in the Queens tomato. The ripening process in this fruit is reversed—from the outside in—the result of an effort to produce a tomato for roadside stands. Written descriptions of the plants resulting from such work are published, and the seeds are made available to commercial distributors, who multiply them for sale.

Other research have led to the isolation of animal diseases and the finding of vaccines. Two poultry illnesses, Newcastle disease and laryngotracheitis, are virus diseases which not only infected chickens, but sometimes led to virus infections in other animals and human beings. Rutgers' F. R. Beaudette conducted studies that led to vaccines which check these diseases. By 1955 the perfected vaccines were saving an estimated one hundred and fifty million dollars annually in the poultry industry.

The Rutgers College of Agriculture owns nine hundred acres of farmland in New Brunswick and New Brunswick Township. In the fall of 1961 an additional two hundred acres were purchased at Adelphia in Monmouth County. Besides the Experiment Station, the college operates the Extension Service, one of the first established in the United States; this organization attempts to solve peculiar and individual problems of New Jersey farmers. Today the Experiment Station is a cooperative federal, state, and county enterprise.

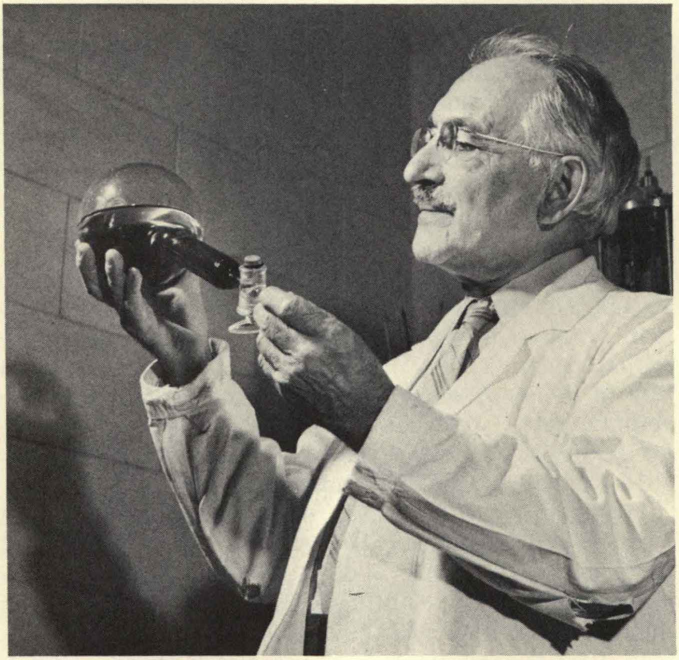
Beginning of the Mycins

Selman Waksman, like Lipman, had emigrated from Russia. He entered Rutgers in 1911 as a student. Waksman's interest in soil studies began with his senior thesis on bacteria and fungi in the soil, and Lipman interested him in the study of a third type of micro-organism—the actinomycetes. Waksman left to take his doctorate at the University of California, but he returned to Rutgers after 1918 to a lifetime study of microbiology.

For many years Waksman studied substances in soil samples collected from all over the world. He studied the role played by microbes in humus, which led to an understanding of the formation of coal. He also examined microbes in marine environments.

In 1952 Waksman received the Nobel Prize in physiology and medicine for his discovery of streptomycin, produced from one of his actinomycetes. Two years later the college dedicated to him the three-and-one-half-million-dollar Institute of Microbiology. This building has been entirely paid for by royalties from the sale of streptomycin. This admirably illustrates how research can be supported through the profits it leads to. Today the Institute is considered to be the world center of research on micro-organisms.

Private industry, as well as governments and foundations, has played an important part in agricultural research in New Jersey. In the final stages of the development of streptomycin, for example, the Merck Laboratories in Rahway joined Rutgers in conducting tests and setting up pilot operations for commercial manufacture.



Rutgers' Nobel Laureate Dr. Selman A. Waksman, discoverer of streptomycin and neomycin

Courtesy of Rutgers University

The association with Merck Laboratories was not unique, however, in the operation of Rutgers research. An important development in fungicides came out of work at Rutgers on compounds that were by-products of petroleum research done by A. L. Kittleson at the Esso Research Laboratories in Linden. This was the fungicide Captan, known officially as SR 406 (*S*tandard Oil—*R*utgers—the *406*th compound tested). As a preventive of fruit blight, particularly for apples, Captan saves crops worth millions of dollars each year in the United States.

Industries Contribute

The contributions of private industry to agriculture have gone far beyond specific cooperative programs. For example, American Cyanamid in 1962 established an eleven-million-dollar Agricultural Research Center on a 640-acre site near Princeton for research in plant and animal health. This Center employs over five hundred people, 160 of whom are research workers. Buildings at the center can house twenty-five thousand poultry, five hundred swine, and two hundred ruminants.

The American Cyanamid Company chose the Princeton area because the climate and soil there are favorable to this type of research. The scientists are near the Princeton University Library and Rutgers College of Agriculture is nearby. The Research Center also benefits from having allied industries, such as chemical firms, as neighbors.

The Research Center has facilities for all-inclusive agricultural research. It works on drug and other health products for animals as well as on feed supplements. It develops and improves insecticides, fungicides, herbicides, nematocides, defoliants, fertilizers, and also antibiotics. To carry out these programs it employs chemists, chemical engineers, bacteriologists, botanists, pathologists, mycologists, agronomists, entomologists, physiologists, nutritionists, zoologists, parasitologists, biologists, biochemists, and veterinarians.

Aware of the inherent dangers in chemicals used to aid or inhibit plants or control pests and fungi, the American Cyanamid Research Center employs safety testing equipment which exposes a newly developed chemical compound to exhaustive tests designed to protect the consumer as well as the farmer who handles the compound. One technique is the use of radioactive tracer laboratory equipment which tells where and how much of a spray residue goes ultimately into a plant or the animal that eats the plant. Close cooperation is maintained with agricultural colleges and extension stations for more far-reaching tests and those designed to determine the effects of climate and geography on agricultural chemicals.

The FMC Corporation, at its Chemical Research and Development Center near Princeton, also explores the intricacies of pesticides and other agricultural chemicals. In environmental laboratories FMC scientists screen potential pesticides and herbicides. Working with state and federal Agencies, FMC conducts field tests to ascertain safe rates of application for various crops, the best time to apply the chemicals, and their residual effects.

V

LONGER LIFE FROM THE LABORATORIES

During the past few years science writers have divided their columns about equally between stories of space and the atom and stories of medicine and "miracle" drugs. Yet thirty years ago, physicians had only a few generally useful drugs, such as opium, digitalis, iodine as an antiseptic, and a very few specific curative drugs—chiefly, quinine for malaria and salvarsan for syphilis. New Jersey pharmaceutical work extends into this earlier period.

In the nineteenth century the medical profession became aware of some of the causes of disease and began to practice measures of prevention. The work of Louis Pasteur and Joseph Lister proved the need for antisepsis and asepsis in medicine. New Jersey's pioneer was Johnson & Johnson in New Brunswick, whose first research director, Frederick B. Kilmer, began a program of research in surgical dressings and antiseptic products in 1888.

But in New Jersey, as elsewhere, the great advances in curing diseases have come in the twentieth century. These have included advances in chemotherapy far beyond salvarsan and in the use of the products of micro-organisms to fight micro-organisms. A new science, biochemistry, has arisen from the linking of chemistry and biology. As one result, medical research has evolved antibiotics, sulfas, synthetic hormones, vitamins, tranquilizers, and other new therapeutic agents. This work has been a happy outcome of the combined resources of medical and biological investigations in universities and other nonprofit laboratories and of the powerful resources of profitable chemical and pharmaceutical industries.

SULFAS

We can trace one important chain of advances in chemotherapy back to the observation in 1935 by Gerhard Domagk of I. G. Farben in Germany. Domagk discovered the clinical value of a red dye compound, prontosil. Then M. Fourneau of the Pasteur Institute found that the nondye part of the prontosil molecule, paramino-benzene-sulfonamide, was the portion effective in attacking bacteria, and he gave it the name sulfanilimide. This drug was introduced in 1936 as a defense against streptococci. But it displayed unpleasant side effects–skin rash, blood-cell damage—and so the drug industry sought to discover different, stronger forms of the molecule that would kill the germ while avoiding the side effects. The resulting synthetic organic molecules were drugs such as sulfapyridine, sulfathiazole, and sulfadiazine.

Merck Laboratories in Rahway contributed to this research. Merck scientist, J. M. Sprague, was the first to synthesize the group of sulfas called sulfapyrimidines in 1939. Sulfas, however, are only one item on a list of accomplishments in pharmaceuticals by this sixty-year-old Rahway firm. During World War II, Merck and two other drug firms teamed with the United States Department of Agriculture in finding ways to produce penicillin in large quantities.

PENICILLIN

In 1928 when Alexander Fleming, professor of bacteriology at St. Mary's Hospital in London, was working with cultures of *Staphylococcus aureus,* some pencilshaped spores literally blew in the window and devoured portions of the cultures. (The name "penicillin" came from the rod- or pencil-shape of the spores.) Fleming understood what had happened and published the results of his experiments in 1929 in the *Journal of Experimental Pathology*. Then there occurred one of the unfortunate lags in research, and no major work on penicillin was carried out for ten years. Possibly this was because the idea of deriving a medicine from molds was not considered respectable, but more likely it was because pharmaceutical research workers were busy synthesizing organic molecules. The success of sulfanilimide as a drug was unlikely to inspire work on molds.

It soon became apparent, however, that the sulfas were no panacea. When England went to war in 1939 work on penicillin was resumed. As with many untried drugs, the first clinical tests were made on "hopeless" cases of infection. The immediate results were spectacular, but clinical success raised the problem of producing the drug in bulk.

Thus it fell to organizations in the United States—Merck and Squibb in New Jersey and the Charles Pfizer Company of Brooklyn—to find a method of mass production. Eventually 16 pharmaceutical firms came into the search. The Squibb Institute for Medical Research in New Brunswick received the first Fleming culture in 1941 and was the first to produce penicillin in fermentation tanks.

Squibb was later involved in a successful process for the production of penicillin in crystalline form. This process, developed by Radio Corporation of America scientists George Brown, Robert Bierwirth and Cyril Hayler, involved a radio-frequency heating technique.

Even while Squibb was installing the radio-frequency equipment, however, Brown, Bierwirth, and Wendell Morrison were developing a method for concentrating penicillin using butyl alcohol in water. Squibb immediately adopted this far simpler and more elegant process as preferable to the radio-frequency technique.

Like the sulfas, penicillin is believed to work as a blocking agent. By feeding fraudulent molecules to an unwanted bacteria, the drug literally starves the disease to death. Penicillin has proved to be effective against most of the Gram-positive bacteria and two of the Gram-negative—gonococcus and meningococcus, the germs of gonorrhea and syphilis. (The negative-positive classification divides germs into two types according to whether or not they are colored by a particular stain.) Gram-positive bacteria include streptococci, staphylococci, pneumococci, anthrax; the Gram-negative germs cause ystitis, kidney infections, inflamed gall bladders, and undulant fever. The distinction is important; a subsequent major project of medical research has been an attack on the Gram-negative bacillus of tuberculosis.

Soil Bacteria

We saw in Chapter IV how the fruits of many years of soil research led to the discovery of streptomycin by Selman Waksman and a staff at Rutgers. In 1939 Waksman started an organized search for an antibiotic to cure tuberculosis. (In 1932 the National Research Council had financed a Rutgers study of tuberculosis bacteria in the soil.) He had noted many years before that in addition to the bacteria and fungi residing in the soil there was a third element—a filament-like "actinomycete" which was not exactly like bacteria nor exactly like fungi. He also noted that all disease-producing bacteria eventually reach the soil. But they don't accumulate. They disappear! With about forty graduate students, Waksman set about examining over ten thousand samples of soil.

A form of actinomycete called actinomycin was isolated but proved to be too toxic or poisonous for medical use. Waksman and his students searched for a particular actinomycete able to penetrate the waxy shell of the tuberculosis bacillus and destroy it. They found certain nontoxic strains which would do this, but these particular strains were very weak. The weak strains were returned to the soil, and gave rise to stronger and more prolific strains. These strains were tested on chick embryos, mice, and guinea pigs.

At this point Merck Laboratories joined the program in order to help finish the tests and to start production of the drug. In 1945 a Merck pilot plant was supplying doctors and the Army Medical Corps with streptomycin to kill organisms resistant to penicillin and sulfa—the Gram-negative microbes of tuberculosis, dysentery, whooping cough. By the following year the drug was universally accepted and used.

Waksman freely credits Merck with tremendous help in isolating, purifying, manufacturing, and testing streptomycin. He called the program "one of the most fruitful connections ever entered into between a university and an industrial organization." The Rutgers scientists not only were able to work in an industrial laboratory, with an atmosphere which was much like their own at the University, but they also had free interplay with a number of Merck scientists skilled in disciplines other than microbiology.

Neomycin, as a companion drug, originally proved to be too toxic for injection into the bloodstream. Furthermore, the tuberculosis bacillus was found to resist it. Eventually neomycin found use, when mixed with certain sulfas, as an internal antiseptic for infant diarrhea and dysentery.

Streptomycin proved effective against more than seventy types of germs which had thumbed their molecular noses at penicillin. A good many "mycins" have since evolved from the soil. In the ten years since streptomycin was first discovered over ten thousand scientific papers have been published on it. Some of the later drugs, such as chloromycetin, or terramycin, are classed as "broad spectrum" because they affect a wide range of bacteria.

Help for Arthritics

Cooperation in the development of a drug seems to be characteristic of operations at Merck Laboratories.

Another important contribution to modern medicine came directly from these laboratories when Lewis H. Sarett, at the age of twenty-six, became the first chemist to synthesize cortisone—the drug that gave rheumatoid arthritics a new lease on life.

The role played by the hormones in human health is not fully understood. It is known that they are secreted by the endocrine glands and act as chemical messengers to other organs or parts of the body. One of the functions of the adrenal glands is the production of cortisone, and a deficiency of cortisone causes Addison's disease. Addison's disease can be arrested by administering adrenal cortex, and extracts of this were made in 1929. But the process was expensive and the results uncertain. Chemical research workers sought to identify the active ingredient, find a way to purify it, determine its chemical structure, and find a practical synthetic. The active ingredient turned out to be a steroid hormone, but many steroids are produced by the adrenal glands, and not all steroids act as hormones.

By rearranging the atoms of the compounds, chemists can devise different steroids. During the 1930's Dr. Edward C. Kendall at the Mayo Clinic in Rochester, Minnesota, studied the great number and variety of steroids produced by the adrenal cortex and isolated six of them, which he labeled Compounds A through F. In 1941 Kendall turned to Merck in Rahway for help in producing the compounds in sufficient quantities for meaningful tests and for help in the search for ways to determine which of the six was the effective steroid. Three years later Sarett found that this was "Compound E," although he had produced only a small quantity of it. Remember, they were searching for a drug to alleviate Addison's disease!

In 1948 Kendall's co-worker at the Mayo Clinic, Dr. Philip Hench, administered Sarett's Compound E to a patient suffering from advanced arthritis. Almost immediately the patient showed a marked decrease in pain and swelling in the joints. Thus the cure sought for a disease suffered by hundreds of people turned out to alleviate the pains of one suffered by thousands.

Cortisone neither kills germs nor deadens pain. Rather, it changes the internal tissues in some way so that they become resistant to stress, injury, or disease. Synthetic cortisone has also proved to be useful for treating a number of allergies, certain skin diseases, and asthma.

Photomicrograph of cortical steroid
Courtesy of Merck, Sharp & Dohme Research Laboratories

Production of the arthritis-relieving drug in large quantities was initially a problem, but Merck, joined by Schering in Bloomfield, overcame this and by the end of 1950 both companies were in full production of the drug. Schering, offspring of a German firm which was Americanized by the Alien Property Act and subsequent public sale in 1952, had had a long history of success in synthesizing sex hormones. And so it was not surprising to see the next breakthrough in steroid research come out of Bloomfield.

To be fully effective cortisone must be administered in substantial doses. Furthermore, and unfortunately, it has some severe side effects. Schering scientists sought ways to modify the chemical by altering its structure. Biochemist Preston Perlman decided to look for a microorganism that would nibble on the cortisone molecule enough to produce these desired changes. In 1954 he found it—a fermenting process in which a microbe changed the corticosteroid molecule.

As a result of this discovery Schering, by the following year, was producing meticorten and meticortelene (chemically prednisone and prednisolone) in large quantities. Not only are these five times as potent as cortisone, thus requiring only one-fifth the dosage, but also they do not produce edema, the salt retention in tissues that waterlogs the body. During the first year the meti-compounds were produced, 324 medical papers were written about them.

The Vitamins

Something which is not a drug, nor even a food, but yet has as much to do with human health, is a food constituent called a "vitamin." It is a specific organic compound, peculiar in that it is needed in minute quantities: 0.005 to 0.00002 per cent of the weight of food. Vitamin absence in the young leads to growth failure and, in both young and old, to diseases such as beriberi, scurvy, rickets, pellagra, xerophthalmia, and pernicious anemia.

About 1900, life-science researchers discovered that a lack of something in the diet could cause disease. In 1911 the Polish scientist Casimir Funk, working with rice bran, isolated the first vitamin. During 1915 and 1916 Funk worked for the Calco Chemical Company (now part of American Cyanamid) in Bound Brook but he was unable to arouse interest in vitamins. Eventually he went abroad, where he was acclaimed for his work.

New Jersey had a second chance, however. About the time of Funk's discovery Robert R. Williams found that feeding rice bran to children in the Orient lowered the high mortality rate from beriberi. In 1919 Williams, back in the United States, went to work as a research chemist, but he continued his vitamin studies at his home in Roselle after hours. Working with him was his son-in-law, Robert Waterman, who was also a chemical researcher and later became research director at Schering.

In 1934 Williams succeeded in making vitamin B_1 in pure form, and two years later, with the aid of Merck Laboratories, he synthesized the "anti-neuritic" vitamin B_1, also called thiamine. It was possible to produce this vitamin in large quantities.

In addition to the help it gave on vitamin B_1, Merck was responsible for the discovery of vitamin E and also did important work in the isolation of B_6. One of its greatest contributions in this field, however, was the isolation and synthesis of Vitamin B_{12}.

For many years doctors had known that sufferers from pernicious anemia could gain relief by eating a half pound of raw liver each day. Later a crude extract of the liver was found which produced the same result when injected directly into the blood stream. For many people, however, the remedy was physiologically impossible—they could not tolerate eating so much liver, and the extract produced severe reactions.

At Merck, Karl Folkers and his associates became convinced that the anti-pernicious anemia substance in liver was a vitamin. Related work in bacteria nutrition at the Department of Poultry Husbandry in the University of Maryland showed that liver extracts could help bacteria to grow. Dr. Mary Shorb, who was conducting these studies, was persuaded to come to Rahway and join the search.

Folkers and his associates used chromatography to separate the various components of liver extract. In this process a solution of an extract passes through a column of absorbing material and crude fractions settle at different heights. Chromatographic separation led to a pink component which turned out to contain the desired substance. Continued separation led to a red fraction, and finally the research team obtained bright red crystals of the pure vitamin. In December, 1947, the substance was tried on the first patient and termed successful.

Over twenty-five hundred technical papers have since been written about vitamin B_{12}. In addition to its original use in alleviating anemia it was found to be an important growth factor present in animal protein. Today farmers can supply this relatively cheaply by adding B_{12} to animal foods. Interestingly enough, the ultimate source of the vitamin came from an antibiotic Merck was testing for Dr. Waksman in connection with his work on streptomycin.

Bulk production of all vitamins has been a continuing business of New Jersey firms. Merck is responsible for a number, producing vitamins A, B_1, B_2, B_6, E, K, and, of course, B_{12}. In Nutley, scientists at Hoffman-La Roche Applied Research Laboratories have discovered ways to make synthetic vitamins in bulk at a cost less than it would take to produce the natural vitamins. In some cases the costs are so low that the compounds can be added to enrich food products and animal-feed supplements without significantly increasing the cost of the basic food.

In addition to applied research, Hoffman-La Roche conducts basic research in the area of synthesis of vitamins—C (ascorbic acid), B_1 (thiamine), B_2 (riboflavin), B_6 (pyridoxine), A and beta-carotene, E, and K. Research in vitamin A and beta-carotene has led to the development of synthetic aromatic compounds which are the synthetics used in perfumes, soaps, and toiletries and are better than the natural compounds because they can be standardized.

Medicine for the Nerves

The tranquilizer is the youngest child in the family of modern pharmaceuticals. Tranquilizers were first introduced to America in 1950 specifically for the control of high blood pressure. Within four years they accounted for 40 per cent of the increase in volume of prescriptions written in the United States. Moreover, since 1955 barbiturates and other "old-line" sedatives have slowed appreciably in sales growth, primarily because of the upsurge in tranquilizing drugs.

The first notable drug was Reserpine, made from Rauwolfia, or snakeroot. It had several deleterious side effects. Another early type was Atarax, made from a hydrochloric acid salt of hydrazine, which afforded relief from anxiety and tension. In 1953 the Ciba Pharmaceutical Company in Summit isolated the pure alkaloid from Rauwolfia to form the anti-hypertensive called Serpasil and coined the word "tranquilizer" because of its effect. As counterpoint, Ciba devised Ritalin—one of the first psychic energizers or "pep-up" drugs.

Ciba continues to work in the field of sedatives and stimulants. In 1961 it introduced Metopirone which tests a patient's probable response to stress—for example, to that of an impending operation. It has also made major discoveries in drugs for treating cardiovascular and related conditions.

Other New Jersey drug firms have made important contributions in the field of tranquilizers. Miltown—one of the best known tranquilizers—was developed by Carter Products' Wallace Laboratories in Cranbury. Warner-

Chilcott in Morris Plains developed Nardil as an antidepressant for moderate depression and Pacatal for more severe psychotic problems. In 1957 Schering introduced Trilafan, a "full range" tranquilizer—the amount of the dose can be adjusted to treat the slightly nervous or the deeply psychotic.

The Squibb Institute for Medical Research has evolved a program of coordination between the disciplines of psychopharmacology and neuropharmacology to study the effect of tranquilizers, energizers, and other stimulants to the brain and nervous systems. This is an appropriate follow-up and happy fruition of an early means of calming man's nerves; it was Dr. E. R. Squibb, the founder, who first introduced an anesthetic, ether, to the medical profession before the Civil War. Squibb came to New Jersey when its Biological Laboratories were established in New Brunswick in 1907. During World War I these laboratories developed an arsenical preparation for syphilis, preparation 606, to replace a similar German drug. The Institute for Medical Research was established in 1938.

Squibb pioneered in the development of curare products—the poisons used in the blow guns of South American Indians. Used in conjunction with other compounds, these are important adjuncts to modern anesthetics.

Facets of Drug Research

Much drug research involves realigning the structure of a molecule. The method by which this is done and the resulting effect on the organ or organism to be treated involve literally thousands of molecular arrangements, each one of which must be tested. There is little wonder at the need for research "teams" such as were involved in the search at Rutgers for streptomycin. For example, in 1959 the drug industry tested over one hundred thousand compounds. Two years later only 63 of these had become prescription drugs.*

* L. J. Sichel, *New Jersey Business,* October, 1961.

Pharmaceutical research has many other complexities and involves many scientific disciplines and methods: spectroscopy, gas chromatography, nuclear magnetic resonance, tracing with radioactive isotopes. The scientists in the field have become increasingly specialized, keeping up with the examination and evaluation of mountains of technical literature.

Finding a useful drug without harmful side effects is often only the first step in medical research. It may become necessary to find a way to produce the drug efficiently, either by natural or synthetic means. In some cases the production problem is one of quantity, as in the case of penicillin and many vitamins.

Quality control is of course of the utmost importance in drug production. Every possible care must be taken in the production of medical products. New Jersey drug companies conduct thorough and expensive programs for this purpose. As an example, Schering has a quality-control center in Union where 70 scientists and technicians perform thousands of tests every year.

Applied research in the drug laboratories has led to research of a more fundamental nature. Pharmaceutical research is increasingly concerned with reactions of the human body which are little understood. Studies on the correct dosage of antibiotics have led to questions about the character of micro-organisms and, further, to questions concerning the very nature of infection and how the body fights it.

Outside of drugs, New Jersey's contributions to medical research are not spectacular. Seton Hall University has the only medical school in the state; it was established in 1956. A two-year medical school has been proposed for Rutgers, to carry students to the level of the master's degree and prepare them for the third and fourth years in full-curriculum medical schools. Hospitals near New Brunswick will furnish facilities for diagnostic study.

Some medical research is conducted in New Jersey's colleges and hospitals. The grants and awards of the National Institutes of Health (NIH) to New Jersey organizations are a measure of the extent of this research. During 1962, for example, NIH made 211 research grants for nearly five million dollars out of a total of $372 million. During the same year NIH allocated funds to Rutgers and the New Jersey State Department of Health for the construction of medical research facilities and to several state agencies for various studies in control of diseases and health services.

The New Jersey State Department of Health carries on research in its Division of Laboratories. A typical project of recent years was the evaluation of techniques to determine the presence of rheumatic fever streptococci at an early stage in the disease to permit quick preventive treatment. Another program was the evaluation of new methods of testing for syphilis to reduce time and cost. In 1961 the State Health Department provided a grant-in-aid to the Child Guidance Center of Mercer County to carry out a research project involving the detection and control of diabetes in children. Following an outbreak of Eastern encephalitis in 1959, the Department initiated a coordinated study among the various state departments and Rutgers University to determine how the disease is spread by certain insects and migratory birds.

VI

THE MOLECULE MANIPULATORS

THE CHEMICAL INDUSTRY is so complex and far reaching in its technological applications that it is often difficult to determine where it leaves off and some other industry begins. Chemical research includes and transcends both its agricultural and pharmaceutical aspects, which were described in the last two chapters. It is intimately associated with engineering research, which will be described later. The fruits of chemistry not only feed man and keep him well; they clothe him, house him, transport him, and supply him with literally thousands of different products.

The role which small New Jersey plays in the chemical industry is even more astonishing than its roles in farming and drugs. New Jersey, with more than eight hundred chemical manufacturers, develops and produces over 60 per cent of all the chemicals used in the United States. The reasons for this are various. The state has long had a variety of industries which need and attract chemical firms. Also, chemical firms tend to attract one another. The industry requires large amounts of fresh water, and the streams and rivers and bays of New Jersey supply this in abundance. New York offers nearby markets in addition to those of New Jersey itself.

Of the several main divisions in chemical products petroleum is outstanding. Although New Jersey produces no crude oil, it ranks sixth in volume of refined petroleum. But crude oil is more than a source of energy and a lubricant, and petroleum research has gone far beyond the refining of oil for light and fuel. It now encompasses a wide field of petrochemicals, including plastics, synthetic fibers, synthetic rubber, paint solvents, detergents, and many others.

The oil industry came to New Jersey in 1875, when the Prentice Oil Company established the state's first refinery in Bayonne. This area, which was attractive for its convenient markets and transportation and for the great quantities of water which were needed in the refining process, soon attracted a number of other oil companies. Ocean Oil, Lombard Ayers and Co., Polar Oil, and John D. Rockefeller's Standard Oil, which came to Bayonne in 1877 and eventually took over Prentice Oil.

The growth of oil refining began with the building of oil pipelines between eastern New Jersey and Titusville, Pennsylvania, in 1879, only twenty years after Colonel Edwin Drake had drilled the world's first successful oil well in 1859. After some early corporate conflict, the various companies cooperated on pipeline transportation and settled down to produce oil in great quantities. Pipelines also were instrumental in keeping New Jersey in the oil refining business when the fields in the Southwest came into prominence. During World War II the Big and "Little Inch" pipelines carried oil from Texas and Oklahoma to the New Jersey refineries.

After 1900 new names appeared in the industry: Gulf Oil, Texas Company, and on the Delaware at Paulsboro, the Socony-Vacuum Company. In 1907 Standard Oil built its refinery at Bayway, where there was room to grow and where rail and deepwater transportation made an ideal eastern terminus for the pipelines. Although at the time the electric light was making huge inroads in the sales of kerosene, the infant automobile industry had already begun to increase the consumption of refined oil. Requirements arose for more complicated refining processes to serve the needs of the finicky internal combustion engine, and thus there came the need for an organized research program.

From its crude and untraceable beginnings to its most advanced forms, oil refining has depended on the control of time and temperature. This is true of both pyrolytic cracking and fractional distillation—the breaking down of the crude oil molecule and its division into the various forms of useful products.

Cracking uses catalysts—chemical agents which operate on the petroleum molecules in a way that leaves the catalysts unaffected. During the refining process the catalysts become contaminated with residues and must be cleaned periodically.

Like most processes, refining is more efficient when it can be continuous. E. V. Murphree led a team of researchers at the Standard Oil Development Company, which was set up in Bayway in 1919, in developing a "fluid" catalytic cracking process. They found that if the catalytic particles were small and were agitated by oil vapors, they would take on the characteristics of a fluid and thus periodically could be "flowed" through a cleaning process and back to the cracking area of refining with little time lost.

The "double coil" process came from the Standard Oil Development Company in 1920. In this process oil is heated rapidly to the necessary high cracking temperature in pipes which are exposed directly to the head of the furnace. The oil is then "soaked" or held at this high temperature for a period in which the pipe coils are exposed only to mild heating of the low-temperature combustion gases. In another "tube-and-tank" process a large digester or pressure tank takes the place of the low-temperature coil. These processes provide the time necessary for the cracking action to complete itself.

More than 70 per cent of the gasoline used in the world today has some elements in it that were refined by the fluid "cat" crackers.

No less important to the efficient refining of petroleum is the part played by fractional distillation. During the 1920's the various grades of petroleum were separated in a process that made a great deal of condensation and redistillation necessary. Batch "stills" were mounted in brick settings over a fire; the oil vapors passed through a series of air-cooled towers. The heavier components condensed partially while the lighter components condensed fully in a water-cooled worm or coil pipe. This meant the heavier elements then had to be redistilled, requiring several batteries of fractional stills for each crude oil still.

A chemical engineering consultant to Standard Development, Warren Lewis, designed a fractionating tower in the 1920's. In this tower, oil from a continuous cracking tube-still produces a constant stream of petroleum. The vapors go up a tall column containing numerous cooling "plates" which make the weight separation of the different components.

Beginning of Petrochemicals

One of the first departures from research in oil processing itself came early in the life of Standard Oil. During World War I the scientists produced for the first time an alcohol from olefins which were by-products of refining. The resulting compound was invaluable as wing dope for the aircraft of that era.

But what really established petroleum as a fountain of products was the advent of butyl rubber—one of the most versatile and widely used petrochemicals. In 1937 Standard Oil chemists W. J. Sparks and R. M. Thomas found that in an environment of extreme cold, 150 degrees below zero Fahrenheit, the molecules of petroleum gas form into a coiled chain of giant molecules when compounded with chemicals such as sulphur and carbon black. The result is butyl—a compound which is tough and flexible and applicable to many products.

The Development Company was organized as a separate affiliate of Standard Oil in 1927. In 1948 it became the Esso Research and Engineering Company and moved to its present location at Linden. The word "research" in the present title indicates what has been going on in the petroleum industry since World War II. For although the Linden Laboratory still is very much concerned with the problems of refining oil, it has an added concern for the other products of petroleum, forming the industry known as petrochemicals.

Across the state at Paulsboro is the Socony-Mobil Company, which settled there in 1917 as the Socony-Vacuum Oil Company and has since contributed a great deal to the development of the petroleum industry. The Paulsboro laboratories have helped improve catalytic cracking; there the first steps were taken that made it commercially practicable, and there, in 1928, a two-stage fractionating process was developed. These laboratories conduct research in refining processes and the development of new products (applied research and development) as well as give technical service to the Mobil refineries. In 1961 Paulsboro scientists produced a new catalyst, Durabead 5, which substantially increased the yield of high quality gasoline from crude oil.

One of the most fundamental achievements of oil research in recent years has come from Paulsboro. During the period from 1957 to 1961 Mobil mathematicians and chemists identified and isolated two portions of the chlorophyl molecule—pristane and phytane.

The Socony-Mobil research organization has seen a value in decentralizing. For Paulsboro is only one of six divisions (three of them in New Jersey) devoted to finding new uses for the oil molecule. At Princeton the Mobil Central Research Laboratories does fundamental and exploratory studies on petroleum. The Central Research Laboratories has access to a five-megawatt nuclear reactor at the Industrial Reactor Laboratories in nearby Plainsboro. Socony-Mobil is one of the ten major industries for which the reactor is operated.

At Metuchen the Mobil Chemical Company Research and Development Laboratory does basic research on long-range projects. The scientists there are searching for new catalysts and catalytic reactions. They are looking for new chemicals as well as new ways to make existing chemicals. They are studying chemonuclear reactions in the high neutron flux field of a nuclear reactor. And they are looking at fuel cells and other energy sources. In applied research and development Mobil engineers are studying problems of commercial runs in refineries. From their studies they are developing new types of fuels and lubricants and studying catalysts in the search for more efficient ways to synthesize petroleum products. They also are studying the relations between lubrication performance and the structure of the oil molecule.

The approach of Cities Service Research and Development Laboratories is somewhat different. In 1957 Cities Service set up a laboratory in Cranbury, New Jersey, halfway between New York City and Philadelphia, an area free from industrial and urban commotion and yet near livable communities. The laboratory can take advantage of these surroundings because its work does not involve the need for refineries. Scientists at Cranbury concern themselves with analytic chemical studies. They do physical testing of lubricating oils and greases, gasolines, fuel oils, and asphalt. They search for new polymers from which they hope to develop improved rubbers, plastics, paints, and inks. The scope of this activity by 1962 had widened with a budget of nine million dollars, well over twice the annual expenditures of five years before.

Plastics

In the value of plastic products manufactured in the United States, New Jersey ranks at least third. We have already seen how John Wesley Hyatt brought celluloid to Newark in 1882. The next notable contributions to the plastics industry began when the General Bakelite Company was formed at Perth Amboy in 1910. Leo H. Baekeland, a Belgian-born chemist, had received a patent for his plastic—a phenol-formaldehyde resin—in 1907. The new plastic was a synthetic product as compared to Hyatt's "natural" celluloid.

Baekeland's company became the Bakelite Corporation in 1922. In 1939 it joined Union Carbide and is now known as the Plastics Division. The Research and Development Department, which is part of the Bound Brook facility, conducts exploratory and applied investigations in organic, polymer, physical, physical-organic, inorganic, and analytical chemistry. In its research it uses the talents of physicists and chemical and mechanical engineers.

Highlights in plastics through the pre-war years include the auto safety glass developed by the Arlington Company, a division of the Du Pont Company, in 1921. (A sheet of clear pyralin plastic was put between two thin sheets of clear glass.) Arlington scientists also developed in 1943 the tetrafluoroethylene resin known as Teflon—the plastic which can "live" with human tissue and thus has found as one application important uses as compatible artificial parts of the human body.

World War II saw the birth of many new plastics. The Bakelite Company developed Vinylite for military uses. After the war this plastic found use in beach balls, raincoats, and swimming pool liners. Scientists at the Du Pont Chambers works discovered a synthetic camphor that proved to be a vital ingredient for both plastics and medicine.

Many of New Jersey's chemical houses conduct plastics research as part of their total programs. Allied Chemical, for example, devotes a great deal of its research and development to the plastics field. Most of these studies involve "intermediate" chemicals derived from petroleum. At the Central Research Laboratory in Morris

Township Allied chemists work in all phases of chemistry but place their emphasis on polymers—the big-chain molecules. At the Plastics Division in Morristown the Research Section studies new plastics, new families of plastics, and ways to improve existing plastics. The Development Section works out pilot plants to scale and perfects methods and equipment for commercial production of plastics.

Some organizations in New Jersey specialize in the plastics field. For example, the Hatco Chemical Company at Fords, a Division of W. R. Grace Corporation, has two hundred people working on plasticizers—compounds that make plastics pliable. Many plasticizers are made by a reaction of an acid with an alcohol to form a compound called an ester. Each ester is chosen according to its molecular structure so that it will be compatible with the desired resin—the organic substance for forming the basic part of the plastic. The choice of ester is also affected by costs. The most popular resin is a vinyl plastic, specifically polyvinyl chloride. The most-used (60 per cent of the United States total) plasticizer is made from phthalic anhydride.

Hatco's particular contribution to the field is a process using benzyl chloride as a starting material, which makes the plastics manufacturing process very economical. Hatco has also developed several polymeric esters which, when blended with other plasticizers, eliminate the brittleness in many vinyl products.

American Cyanamid (when it was the Calco Chemical Company) was responsible for the development of amino- and urea-formaldehyde resins. Today the Bound Brook Laboratory is still exploring the world of plastics with emphasis on additives. It is also heavily involved in textile chemicals, intermediate chemicals, rubber chemicals, and elastomers.

Some of New Jersey's most important work in the field of plastics has come from the chemical department of Bell Telephone Laboratories at Murray Hill. There, chemists have a continuing program which has led to the development of new plastics such as polyethylene and polypropylene. The Bell System is a leading user of plastic cable sheath, of coated wires insulated with colored plastics, and of colored plastics for telephone sets.

An important part of the Bell Laboratories development work involves a long-rang environmental testing program to see how well the plastic compounds hold up, both above and below ground. Scientists have developed anti-oxidants which increase the life expectancy of wire- or cable-coatings 20 times or more.

Synthetic Rubber

Modern synthetic rubber technology is another outgrowth of petroleum chemistry because, like the oil molecule, the rubber molecule is a hydrocarbon—an arrangement of carbon and hydrogen atoms.

The work at the United States Rubber Research Center in Wayne attests to the close alliance between rubber and plastics. One of the big projects over the last ten years has been in elastomer chemistry, particularly that of polyurethanes. This has led to developments such as polyurethane-solid tires, automobile dashboard pads, and certain types of molded sponges. J. A. Batz, A. N. Meyer and other chemists developed a microporous rubber separator for storage battery cells. U. S. Rubber's research has made the company the largest producer of rubber chemicals.

Yet U. S. Rubber is very much in plastics. Its Kralastic was developed for missile nose cones, and its earth-bound achievements include plastic pipe and plastic hulls for boats. From the theoretical side of these laboratories, from the physicists and mathematicians, has come knowledge of how to produce Lamiflo, a coating that reduces the drag on boats or planes.

Ciba has research laboratories working on epoxy resins at Toms River in Ocean County. A good deal of the research done at the Celanese Research Laboratories in Summit is in the field of plastics. Celanese originally gained fame as a textile manufacturer but went into chemicals to assure itself an adequate and independent supply of acetic acid, acetic anhydride, and acetone—compounds needed to turn cellulose into acetate fiber.

Cellulose is the main concern of Rayonier Laboratories at Whippany, New Jersey. Cellulose is a "natural" polymer. In nature many individual microscopic cellulose units polymerize with each other to form the skeletal structure of all plant life. Rayonier's research program in the field of wood chemistry is the largest in the world. Scientists at the Whippany Laboratories study tree genetics. For example, they inject young pine trees with radioactive carbon 14, a tracer that helps them learn about tree growth. The ultimate interest is in the conversion of cellulose to fibers, film, and other wood derivatives.

Organic to Inorganic

Important research in organic chemistry at Princeton University includes work on the steroids which helped pave the way for synthetic production of hormones and cortisone. In allied work Princeton chemists have contributed to knowledge of carbohydrates and chemistry of the amino acids.

Electrochemical research at Princeton University has resulted in useful new methods of chemical analysis. Princeton chemists have also developed the processes of electrodeposition, electrotitration, polarography, and coulometry. In addition, important work has been done on dipole moments and the dielectric behavior of various oxides and halides.

In the early 1930's chemists at Princeton University evolved new theories on the rate at which chemical processes take place. These theories included the concept of "chemisorption" and aided in the understanding of such physical processes as viscosity and diffusion.

Bell Laboratories chemists have made important contributions to a variety of electronic components. Several years ago, for example, they proposed using the DuPont-developed Mylar in capacitors if the substance could be made uniform enough and encouraged DuPont to develop a uniform process. They also developed a capacitor with a solid electrolyte—the tantalum electrolytic capacitor.

The spectacular growth of solid-state technology would not have been possible without modern techniques for growing and refining crystals. Chemical research at Bell Laboratories has played a large part in obtaining ultra-pure semiconductors. One of the most common methods used in growing silicon and germanium for semiconductors is a crystal "pulling" technique recently used in growing crystals for microwave and optical masers (lasers). Another technique, developed at Bell Laboratories, is that of flux growing which has led, for example, to large single crystals of barium titantate, an important ferroelectric crystal. Fluxes are also used in the growth of the electronically efficient ferromagnetic crystal yttrium iron garnet, or YIG.

Quartz, a piezoelectric crystal, is indispensable to modern electronics. It is used in great quantities for filters, oscillators, and frequency standards. In the late 1950's Bell Laboratories chemists, working with Western Electric engineers, developed a high-volume growing technique for synthetic quartz which not only produces the crystals in the quantities needed but also produces them in a more nearly perfect form.

In the refining of crystals the most noteworthy contribution is "zone refining," developed by William Pfann at Murray Hill in the early 1950's. His technique involves "sweeping" a molten zone through an ingot of a material, such as germanium, so that the impurities pile up at one end and can be cropped off. This reduces impurities in the rest of the rod to as little as one part in ten million.

Development of Explosives

A more volatile chemistry for which New Jersey is well known is that of explosives. The Du Pont Repauno dynamite plant built at Gibbstown, Salem County, in 1902 is one of the earliest research laboratories in the United States. This New Jersey Laboratory began with five chemists who moved across the river from Wilmington, Delaware, with two small cases of glassware, a few chemicals, and a microscope. Gunpowder and explosives started the Du Pont Company, but in the early twentieth century it began to develop what has become a great research program in paints and finishes, dyes and pigments, acids and heavy chemicals, plastics and coated textiles. In 1912 the explosives company was divided by an antitrust decree into Du Pont, Hercules Powder, and Atlas Powder. Du Pont at Gibbstown, Hercules at Kenvil, and the Picatinny Arsenal at Dover were primarily responsible for New Jersey's role as chief munitions-making state during World War I.

The first industry in New Jersey concerned with high explosives (discounting the powder mills of the Revolution) was the United States Blasting Oil Company, which built a factory in Little Ferry in 1866, the same year Alfred Nobel invented dynamite. The Giant Powder Company of San Francisco in 1871 set up an eastern branch at Kenvil to fill the requirements of the local iron mines. About the same time the American Forcite Powder Company settled at the southern end of Lake Hopatcong, where it produced its concentrated, low-fuming, water-resistant gelatin dynamite called "forcite."

In 1890 Hudson Maxim began to experiment with smokeless powder at Farmingdale, developing the first multi-perforated grain, which he perfected around the turn of the century. He also invented "stabilite," a smokeless powder that required no drying. Meanwhile, at Gibbstown Du Pont was developing potent products such as low-freezing dynamite. In 1909 this factory perfected the first American trinitrotoluene: TNT.

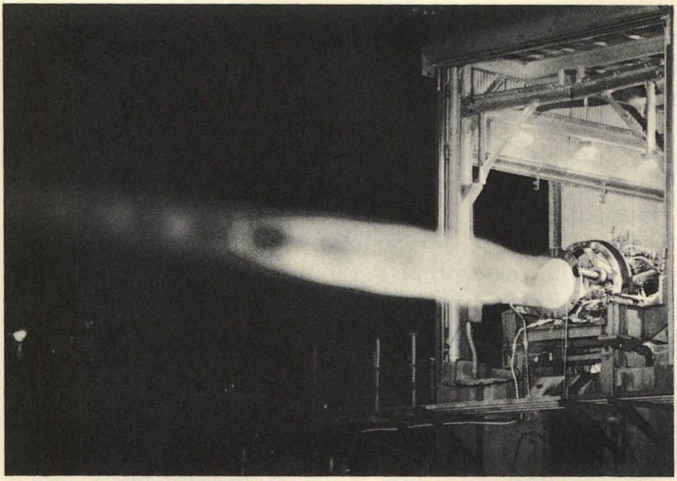
In 1879 the U. S. Army built, near Dover, a powder depot which was to become the Army's first powder factory. The U. S. Army defines Picatinny today as a "Class II field installation of the Army Ordnance Corps." It is concerned with the research and engineering of military propellants and explosives for Army weapons and with the adaptation of nuclear and non-nuclear warheads for missiles.

The Picatinny site near Dover was chosen for the rather grim reason that the mountain ridges cupping the valley would protect the surrounding countryside in case the arsenal someday disappeared in a cloud of smoke. Also, this area is near the large amounts of water required for this type of chemistry.

Because its research and engineering is devoted primarily to advice to private industry on how to manufacture ordnance, Picatinny is strong on pilot plant design. Yet civilian researchers—chemists, engineers physicists, and statisticians—are hard at work on specific projects at the Arsenal, using such tools as an electron microscope, a mass spectrometer, or a gamma-ray spectrometer. The laboratory uses high speed photo equipment to study projectiles "frozen" in flight. Picatinny also has a 25-million volt Betatron which can with its X-rays penetrate 24 inches of steel, permitting the study of the internal structure of all types of shells and projectiles.

At Kenvil the Hercules Powder Company built the second dynamite plant in the United States. Kenvil produced the first United States "cordite" during the first World War; during the second war it produced the bazooka rocket. In 1947 Hercules established the first pilot line to produce cast solid propellant charges and is continuing this research as part of its contribution to rocket propulsion.

Meanwhile, at Parlin, Hercules is working on chemistry of a less belligerent nature. Here research has centered on nitrocellulose since 1915 the basic ingredient in the manufacture of lacquer, photo film, and plastics. Also from this Hercules laboratory has come a chlorinated



Static firing test of XLR99 rocket engine developed at Reaction Motors Division of Thiokol in Denville
Courtesy of Thiokol Chemical Corporation

rubber which is a base for acid and alkali resistant paints. Another product is a chlorinated polyester thermoplastic for corrosion-resistant applications. The Parlin plant is noted for its work in polyolefin chemistry from which is derived polyethylene and polypropylene plastics.

At Rocky Hill, near Princeton, a Hercules plant has developed a filament-wound structure made of resin-bonded glass fibers. It is used in lightweight containers for corrosive liquids and for structural cases in solid-fuel rockets, commercial pipe, and electric circuit breakers. Rocky Hill also produces molded and extruded thermoplastics.

The work of Hercules in rocket propulsion is supplemented in New Jersey by that of another firm—Thiokol Corporation, which oddly enough started out as a rubber producer. In 1929, in Trenton, Thiokol developed the first American synthetic rubber, a polysulfide polymer whose primary uses today are as a seal in jet aircraft openings, as curtain walls in buildings, and as seals in boats and automobiles. The real activity with synthetic rubber started in 1938 when Thiokol began to build up its staff at Trenton. In 1943 it announced creation of a liquid polymer, a polysulfide rubber, that has been used in the Minuteman rocket and in the retro-rockets on the Mercury capsules.

Thiokol has been in the vanguard of the effort to use solid fuel for space vehicles. Before 1953 it stood alone on its insistence that solid fuels were preferable for their simplicity and almost 100 per cent reliability. Thiokol became interested in solid fuel in 1946 when the Jet Propulsion Laboratory in California discovered liquid polysulfide rubber to be a potential fuel for solid-propellant rockets. Actually this polymer is both a fuel and a binder which adheres to the walls of the rocket shell.

Thiokol's space research also includes liquid propellant work; it has designed motors for the Bell X-1, the Douglas D-558, and the Republic XF-91 rocket airplanes. Today at Denville the Reaction Motors division is building engines for the X-15. Liquid-fueled engines are not passé for rocket propulsion—primarily because of the very important advantage that they can be turned off and on again.

Paint Chemistry

Another area of commerce in which chemistry has played a part in helping New Jersey lead the nation is paint. Not only is New Jersey number one in the United States in value of the product shipped, but it also leads in the number of plants and the number of people at work producing paint.

The nineteenth-century story of paint is a story of chicanery: manufacturers making paints and lacquers as cheaply as possible and charging as much as the traffic would bear. As a result, people who wanted really good products imported them.

The advent of the auto industry marks the beginning of the modern paint industry in the United States. The heralded production lines of the auto makers were slowed to a crawl by the paint shops. It took a week to dry each coat of paint on the cheapest models, a month on the more expensive ones. Other industries using paint and lacquer as part of assembly-line techniques had similar problems.

A scientific accident was responsible for changing this situation. As early as 1905 chemists had derived pyroxylin lacquers from cellulose. These had been used for paint but were not practical for covering an auto body. Then in 1920 Du Pont chemists at Parlin discovered a thin syrupy liquid in the bottom of a barrel of newly formed cellulose which was being tested for motion picture film. It became the liquid basis for a new paint. Three years of development yielded "Duco," a pyroxylin lacquer that was to solve the auto paint problem. Duco was durable and quick drying and permitted a wide choice of colors.

A more modern example of paint research is the development by chemists at the National Lead Company in Sayreville of economic production of titanium dioxide as a pigment for white paint. Besides being whiter and a better cover than lead-based white paints, titanium dioxide is nonpoisonous.

Industrial Chemicals

Another important segment of New Jersey chemical production is the dyes and the dyestuffs that are a basic need in producing synthetic chemicals. During World War I, when the United States was deprived of its German supply, the Calco Company learned how to make aniline oil, which is basic to dyestuffs. Today many chemical companies such as American Cyanamid and Ciba devote part of their research to this "chemical of chemistry."

Products and Processes

Consumer products in the chemical field tend to become obsolete rather quickly. Perhaps this is why the most notable trend in modern chemical research is the one towards new-products research. During 1961, for example, Allied Chemical reported expenditures of 22 million dollars on research; half devoted to present products, the other half to the search for new ones.

Much of the research carried on by Du Pont in New Jersey is aimed at discovering new knowledge about new products and processes. These programs are entirely separate from those devoted to improving existing products, and about half of Du Pont's research budget is estimated to go for this purpose.

FMC Corporation operates a Research and Development Center near Princeton which spends part of its effort investigating new fields and products and finding new uses for the products the company already produces. FMC also explores ways to make a product most efficiently. A typical example of the worth of this project is its production of Dimazine®, unsymmetrical dimethylhydrazine used as a rocket fuel. FMC Process Development and Product Services engineers sharply reduced the cost of producing this chemical.

The trend is common. Hercules also devotes half its research budget to new products and product applications. Esso defines its chemical research as "seeking new knowledge in an effort to find new and better ways to make new and better products from petroleum." And as Union Carbide puts it, "the primary reason for research is to maintain and improve competitive position in a world where performance depends on technical competence."

VII

THE SCIENCE OF MATTER AND MOTION

MOST SCIENTIFIC and technological research today could not exist without the fundamental knowledge which has been provided by the study of physics and mathematics. Chemistry, communications, the aerospace field, and the field of nuclear energy are founded on natural principles which the physicist and the mathematician have discovered, explained and to some degree shown how to control. The study of materials such as semiconductors and ferrites and the study of the nucleus of the atom have formed an important part of the research of New Jersey.

Research in semiconductors, materials whose electrical properties lie between those of the metals and the insulators, although considered part of modern physics, actually dates back to the nineteenth century. By 1885 four fundamental properties of semiconductors had been observed: negative temperature coefficient of resistance, rectification, photoconductivity, and photoelectromotive force. In 1904 a semiconductor diode was proposed for use as a radio detector, but vacuum-tube diodes were to perform that task for many decades.

During the 1930's work in semiconductors expanded and physicists began to learn much about the properties of the materials—both body and surface "effects." Particularly, the new quantum mechanics showed that electrons could travel through solids only if they had energies lying in certain ranges or "energy bands."

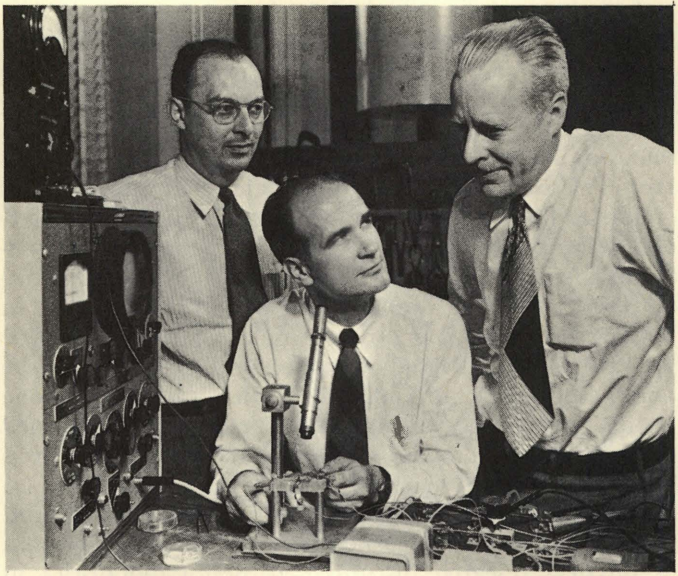
As radio engineers reached for higher frequencies during the 1930's they discovered that it was hard to make vacuum-tube detectors that would function well in the microwave range, and the performance of the best vacuum-tube detectors was much poorer than at lower frequencies. About 1935 Russell Ohl at Bell Laboratories in Holmdel tried silicon detectors, which had been used in crystal radio receivers years before, as microwave detectors. He turned to the chemical and metallurgical departments for help in getting purer silicon. Improved silicon detectors using the purer silicon played a large part in making feasible the microwave radar of World War II. In 1940 Ohl discovered that electrical energy could be obtained from a chunk of silicon when a light was shone on it. The voltage was much higher than that obtained from existing photovoltaic devices, and the material was much simpler to prepare.

Here was a clue to a novel physical phenomenon. And much more was to be learned from an intensive program of physical research instituted at Bell Laboratories in 1946 under the leadership of William Shockley and S. O. Morgan.

Quantum mechanics had brought a new but as yet incomplete understanding of semiconductor phenomena. Shockley and John Bardeen, who worked with him, were both able theoretical physicists, capable of applying this new knowledge in planning and interpreting experiments. Walter Brattain, who with Shockley and Bardeen received the Nobel Prize in 1956 for the discovery of the transistor effect, was an able and ingenious experimental physicist with a keen insight.

In 1947 the work of these men led to a low-frequency amplifier using silicon and an electrolyte. Bardeen then suggested switching from silicon to germanium and the continued experiments led shortly afterwards to the announcement of the observation of the "transistor effect" and the production of a potentially useful amplifier.

The transistor effect requires that both negative current carriers, electrons, and positive current carriers,



Nobel Prize winners, Drs. John Bardeen, William Shockley, and Walter H. Brattain, 1948
Courtesy of Bell Telephone Laboratories

called "holes," exist in the *same* semiconductor. Whether a semiconductor such as silicon or germanium is n-type (excess electrons) or p-type (excess holes) depends on extremely minute fractions of various impurities. By adding impurities near the surface a layer of p-type semiconductor can be produced on an n-type semiconductor. The boundary is called a "p-n junction." When current flows across such a junction, holes will be injected from the p-type region into the n-type region.

If a thin n-type region exists between two p-type regions, holes can flow right through it, and it can be used to control the flow of holes, just as a grid controls the flow of electrons in a vacuum-tube amplifier.

Transistors and their progeny have wrought many changes in electronic equipment. Because of their small size and because they use little power and produce little heat, they can be packed close together. Thus, they make possible very compact devices. Today transistors and related semiconductor devices are used in virtually every sort of electronic apparatus, from pocket radios to earth satellites.

The transistor effect, and the production of p-n junctions in very pure silicon, led to another important invention, an advance on Ohl's production of electricity from light. This was the solar battery, an important semiconductor contribution to space communications—and to all satellite vehicles for that matter. In 1954 a team of Bell Laboratories scientists at Murray Hill, G. L. Pearson, D. M. Chapin, and C. S. Fuller, announced that they had built a device to convert the sun's rays directly and efficiently into useful amounts of electricity.

Physical research on magnetic materials has contributed a great deal to the technology of communications. One of the first important confirmations of magnetic theory was made in the late 1940's when Bell Laboratories physicists at Murray Hill proved experimentally that magnetic "domains" actually exist in certain materials. A domain is a small region which is fully magnetized in a particular direction. Usually the direction of magnetization is different for different domains so that the net magnetization in a material is zero. When the material is magnetized (as when a magnetic field is applied) the walls of these domains move so that some domains grow, others shrink, and the net result is magnetization of the material in the direction of the applied field.

Research on ferrites has been particularly important to communications. Ferrites are a class of magnetic oxides whose electrical properties resemble insulators and whose magnetic properties are similar to ferromagnetic materials such as iron and cobalt. Physicists at Murray Hill have been responsible for studies leading to the understanding of the magnetic properties of ferrites, especially at microwave frequencies, and they have found that even the electrical losses in these materials can serve a useful purpose.

About 1950 C. L. Hogan produced a microwave circuit element called a gyrator by using pieces of ferrite in a waveguide cavity. This device led to a whole new class of devices for use in microwave technology. Their peculiar properties are indicated by the fact that one of them, the isolator, transmits microwave signals freely in one direction but absorbs them in the other.

Bell Laboratories research has been responsible for the study and use of a very valuable class of magnetic materials, the garnets. Particularly, yttrium iron garnet or YIG is well suited to microwave use.

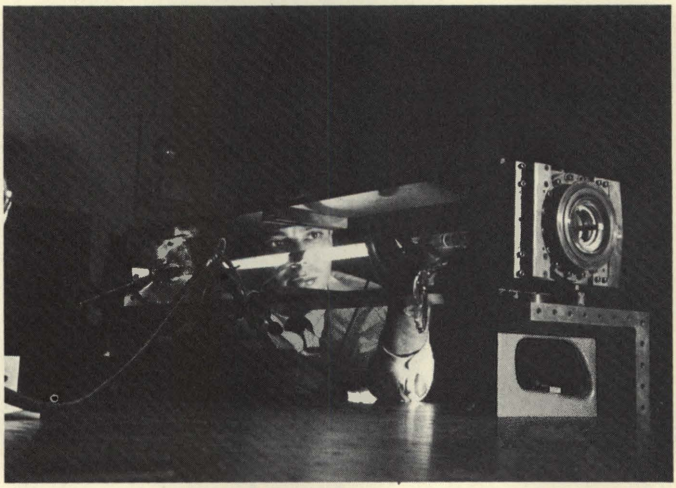
Work on the microwave properties of ferrites was important in early work on parametric amplifiers—one of the two most important low-noise microwave amplifiers in use today. But practical microwave parametric amplifiers make use of p-n junctions in germanium or silicon, and so are another result of the discovery of the transistor effect.

Research in another field, microwave spectroscopy, led Charles Townes to invent the ammonia maser, a new microwave oscillator and amplifier. Townes had started his work on molecular spectroscopy at Bell Laboratories, but he was a professor at Columbia University at the time of his invention.

When a maser amplifies a signal, it adds practically no noise to it. The three-level, solid-state maser amplifier proposed by Nicholas Bloembergen of Harvard was first built at Bell Laboratories in Murray Hill by H. E. D. Scovil, G. Feher, and H. Seidel. A traveling wave structure using a ruby crystal as the active material was the primary receiver amplifier used in the Echo experiment. A similar device is used in the Andover receiver to amplify extremely weak signals received from the TELSTAR, RELAY, and SYNCOM communications satellites.

An extension of the maser principle to the optical portion of the electromagnetic frequency spectrum has resulted in the optical maser or laser. Proposed publicly by Charles Townes and Bell Laboratories' Arthur Schawlow in 1958, this device was first realized as a pulsed oscillator by Theodore Maiman at Hughes Aircraft in California. Maiman's oscillator made use of a synthetic ruby crystal. The first continuously operating gaseous optical maser (using a mixture of helium and neon in a quartz tube) was produced by a team of Bell Laboratories scientists at Murray Hill—Ali Javan, William Bennett, and Donald Herriott.

The laser's prime advantage lies in its ability to generate "coherent" single-frequency light waves that are like the waves produced by a radio transmitter rather than like the fluctuating mixture of frequencies produced by an incandescent lamp. It may some day be possible to transmit enormous quantities of communications—telephone, data, radio and television—over a light beam producer by a laser, and lasers can be used to amplify the signals they produce. Outside of the field of commu-



Bell Laboratories' Ali Javan adjusts first operating model of gaseous optical maser

Courtesy of Bell Telephone Laboratories

nications, the laser, because it provides an extremely narrow and high powered beam, has potential applications ranging from eye surgery to micro-welding and machining.

The phenomenon of superconductivity–the lack of electrical resistance in a wire made of certain metals held at very low temperatures (near absolute zero)—has been known to scientists for many years. But only in recent years have they known of materials that are superconducting at relatively high temperatures, as high as 18 degrees above absolute zero. Bell Laboratories' Berndt Matthias formulated an empirical rule for predicting potential superconductors. One of these high-transition temperature materials–niobium tin—was announced by Matthias and his colleagues at Murray Hill in 1954. Metallurgists thereafter demonstrated the feasibility of producing extremely high magnetic fields with a superconducting solenoid using niobium tin wire. High fields are useful for extending the operation of masers and traveling wave tubes to higher frequencies, for the containment of thermonuclear fusion plasmas for the production of electric power, and for general research in the physical laboratory.

A research tool of inestimable importance to physics, chemistry, metallurgy, and many of the biological sciences is the electron microscope. With much greater resolving power than the light microscope, the electron microscope permits studies of basic molecular structures. It has led to the development of new materials for space exploration, synthetic fibers and plastics, solid-state devices, and has been instrumental in the discovery of a host of viruses and bacterial structures.

The first important work on the electron microscope was done in Germany in the early 1930's. Later Canadian researchers, chief among them James Hillier, entered the race to perfect the instrument. In 1940 Hillier came to Radio Corporation of America in Camden through the influence of Vladimir K. Zworykin. Taking advantage of new advances in power supplies and high-speed evacuating equipment, Hillier and A. W. Vance constructed the first commercially practical electron microscope in the United States that same year.

Research in physics at Princeton University started with Joseph Henry's work in induced electric currents in the 1830's. One of the first significant physical discoveries in the twentieth century at Princeton was made by O. W. Richardson in the early twentieth century. This English physicist taught at Princeton between 1906 and 1913, and during this time he formulated most of his ideas concerning the emission of electrons from hot bodies. The effect, which he named "thermionics," is the basis for the operation of all vacuum tubes.

Karl Compton, known for his long tenure as president and chairman of Massachusetts Institute of Technology, taught physics at Princeton from 1915 until 1930. While there, he conducted important experiments in the field of ionized gases. He also did work in spectroscopy in the extreme ultraviolet portion of the electromagnetic frequency spectrum and is credited with important contributions to photoelectricity. Compton was awarded the Rumford Medal of the American Academy of Arts and Sciences for his work in spectroscopy and thermionic emission.

A major program in Princeton's Astronomy Department is one on high-altitude astronomy under the direction of Martin Schwarzchild. The program is called Stratoscope and is sponsored by the Office of Naval Research, the National Science Foundation, and the National Aeronautics and Space Administration. During the first phase of Stratoscope, Schwarzchild supervised several balloon flights in Minnesota which lifted 12-inch solar telescopes into the stratosphere to take photographs of the sun's surface.

In 1963 the second phase of Stratoscope began to obtain high-definition photographs of planets, galaxies, globular clusters, and gaseous nebulae. The first balloon in this series carried a 36-inch telescope which was designed to obtain information on the water vapor and other compounds in the atmosphere on Mars.

A Princeton professor renowned for his eminence in mathematics is Solomon Lefschetz, who served on the faculty from 1925 to 1953. He was chairman of the Mathematics Department from 1945 until he retired. Lefschetz was a pioneer in developing algebraic geometry and topology.

A host of important names in the physical and mathematical sciences have been associated with the Institute for Advanced Study at Princeton. Some of the scientists have spent a short time there; others have stayed for decades. Men like Albert Einstein, of course, are instantly recognized as long-time participants. Although Einstein worked out his theories of relativity in Europe, his presence at the Institute had a great effect on others who studied there. While at the Institute, Einstein spent much time working on his unified field theory in which he hoped to find the link between electric, magnetic, and gravitational fields.

Oswald Veblen, a mathematician who contributed to geometrical and statistical mathematics, taught at Princeton University from 1905 to 1932 and did research at the Institute after 1932. Veblen was instrumental in persuading many important mathematicians to come to the Institute.

John Von Neumann, the Hungarian-born mathematician, was a scientist with a wide variety of interests and accomplishments. He worked on many problems in the fields of physics and engineering. Von Neumann's work in mathematics led to a variety of important concepts in mathematical logic and he contributed a great deal to the orderly mathematical formulation of quantum mechanics. He was at Princeton University from 1930 to 1933 and then shifted to the Institute for Advanced Study, where he remained until his death in 1957.

During World War II Von Neumann became interested in digital computers for solving problems concerning the atom bomb. He is generally credited with the idea of storing the program of a computer in the computer memory. Von Neumann designed or contributed to the design of several of the acronymous computers, including MANIAC (mathematical analyzer, numerical integrator, and computer) used in the development of the hydrogen bomb, ORDVAC (ORDnance Variable Automatic Computer), NORC (Naval Ordnance Research Computer), and the more familiar UNIVAC.

Von Neumann invented a branch of mathematics called "game theory" and his "minimax" theorem is of fundamental importance. Game theory has applications in the study of government operations and in sociology, and it has been applied to problems of military strategy and tactics.

A concept in basic physics which has had recent attention is the "many-body problem" which asks the question: "If there exists an atom at one place, what is the chance of finding another atom at another place?" The solution to this problem may completely describe the behavior of matter.

The world's first symposium on the "Many-Body Problem" was held at Stevens Institute of Technology in 1957. A Stevens physics professor, George Yevick, and a Stevens consultant, Jerome Percus, have developed a mathematical equation to describe the problem. The equation has been quite successful in explaining the properties of liquids and is being applied to solids and plasmas.

However important other branches of physics may be, many people think of physicists principally in connection with atom bombs and nuclear energy. New Jersey's first "discovery" in nuclear science may have been the production of pellets of pure uranium in 1922 by scientists at Westinghouse Electric's lamp division in Bloomfield, who were looking for better materials for lamp filaments.

Accelerators, which give protons, electrons and other charged particles enough energy to smash the nuclei of atoms, are a chief tool of nuclear physicists. In 1929 Professor Robert J. Van de Graaff of Princeton University invented the high voltage generator which bears his name. Today the Van de Graaff generator is the most widely used type low-energy accelerator in the world. In

1934 Princeton built a 400,000 electron volt particle accelerator and in 1935 built an 8 MEV (million electron volt) proton "cyclotron." Still being used and operated today by the Atomic Energy Commission, this accelerator has been modified to produce 19 MEV particles.

The production of high-energy particles by means of accelerators led to a new appreciation of the complexity of matter. In the nineteenth century matter was thought to be composed of irreducible chemical elements. In the early 1930's the atoms of these elements were shown to be made up of nuclei containing varying numbers of protons and neutrons, around which revolved a swarm of electrons. Chemical reactions, such as burning or rusting, affect only the outer swarm of electrons. Nuclear reactions, including the A-bomb and the H-bomb, involve splitting or fusing of nuclei.

As tools became more powerful and sophisticated, bombardment of atomic nuclei was found to produce, not only neutrons, protons and electrons, but a host of "fundamental" particles, many of which upon examination indicated that others were hiding in some form. The discovery of these particles (over 30 are now known) has caused physicists to throw out the old theories and search for new ones. As J. Robert Oppenheimer puts it, the physicist was left "with vast jumbles of new numbers, all with an insulting lack of obvious meaning." *

To obviate the insult, particle accelerators (atom smashers) have come into more general use. Proper study of the elementary particles of the atom requires accelerating them to enormous speeds and making them collide, splitting off the short-lived particles which constitute the atom. With luck, these then may be discovered and measured.

At Princeton University most of the research in nuclear physics is done at the James Forrestal Research Center. Part of this Center consists of the Princeton-Pennsylvania Accelerator Laboratory, built by the Atomic Energy

* Dael Wolfe (ed.), *Symposium On Basic Research* (Washington, D. C.), 1959.

Commission, managed by both universities and dedicated to the study of fundamental particles. The accelerator, or proton synchrotron as it is also called, produces a stream of high-energy protons, accelerates them to nearly the speed of light, and bounces them off a special target, such as beryllium, to produce secondary particles called "mesons." Magnetic lenses collect these mesons and focus them on various other targets and detecting devices, bubble chambers, liquid hydrogen, parallel plate spark chambers, which may capture for an instant a fundamental particle about which little or nothing is known.

The proton is first obtained from "de-electroned" hydrogen formed by an electric arc, accelerated to 3 MEV in a Van de Graaff generator and then injected into the evacuated doughnut-shaped chamber of the accelerator where its energy is increased to three billion electron volts (3 BEV) and its speed approaches that of light. Entering at the rate of 20 bursts per second, the protons are confined in the circular chamber by a powerful electromagnet. As they circle the synchrotron, they receive their "push" from four complex "exciters" spaced at four points on the circular chamber. Side effects from the accelerator—neutrons, gamma rays, induced radioactivity—are absorbed by a 15-foot-thick concrete wall surrounding the entire synchrotron.

Another division of the James Forrestal Research Center at Princeton is the Plasma Physics Laboratory whose work, also sponsored by the Atomic Energy Commission, is on the problems of controlled thermonuclear fusion for the production of power.

Since 1951, in the United States and abroad, there have been efforts made to discover how to fuse ionized heavy hydrogen to helium by heating it to enormously high temperatures. The aim is to produce thermonuclear power in a controlled manner. This requires the use of high magnetic fields to confine the ionized gas and electromagnetic fields to add energy to it. Success in this program would permit tapping the enormous potential of the world's supply of water in which there is enough

Proton synchroton at the James Forrestal Research Center
Courtesy of James Forrestal Research Center

energy to satisfy one thousand times today's requirements for a million years. The fusion of heavy hydrogen has the great advantage that it would be practically free from radioactive waste. Alas, it appears that we are far, far, from achieving this attractive goal—but research persists, spurred on by scientific curiosity, lingering hope, and ample government funds.

To carry out the research, scientists at the Plasma Physics Laboratory have designed and built five "stellarators." Each of these devices consists of an evacuated continuous cylinder in which a gas such as hydrogen is heated by radio-frequency induction and held in the center of the cylinder by strong magnetic fields.

About a mile from the main site of the Research Center stands the largest stellarator in the world—the "C" stellarator. The "C" requires an enormous amount of energy to heat the hydrogen plasma and to produce the confining magnetic field by direct current generators. The main power, supplied by three motor generators, can produce a pulsed output for one second of 200 million watts.

The stellarator is so named because the temperature involved approaches that of the stars—it is a *stellar-*gener*ator*. Knowledge of nuclear fusion in plasmas first came from the study of the stars. This is why astrophysicists and astronomers, along with the physicists, mathematicians, and engineers are on this research team.

In a New Jersey establishment of its own the Atomic Energy Commission carries out fundamental studies of materials. In 1949 the AEC built the New Brunswick Laboratory which is today operated by a staff of about sixty federal employees. Activities there include performing complex analyses on nuclear and potential nuclear materials as well as the development of analytical methods for nuclear reactor materials. The Laboratory also performs these analyses for contractors to the AEC and for other industrial firms.

The choice of a nuclear fuel depends on its potential cost, purity, and isotopic composition; analysis of materials must consider all three. Thus, the New Brunswick Laboratory employs special and complex facilities where the high degree of accuracy requires physical as well as chemical methods of measurement. For example, an X-ray spectrometer helps determine, rapidly and non-destructively, what elements are present in a series of liquid or solid samples. Vacuum fusion or gas analysis apparatus helps determine the amount of oxygen and hydrogen expelled from a molten sample of uranium to an accuracy of one part in two million.

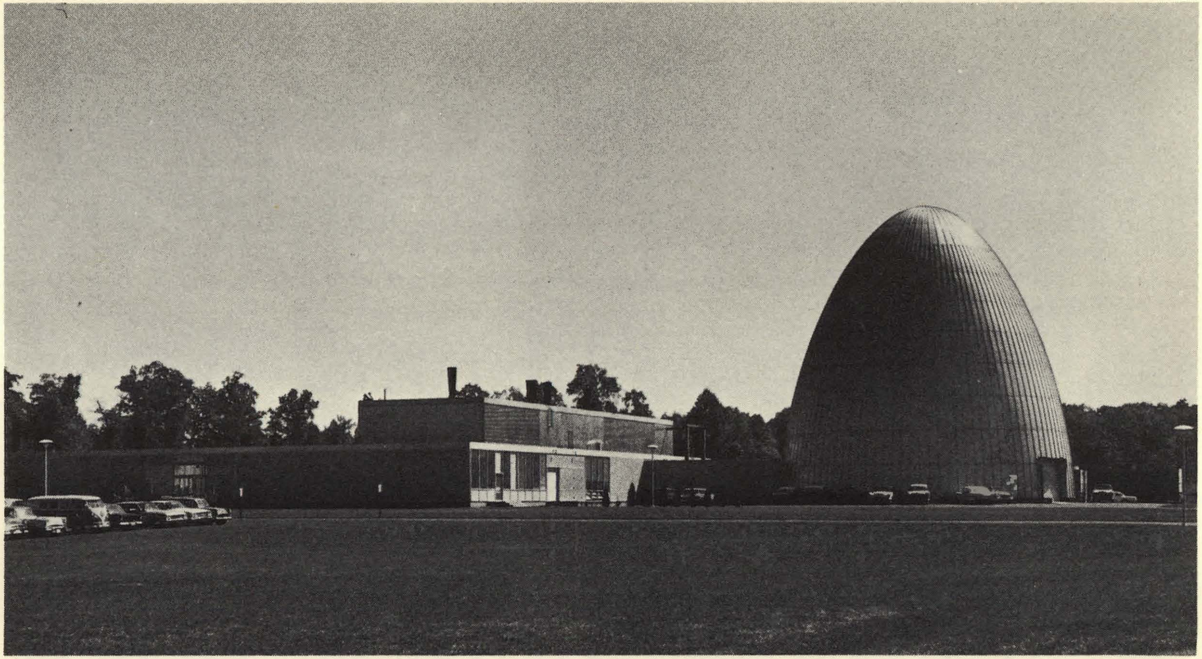
The Atomic Energy Commission sponsors a variety of research projects in New Jersey. The most recent figures show that it annually underwrites nearly a quarter of a million dollars' worth of bio-medical research and dispenses nearly two million dollars for research in the physical sciences. Many of the research contracts, in physics, chemistry, metallurgy, or genetics are carried out at Princeton, Rutgers, or Stevens Institute. But there are also contracts with smaller organizations—with Georgian Court College in Lakewood, for example, for studies of absorption spectra and conductibility in metal chelates. The New Jersey State Department of Health has received funds for studies of the effect of radium on the skin. And at Muhlenberg Hospital in Plainfield a research team under Dr. Jack Makari is studying techniques for localizing tumors with the help of AEC funds.

Atomic energy research does not always involve the AEC nor is it restricted to the university campus. More and more, private industry is becoming involved in studies of how to use the power of the atom. For example, the Esso Research Center in Linden has a small nuclear radiation laboratory in which chemists study the effect of radiation on catalysts, and they are also studying fuel cells and other power generators. The Cities Service Laboratory in Cranbury has a section that houses six stainless steel bars, each enclosing a half-pound of radioactive cobalt-60. These have a potency of two and one-half times the world's supply of radium. They are used by Cities Service in the study of the oil refining process and in the study of the effects of radiation on existing fuel and lubrication products.

But the best evidence that private industry is serious about putting the atom to work is the Industrial Reactor Laboratories, Incorporated, set up at Plainsboro. The five-million-watt reactor is operated by Columbia University for its ten equal-share owners: American Machine and Foundry, American Tobacco Company, Atlas Chemical Industries, Continental Can Company, Corning Glass Works, National Distillers and Chemical Corporation, National Lead Company, Radio Corporation of America, Socony-Mobil Oil Company, and the United States Rubber Company. The diversity of these industries indicates the many technologies and the thousands of products in which nuclear radiation can play a part.

The primary purpose of the reactor is to provide a source of neutrons, gamma rays, and radioactive isotopes for experimentation. Radiation techniques are used to study chemicals, including catalysts, petroleum additives, paint, plastic, and rubber; electronics, including radio and television components; and product areas such as tobacco, fibers, and metal alloys. Each owner-company maintains a separate research laboratory adjacent to the reactor building. Columbia University employs 50 permanent staff members who operate the reactor and perform other services for the companies.

The reactor is enclosed by an 87-foot-high "beehive" dome of 12-inch reinforced concrete covered with aluminum. Inside is a 30-foot-deep "swimming" pool filled with demineralized water which serves as a moderator, coolant, and shield for the chain reactions. There are several types of locations for inserting specimens to be studied or to conduct experiments using the radiation. For example, there are tubes extending from the core of the reactor through the vertical walls to the outside. There are horizontal "thermal" columns in which can be placed materials for "slow" reactions. And there is space in the water around the reactor and unused posi-



Industrial Reactor Laboratories at Plainsboro tions on the core grid plates where specimens can be irradiated. Facilities for gamma-ray research are set up outside the pool area, using the reactor fuel elements as the source of radiation.

Typical of the knowledge sought at Industrial Reactor Laboratories is radiation damage on materials in a nuclear environment. This is especially important if scientists are to find suitable materials for nuclear power plants. Radiation chemistry has added a new dimension to chemical reactions, joining the effects of temperature, pressure, and catalysts in making chemicals react. And in the physical world nuclear energy is invaluable in neutron scattering, diffraction work, decay studies on short-lived isotopes and other attempts to learn what goes on inside the atom.

VIII

RADIO COMMUNICATIONS

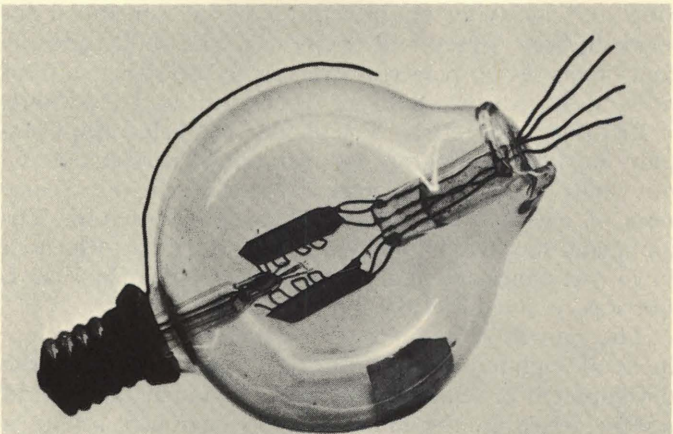
RESEARCH IN THE INDUSTRIES DESCRIBED in the previous three chapters is concerned primarily with the structure of the molecule—the arrangement of atoms representing the different elements and compounds. Science and technology are also vitally concerned with something on the periphery of the atom—the electron. For, the control of this tiny, mysterious, and elusive bit of nature has led to the vast industry of communications. Here too, the research laboratories of New Jersey are responsible for the discovery and development of a great many important concepts.

We have already seen how the telegraph was developed in a Morristown iron factory. And we know of Edison's contributions to telephony through the carbon transmitter. Moreover, both the Edison effect, and his "etheric force" were phenomena that were to lift communications off wires and send them through the skies. James Clerk Maxwell, an English theoretical physicist, had predicted the existence of radio waves but had not produced them. It remained for Heinrich Hertz in Germany to establish the existence of radio waves and for Guglielmo Marconi, excited by Hertz' experiments, to put together in England a crude transmitter and with it send telegraph signals over long distances. This set the stage for another important phase of technology in New Jersey.

In 1899 Marconi sent bulletins via his "radio" from Sandy Hook, New Jersey, to the offices of the *New York*

Herald to announce the results of the America's Cup race. Two years later the Publisher's Association brought the American inventor Lee De Forest from Chicago to New Jersey. De Forest set up similar equipment to transmit the results of the 1901 race. Atmospheric disturbances and the crudeness of the equipment kept these first commercial applications of radio from showing spectacular results.

In the early 1900's Sir John Ambrose Fleming in England invented the first electronic detector of radio waves. Like Edison, he noticed the "negative shadow" on the inside of incandescent lamps. But unlike Edison he indulged his curiosity, studied the fundamental causes, and found that putting a metal cylinder, or plate, around the negative filament of the bulb gave him a rectifier and modulator, not only of low-frequency alternating currents but also of the higher frequencies used in the then-infant radio. De Forest improved the operation of this device by putting a battery in the circuit with the plate-filament combination.



The audion of Lee De Forest, 1906
Courtesy of Bell Telephone Laboratories

Then, in 1906, De Forest, working in his New Jersey shop, added a zig-zag piece of platinum wire, which he called a grid, between the filament and plate of a vacuum-tube diode and turned the detector into an amplifier and a generator of radio waves. He named this first three-element thermionic tube the "audion."

The device revolutionized radio. George C. Southworth, in *Forty Years of Radio Research,* states that the audion's development as an amplifier, modulator, and oscillator made radio telephony (as distinguished from radio telegraphy) a reality. And, the amplification provided by the audion opened up a broader age of electronics extending far beyond radio.

Soon after Marconi's first experiments he improved his equipment enough so that ship-to-shore telegraphy could be made available, and by 1904, 32 ocean-going vessels were equipped with the Marconi wireless. The Marconi Wireless Telegraph Company of America, at Roselle near Westfield, was manufacturing standard receiving sets by 1913. During the next few years, demand for radio service led to intensive efforts to improve the transmitting and receiving equipment. Marconi continued his work in New Jersey and over the next two decades he and others set up powerful overseas transmitting stations at New Brunswick, Belmar, Tuckerton, and elsewhere.

In 1914 the American Telephone and Telegraph Company initiated a program for research in wireless telephony and the following year conducted the first voice tests of overseas transmission, between Arlington, Virginia, and the Canal Zone, Honolulu, and Paris. Research in long-distance telephony ceased during World War I, but was resumed in 1919.

The growth of radio was to depend on the development of high-powered transmitters concurrent with the development of sensitive receivers. Obviously both could not be tested in the same area. So engineers set up a radio station in Cliffwood, New Jersey, for the operation of low-power receivers, and a transmitting station at Deal

Beach. Three transmitting towers were built at Deal from which Bell System engineers conducted most of their early research at frequencies around one megacycle. Then in 1921 a minor economic depression caused an interruption of this work. Ship-to-shore telephony reappeared some years later after research had showed the feasibility of using higher frequencies for radio communications. Ship-to-shore telephone service was established commercially in 1929.

Transmission of intelligence through the air has always been intimately tied to the length of the electromagnetic waves which are used. Radio men discovered early that longer waves, and corresponding lower frequencies, would bend around the curved earth more easily than shorter waves. Fleming once estimated Marconi's first transatlantic transmission to be on a wavelength of at least 3000 feet, or a frequency of about 500,000 cycles per second (500 kilocycles). Early commercial transmission employed even lower frequencies, around 30 kilocycles. Frequencies around 500 kilocycles were reserved for ship-to-shore radio telegraphy because small and simple antennas had to be used aboard the ships, and because, for efficient operation, the antenna size must be increased in proportion to the wavelength.

Between 1910 and 1913 the United States Navy conducted tests on waves longer than 500 meters while other researchers were working in the area between 300 and 600 meters. Soon radio engineers began pushing into the higher portion of the frequency spectrum because of the crowding of the airwaves by increased radio traffic. And the research became concerned not only with ways to produce higher frequencies, but with how the shorter radio waves would propagate, or travel, through the air.

Many of the early propagation experiments were carried out in New Jersey. In 1925, for example, Bell System engineers carried out field intensity measurements at frequencies between 2.5 and 7 megacycles (million cycles per second) using a transmitting antenna at Deal. George

Southworth recalls traveling west with equipment in his Model-T Ford to measure periodically the strength of the signals as far away as the Ohio-Indiana border.

In the middle of the 1920's numerous investigations were made by researchers in New Jersey of "skip distances." In this phenomenon the ionosphere reflects shortwaves back to earth at a distant point in whose surrounding area there may be no appreciable signal. The distance varies with time of day or night and wavelength.

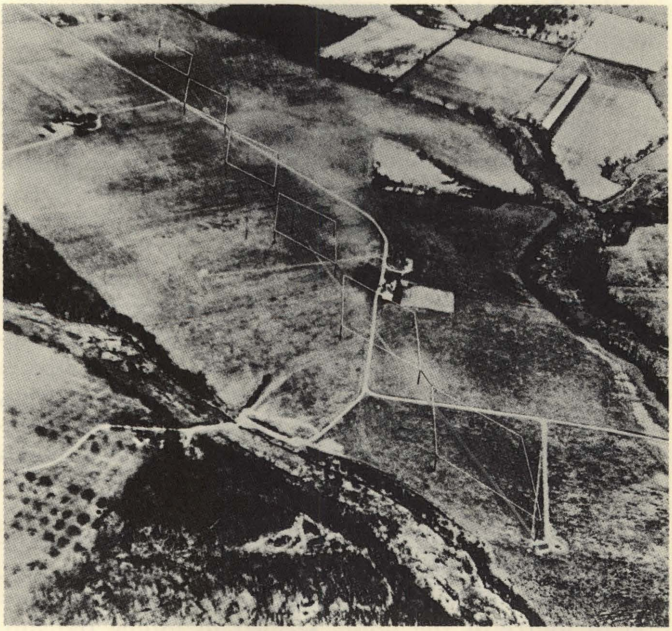
After 1924 it became apparent that the very long waves —around 10,000 meters—and the very short waves—around 100 meters—were both suitable for long-distance transmission.

The first two-way transatlantic commercial telephone system was opened between New York and London in 1927. This circuit used low-frequency waves (about 60 kilocycles) in both directions and provided usable commercial telephone service for several years. However, the transmission quality was often rather unsatisfactory, particularly in the direction from England to New York because of the static due to atmospheric conditions and variations in the earth's magnetic field.

This further stimulated communications engineers at Cliffwood and Deal to push to higher frequencies with studies of the different wavelengths. In June, 1928, successful experiments were carried out using a high frequency link from London to New York. These high frequencies or short waves came into commercial use between New York and London in June of 1929.

Concurrent with the development of transmitters and receivers for wireless communications was the development of suitable antennas. The earliest antennas were simply vertical wires; later versions resembled an inverted *L*. De Forest in 1901 proposed an antenna with a relatively short vertical arm. In 1904 he patented an antenna with a grid of vertical wires supported so as to rotate on a vertical axis. Designed to be used with both transmitter and receiver, it was one of the first directional antennas.

In 1929 there was built at Lawrenceville a wire "fence" a mile long with 185-foot-high towers. This comprised the transmitting antenna for the three circuits to Europe. In 1931 E. Bruce at Bell Laboratories in Holmdel (which replaced the Cliffwood Laboratory in 1929) published a description of an antenna made up of a series of four horizontal "radiators" set up in the shape of a rhombus. The idea was to limit transmission or reception to a small solid angle in the desired path. The rhombic antenna was particularly valuable because it could operate over a wide range of frequencies; the frequency could be changed to maintain good transmission as conditions of propagation changed with time. In the late 1930's an



An experimental directional antenna near Holmdel, in the 1930's

Courtesy of Bell Telephone Laboratories

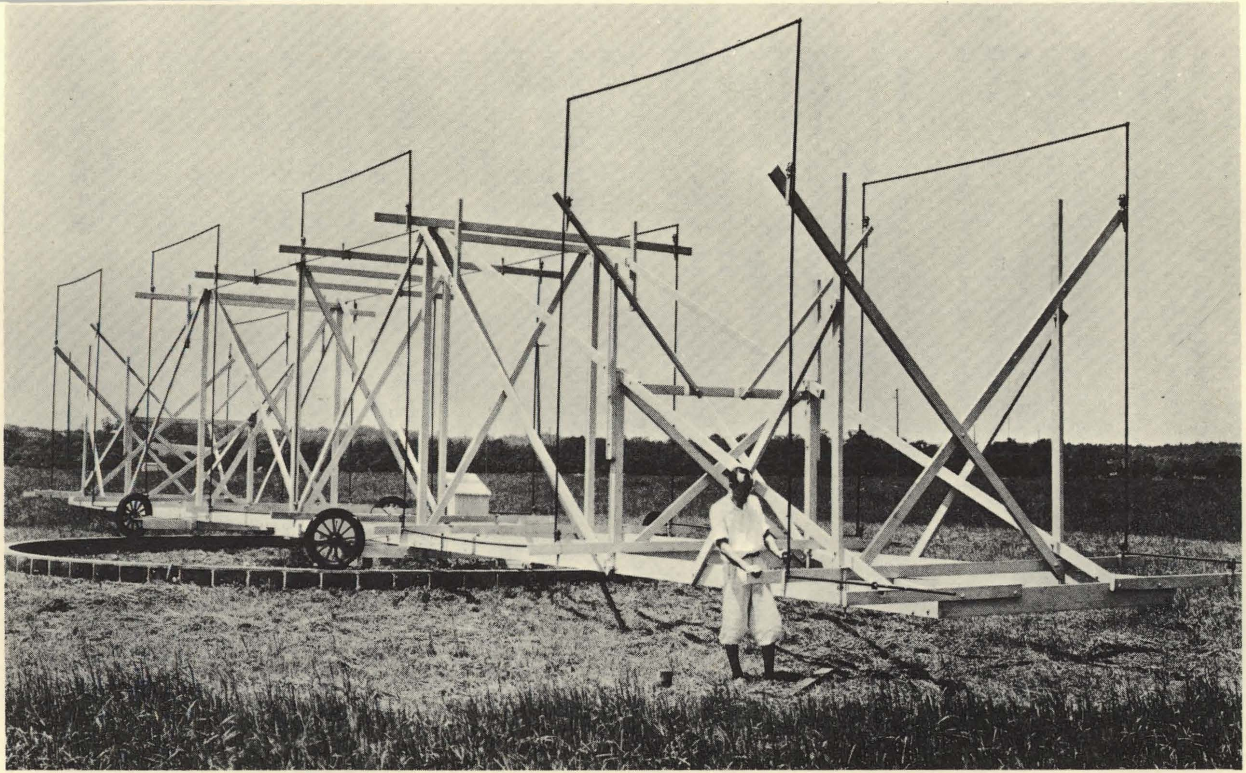
array of rhombic antennas replaced the broadside fence at Lawrenceville.

The receivers for overseas transmission were erected at Netcong and Barnegat Bay. A highly directional receiving antenna also came from research at Holmdel by Harold T. Friis and C. B. H. Feldman. This was the multiple unit steerable antenna, or MUSA. It consisted of several rhombic antennas interconnected in an adjustable manner. MUSA was designed to remedy fading and distortion in short-wave reception by responding strongly to signals coming from a particular direction. By varying the interconnections among the antennas the direction in which MUSA was most sensitive could be changed up or down and adjusted to coincide with the angle of the incoming waves which had been reflected to earth from the varying ionosphere.

One of the most spectacular radio experiments conducted at Bell Laboratories in Holmdel took place in the late 1920's when Karl Jansky was assigned the task of searching for the cause of a troublesome intermittent static that encumbered overseas radio. What Jansky found led to the establishment of a new fundamental science—radio astronomy.

Communications engineers had noticed less static interference with transmissions at shorter waves, so Jansky constructed a large rotary antenna for short-wave measurements. He did find less interference from the sources of trouble common to the long waves—thunderstorms, man-made interferences, noises in the receivers themselves—but he also noted a series of entirely new noises whose direction he recorded continuously for more than a year.

At first the sources appeared to have a diurnal variation, suggesting some relation to the motion of the sun. His reports of 1931 show that the variations in the direction of source of the noises seemed to follow the sun. As the months passed, however, it became obvious that this was no simple diurnal cycle—perhaps it was a seasonal one. But over the summer of 1931 the direction



Jansky's rotary antenna
Courtesy of Bell Telephone Laboratories

from which the signals entered the Holmdel antenna did not support this hypothesis either. By the following year Jansky realized that the effect followed sidereal time and that the noise must be coming from outside the solar system.

The data Jansky collected led to calculations that the radio waves were coming from the Milky Way—specifically from the star Cygnus. The source of interference found, Jansky turned to other problems. It wasn't until after World War II that radio astronomy came into its own.

In reaching for shorter and shorter waves to transmit on, radio research eventually came to the range known as microwaves. These extend from 30 centimeters to 1 millimeter (1 to 300 kilomegacycles in frequency). In 1931 Bell Laboratories' George Southworth began what is now internationally acclaimed work on the transmission of these waves through hollow pipes. Transmitting these waves had presented a problem. Radio, as ordinarily used, wasted energy because of lack of directivity, and the other alternative—coaxial cable—was not suited for the extremely short waves because of substantial electrical losses. Starting out in Netcong, a team under Southworth moved to Holmdel in 1934. Waveguide research engendered not only methods of getting radio waves to travel through the pipe but also resulted in the development of allied equipment—more intricate tuning components and new, highly directive antennas.

The Institute of Radio Engineers awarded Southworth the Morris Liebmann Memorial Prize in 1938 for his experiments. The citation read: "For his theoretical and experimental investigation of the propagation of ultra-high frequency waves through confined dielectric channels and the development of a technique for the generation and measurement of such waves."

A number of problems have beset the waveguide transmission program. But some of the components developed for high frequencies have been carried over into the research on microwave radio techniques carried out by others at Holmdel. For example, today the transcontinental microwave systems use highly directional antennas derived from work in waveguide at Holmdel prior to World War II.

During the 1930's a great deal of thought and technology went into the development of high-frequency radio, and experimental links of a microwave relay system were set up at Deal and at Holmdel. A system successfully developed for the Army some years later (during World War II) helped to convince the Bell System of the feasibility of adding high-frequency microwave radio relay to its methods of transmission. An intensive research program carried out under Harold Friis, director of the Holmdel Laboratory, immediately after World War II provided much data on propagation and led to prototypes of all key devices which would be needed in a microwave radio relay system for telephone and television transmission. In November, 1947, an experimental commercial link based on this research, called TD-X, was opened between New York City and Boston.

Experience with this field trial and improvements in microwave devices and antennas led to the development of the TD-2 system, first installed in the early 1950's. This system, operating at 4 kilomegacycles, has six broadband channels in each direction, each channel capable of handling six hundred telephone circuits or one television circuit. Other major radio relay systems evolved and are operating today. The TH system operates at six kilomegacycles with eight channels in either direction and the TJ system at 11 kilomegacycles is used for light traffic over distances up to 200 miles. The most recent system, is the TL system which will also be a light traffic, "short-hop" radio relay link with emphasis on simplicity, flexibility, and low cost. It was designed primarily with solid-state devices.

Experiments conducted on microwave systems led to the use of another transmission medium—the troposphere. As early radio transmission studies had shown, layers of the atmosphere were handy for bouncing radio signals from one point to another on earth. Radar studies during World War II gave rise to suspicions that electromagnetic energy at radar frequencies was being reflected from a layer other than the ionosphere. Measurements between Holmdel and the Middle and Far West in 1947 in conjunction with the TD-X system also indicated that a lower layer was involved.

In 1951 the U.S. Air Force sought a microwave system in Newfoundland where line-of-sight towers were impractical. Bell Laboratories engineers devised a multichannel system using big antennas which operate through the winter season. All of these attributes had been considered impossible for tropospheric scatter at high frequencies. Both the Whippany and Holmdel Laboratories were used in propagation research important to such a system. For many years a landmark off the Garden State Parkway has been one of the 60-foot reflector antennas on Crawford Hill, near Holmdel, which was used in extensive studies of tropospheric scatter propagation from Crawford Hill to Pharsalia, New York, 170 miles away.

Radio engineers at International Telephone and Telegraph (ITT) have also been active in research on the tropospheric scatter principle for transmission. Knowledge gained from the Newfoundland success proved that tropospheric scatter was a feasible wide-band transmission system. This led to Bell Laboratories' engineering and International Telephone and Telegraph's building, in 1957, the world's first broadband over-the-horizon trunk circuit from Florida to Cuba, capable of transmitting 120 voice channels plus a television channel a distance of 180 miles.

Tropospheric scatter is also used to provide telephone and telegraph facilities for the inhabitants of the inaccessible parts of Alaska. A network known as "White Alice," designed by Bell Laboratories engineers in Whippany, links Alaska to its neighbors and provides communications between the United States air bases and radar stations in Alaska and on the Distant Early Warning (DEW) line. Moreover, the main method of communicating between the DEW line and the other warning networks and with defense centers in the United States is by the tropospheric scatter principle.

IX

SOME FINER POINTS OF COMMUNICATIONS

In the previous chapter we saw the important role New Jersey research has played in the development of communications and communications systems. At first it was a struggle to make the technology work at all. Then there was the process of refining: to increase efficiency, to reduce cost, to make the service more enjoyable to the people who use it. Refinements and improvements—some involving simple devices, others completely redesigned systems—help to make the telephone more useful, or television more enjoyable. A number of contributions to these advances in communications have been made in New Jersey laboratories.

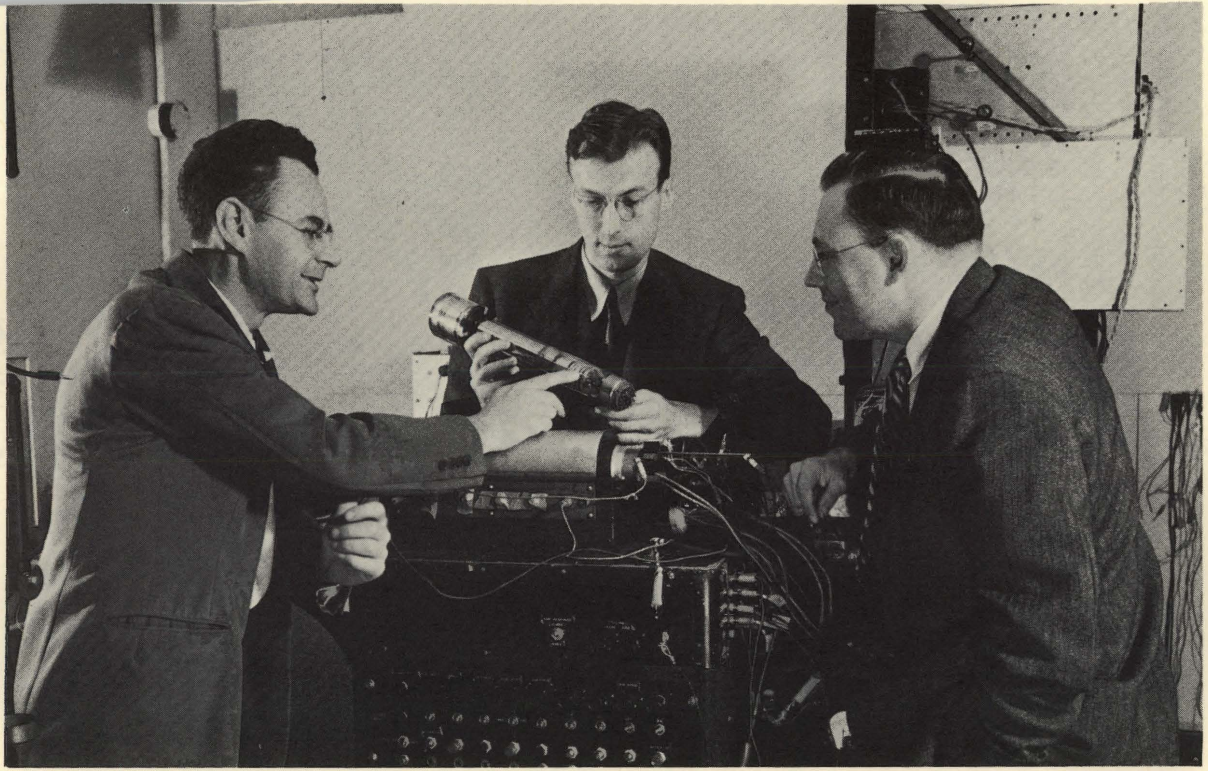
In putting intelligence—telephone conversations, radio, television, or data—onto the transmitting frequencies, engineers use a variety of methods of "modulation." Originally, the technique involved changing the amplitude of the radio wave in accordance with the amplitude, or strength, of the intelligence to be transmitted—Amplitude Modulation, or AM. In an experimental laboratory at Haddonfield, Major Edwin H. Armstrong devised high-deviation Frequency Modulation of the radio wave, the familiar FM which avoids static and other disturbances in high-fidelity radio transmission. In 1927 Armstrong built the world's first FM broadcasting station on the New Jersey Palisades.

Professor Louis Hazeltine, a physicist with a mathematical bent at Stevens Institute of Technology in Hoboken, was responsible for overcoming one of the most annoying defects of early commercial radio. Receivers had a tendency to oscillate, or howl, because of energy fed back by capacitance in the circuit. In 1923 Hazeltine introduced a radio set with circuits which balanced out, or "neutralized," the eletrical effect causing this oscillation. He called his receiver the Neutrodyne.

The rapid growth of television has resulted primarily from the contributions of a few major research laboratories. Chief among these in New Jersey have been the laboratories of the Radio Corporation of America. Engineers at RCA were responsible for important improvements in both the early transmitting tube, the iconoscope, and the early receiving, or picture tube, the kinescope. Both of these fundamental photoelectronic tubes were developed at Westinghouse in the 1920's by Vladimir K. Zworykin, who later joined RCA.

The orthicon, forerunner of the present image orthicon, was developed at the RCA laboratories in Harrison in 1937 by Albert Rose and was the transmitting mainstay of the infant television industry. The fruits of RCA's wartime research on cathode ray display tubes resulted in 1945 in the development of the image orthicon. This device is one hundred times more sensitive than its predecessor and has thus reduced lighting requirements and made possible outdoor telecasts at night.

Developments that also led to commercial practicality of television came from Allen B. DuMont, an electrical engineer with a background in radio-tube engineering at Westinghouse in Bloomfield who worked from 1928 to 1931 at the De Forest Radio Company in Passaic. In 1931 DuMont organized his own company in the cellar of his Upper Montclair home which specialized in high-volume tube production. DuMont's developments overcame the small size (5-inch screen) and short life (100 hours) that were characteristic of the first television receiver picture tubes.



Co-inventors Albert Rose, Paul Weimer, and Harold Law with the first model of the image orthicon, built in 1945
Courtesy of RCA Laboratories

RCA scientists began working on color transmission even before black and white had become commercially acceptable. Even so it was 13 years before color sets began to turn a profit. Operating without assured approval by the Federal Communications Commission that channels would be available, RCA engineers had to put up with patent infringement suits and professional jeers at their all-electronic compatible color before they were able to perfect the "three-gun, shadow-mask" picture tube.

The main research effort started in 1949 when the Federal Communications Commission decided to set industry-wide standards for color broadcasting. The Columbia Broadcasting System proposed a mechanical system operating on channels separate from the black and white channels. Such a system at that time could produce a good picture. RCA engineers leaned toward an all-electronic system which could operate on the standard black and white channels and also be compatible—be received simultaneously in black and white on black and white sets.

Because, at the time, the Columbia Broadcasting System could demonstrate a better system than RCA, the Federal Communications Commission first set the standards according to the CBS proposals. But a few years later the FCC adopted new color standards, reversed itself on the type of system, and paved the way for the all-electronic compatible system. RCA engineers continued to improve the picture tube which uses three electron guns, each shooting at an array of spots of phosphors of a single color. A shadow mask assures that each beam illuminates only one set of spots on the face of the tube. The recent increase in color telecasting coupled with improvement of the sets and the reduction of their cost has accounted for color television's growing popularity, and RCA enjoys a predominant position in the field.

Communications engineering involves a great deal besides the invention and development of electronic equipment. As we have seen, one of the invisible but indispensable aspects of communications is the manipulation of the electromagnetic frequency spectrum. In addition, scientists and engineers are continuing to study and improve the design of switching and transmission equipment.

Since its organization in 1925 Bell Telephone Laboratories has been concerned with the development of switching systems. The methods of connecting telephones next door, across the nation, or across the world, and the tying of commercial radio and television as well as business data into the variety of transmission methods available presents a problem in computation as complicated as has ever been solved.

Until now the "computers" have been of an electromechanical nature involving the use of devices such as magnetic relays and crossbar switches. The growth of communications traffic and the subsequent need for higher switching speeds has caused Bell System engineers to seek faster switching systems, operating electronically. Such a system presently is being prepared for customer use in Succasunna. It is the product of many years of research at the Whippany Laboratory, research now being continued at Holmdel.

Electronic switching was considered before World War II. Work was resumed in 1949; the first major idea was the use of an electronically controlled memory. By 1954 the solid-state devices with their long life, low power needs, and extremely high switching speeds made an electronic central office feasible.

With increased speed has come also versatility: with such features as two-digit dialing for numbers called often, and the temporary transfer of calls from one telephone to another. Central to this technological development was the primary requirement that the new system be able to work with, or be compatible with, more than a half-dozen existing electromechanical systems.

The electronic central office is one of the most massive single research and development projects ever undertaken by a private enterprise. By the time final development is completed, fifteen hundred man-years and approximately fifty million dollars will have been spent. Yet with the flexibility and speed potentially available, the new telephone switching system will provide better service and be more economical to produce and maintain than those now in use.

One of the more esoteric advances in communications to come out of Murray Hill is that of Information Theory—a concept of how to get the most information into a single communications channel. In 1948, Claude Shannon, then at Bell Laboratories, showed how messages could be represented by "bits" and calculated the capacity of a communication channel in terms of bits per second. His theory was related to earlier work by Ralph Hartley and Harry Nyquist of Bell Laboratories and is related to contemporary work by the late Norbert Wiener of Massachusetts Institute of Technology. Shannon's theory shows that any message within the capacity of channel can be transmitted essentially free of error even if a good deal of noise is present.

X

RADAR AND MILITARY ELECTRONICS

THE TECHNIQUES of high-frequency radio became available to electronics just about the time they were needed for a new application—the radar of World War II. Radar (*Ra*dio *D*etection *a*nd *R*anging) was the chief accomplishment of radio science to come out of the war years. In radar a narrow beam of radio waves is sent out as a short pulse. This echoes off solid objects and provides information on the direction of and the distance to the object. Like the radio research which fostered it, much of the radar technology was developed by New Jersey researchers.

The U. S. Army Signal Corps Research and Development Laboratories at Fort Monmouth has been a major contributor to the art of radar. This facility was established in 1918 as a six-man experimental communications station. The Signal Corps and the Naval Research Laboratories in Washington, D.C., began to develop radar about the same time (around 1935) that Robert Watson-Watt in England was urging the British Government to carry on development of 25-megacycle pulsed radar. The American radar research was at higher frequencies.

Since 1918 the Army had been working on various heat detectors for the location of aircraft, and in 1930 it transferred this work from the Ordnance Department to the Signal Corps. It was felt the World War I sound locator should be replaced by some sort of infrared or radio detector, and the Signal Corps Laboratories experimented with microwaves for this purpose. The Army's first pulse radar was designed as a complete system at the Signal Corps Laboratories in 1936 and the following year was successfully tested against bombers flying over eastern New Jersey. In 1938 the radar, called the SCR-270 was ready for the detection of aircraft.

The Signal Corps established a Radio Position Finding Section on Sandy Hook where work went on to improve transmitter tubes and to refine other pulsing devices, and where lobe switching—the technique of precise direction finding—was developed. The Radio Position Finding Section grew into the separate Evans Signal Laboratory at Belmar, which in turn spawned the Army Air Force's Watson Laboratories at Eatontown. Both were going full steam during the War on the development of radar systems.

The Signal Corps Laboratories has contributed a great deal to military electronics. For example, the famous "walkie-talkie" of World War II came from these Laboratories, as did a basic patent on radar. In 1946 the Signal Corps Laboratories bounced the first radar signal off the moon. This and subsequent achievements in a moon-bounce program have revealed much vital information about how radio waves behave in the upper atmosphere and in space. Fort Monmouth scientists and engineers have also developed equipment for the long-range detection of nuclear explosions by acoustics, developed a basic technique for printed circuits, built the first silicon transistor, and developed the first radiation-resistant solar cells for outer space. In 1948 Fort Monmouth scientists observed a rainstorm 185 miles away and tracked it as it passed Fort Monmouth. This led to the development of storm radar used widely by the military services, and then adopted by the United States Weather Bureau. Mortor-locating radars developed by the Signal Corps Laboratories in 1952 became a major electronic weapon of the Korean War.

In the Signal Corps Laboratories buildings at Evans and Deal, over three thousand civilian employees today work on about one thousand military research and development projects. The most important of these involve the development of lightweight field radios (progeny of walkie-talkies), global communications systems, mobile computers, aerial surveillance systems, radars, lasers, and fuel cells. As a government agency, the Signal Corps Laboratories is eager to share its research problems. Contractural programs with two hundred and fifty industrial laboratories and sixty educational and nonprofit institutions distribute many millions of dollars of government funds annually.

Private industry—the Radio Corporation of America and Bell Laboratories—began working with the Naval Research Laboratory on radar research and development in 1939. As a result, the United States Navy had its first radar aboard ship in December, 1940. By 1941, when General Electric and Westinghouse joined in the work, industry was carrying on intensive research and commercial production.

During the early part of the war Bell Laboratories research on radar was carried out in New York City but later work was done at the Whippany Laboratory and, especially with antennas, at Holmdel. In all, a hundred radar systems were proposed, of which about sixty were actually produced. Work on the first four fire-control radars developed in this country had begun in 1938 and the Navy eventually gave Bell Laboratories its entire ship fire-control program.

Radar transmission greatly improved as a result of work at Bell Laboratories on the magnetron—the main tube of a radar transmitter—and its associated circuitry. Three ways were developed to generate energy pulses to drive the magnetron and a gas-discharge switch was perfected that permitted radars to use one antenna for both transmitting and receiving. A point-contact silicon rectifier for microwave radar receivers was also a product of this research.

Concurrent with these accomplishments was a program to design radar antennas. Much of the research and testing was conducted by Bell Laboratories engineers at Holmdel and Deal while the development was carried on in New York and Whippany. Most of the antennas were designed as part of a complete radar system although some work was done on antennas alone. Early in the war the Navy asked for simple search-radar systems for small vessels such as PT boats. Gradually larger, more complex antennas for search and fire-control radars evolved along with some unique problems. For example, the antennas of submarine radars had to be able to withstand the tremendous force of water moving past the hull. Airborne radar antennas had to be made as light as possible. Fire-control radars are inherently more complicated than search radars in that they not only have to have a locating device but also a computing device operating in a continuous manner. Since the computers required accurate information, the radar antennas had to be extremely accurate.

The complexity of fire-control radar systems was extended after the war when the United States Navy asked Bell Laboratories to design a system for modern high-speed air defense. Out of this came a weapons direction equipment that operates to progressively filter incoming enemy traffic—aircraft or missiles—and make sure the guns or missiles of the ship fire first on the most threatening targets. Engineers at Whippany designed the "Mark 65" system which embodies all-purpose display equipment and means to automate completely the entire defensive equipment on board a ship.

One of Bell Laboratories most notable contributions to military technology has been the family of Nike missile systems, developed at the Whippany Laboratory with Western Electric Company as prime contractor and the Douglas Aircraft Company as builder of the missiles. The first was the Nike Ajax, designed to defend North American cities from high speed bombers. Ajax (now obsolete) had a range of 25 miles and a ceiling of 50,000 feet. The

Nike Hercules missile, with a range of 75 miles, a ceiling of 100,000 feet, and provision for a nuclear warhead, uses the ground station of the Ajax system. The third generation Nike system is Nike-X, embodying both Zeus and Sprint missiles. At present Nike-X is the nation's only anti-missile missile system in research.

The concept of a closed loop system with command guidance is common to all the Nike systems. Hercules employs three radars—acquisition, target-tracking, and missile-tracking—and a high-speed computer as its electronic systems. Commands to make the missile hit the target are computed on the ground. The Nike-X system, which must deal with intercontinental ballistic missiles, is inherently more elaborate (it provides a discrimination radar, for example, to pick up ballistic decoys), but the fundamental concepts of radars and computers are the same.

Engineers at Whippany also developed the radio-inertial guidance system for the Titan I missile—one of the first dependable systems in the still-new technology of rocketry. It has successfully guided more than one hundred and fifty rocket launches and has placed a number of satellites in precise orbits.

In the early 1950's the Bell System was asked to develop a detection and communications system to warn of the approach of winged aircraft over the polar regions of North America. Bell Laboratories engineers at Whippany set about designing the electronics system and arranging for tests of what was to become the Distant Early Warning, or DEW, line. One of the most difficult problems was to find equipment which would work in the far north.

The DEW line consists of radome-protected automatic search radars placed about one hundred miles apart, and interspersed with another detection system. Communications pass laterally along the line via over-the-horizon propagation using 30-foot parabolic antennas, and, on some difficult terrain leaps, 60-foot antennas resembling outdoor movie screens. Communications are also maintained with other warning lines to the south, in the United States and Canada. A great deal of work was required on the control equipment which brings together the diverse detection and communications systems.

An outgrowth of the DEW Line is the warning network for ballistic missiles called Ballistic Missiles Early Warning System, or BMEWS, which at this writing has just been completed and is ready to provide a detection system covering the north polar skies from England to the Bering Straits. Each of three radar sites–in Alaska, Greenland, and England—has scanning and tracking radars, data processing equipment, and a vast network of communications circuits.

Radio Corporation of America as prime contractor for BMEWS has been responsible for the entire system, and RCA engineers at Camden have been responsible for designing the radars and other electronic warning equipment. Bell Laboratories engineers at Whippany designed the rearward communications system which has the task of distributing information in the form of voice, high-speed data, and teletypewriter service. Unimaginably complex engineering concepts were necessary for successful integration of underseas cable with over-the-horizon transmission in the face of the extreme weather conditions in the northern region of the world. These facilities must be distributed over multiple independent routes so that a failure in one communications link will not interrupt the system.

At Nutley, International Telephone and Telegraph's Federal Laboratories work in radar has resulted in the TACAN (Tactical Air Navigation) system, the standard short-range air navigation system for the Navy and Air Force. Also employing TACAN principles is an integrated common system known as VORTAC used for military and commercial navigation on federal airways. For strictly commercial aviation, ITT engineers pioneered airborne distance measuring equipment (DME)—a transistorized system that provides continuous information to ground stations, again along the route of the federal airways.

International Telephone and Telegraph Company is also contributing to research programs in air-traffic control for the Federal Aviation Agency. One device is a three-dimensional display for the air controller. In this same field a communications switching system for traffic control was developed by Bell Laboratories engineers at Murray Hill and is, at this writing, being tested at the FAA research facility in Atlantic County.

ITT holds several basic patents for LORAN—the hyperbolic long-rang navigation system that covers much of the world. The company's missile and space research has produced airborne guidance equipment for the Talos and Terrier missiles. And ITT researchers have contributed to missile-tracking computers for missiles such as Lacrosse, Bomarc, Sparrow, Polaris, and Tarter.

XI

NEW JERSEY'S ROLE IN SPACE

WE FIRST NOTED New Jersey's contributions to space science is the work of companies such as Thiokol on rocket propulsion—the motors and fuels that make rockets go. Without such work space engineering would still be in the realm of science fiction. Equally important to the reality of this science is the payload—and New Jersey's major contributions here, happily, do not center about warheads but rather on orbiting satellites with peaceful uses.

In recent years communications engineers have extended their interest in transmission of intelligence through the medium of space. Because one cannot build towers on the ocean, present microwave radio relay systems are not a practical method for extending transmission overseas. But a satellite at an altitude of several thousands of miles can provide straight line paths linking distant places on earth. As early as 1945 the English physicist and author, Arthur C. Clarke, suggested the general idea of satellite communication. And, in 1954, J. R. Pierce proposed systems using active repeaters at both high and low altitudes as well as passive "balloon" type satellites.

The world's first "talking" satellite was a product of Fort Monmouth. A satellite called Score, placed in orbit by an Atlas missile on December 18, 1958, was designed and built at the Signal Corps Laboratories. The satellite broadcast the first human voice from space: President

Dwight D. Eisenhower's Christmas greetings to the world. This prerecorded message proved that voice and data signals could be efficiently relayed over great distances by communications satellite.

As an extension of the Score concept, Fort Monmouth scientists directed the development of Courier, sent up on October 4, 1960. Courier was able to relay teleprinter messages from one ground station to a second station by recording about four minutes of high speed messages on one pass and then transmitting the messages during a second pass. The ground stations for Courier, one at Fort Monmouth, the other in Puerto Rico, were designed and developed by communication engineers at International Telephone and Telegraph's Federal Laboratories in Nutley.

In August, 1960, the National Aeronautics and Space Administration (NASA) launched the passive satellite Echo—an aluminized mylar balloon 100 feet in diameter, that became the target of numerous transmission experiments primarily between the Bell Laboratories ground terminal at Crawford Hill, near Holmdel, and NASA's Jet Propulsion Laboratory at Goldstone, California. Live and taped voice, telegraph, and facsimile messages were successfully transmitted. Much of the success was due to a specially designed horn antenna and a low-noise maser receiver-amplifier used at Holmdel together with a special receiver using frequency-modulation-with-feedback. All these were developed in New Jersey by Bell Laboratories scientists and engineers.

The Echo experiment laid the groundwork for the next phase in the development of satellite communications—the active, real-time, broad-band satellite. In Andover, Maine, a fantastically huge and complex horn antenna was built which included improvements on the transmitter, receiver, and tracking facilities for space communciations suggested by the work with Echo.

Meanwhile, in Hillside, in a small Western Electric manufacturing building, engineers were putting together the TELSTAR communications satellite. About 3 feet in diameter and weighing 170 pounds, the TELSTAR satellite contains an example of almost every modern electronic device—transistors, solar cells, precision passive components, and a traveling-wave amplifier. The Andover antenna complements the satellite's sophisticated electronics with, for example, its own low-noise receiver-amplifier and its computer-directed tracking facility. Nearly every modern electronic component involved in the TELSTAR satellite experiment was either invented or developed significantly by scientists in New Jersey laboratories.

On July 10, 1962, when the first TELSTAR satellite was placed in orbit, a new resource of radio transmission came into being. Thanks to components made with incredible care and to exhaustive tests of their reliability made at Murray Hill and Whippany, all the communications experiments carried out over the succeeding months were successful. The world's attention was held by live television transmitted across an ocean for the first time. But the real technological success lay in the completing of more than a hundred electronic tests designed to establish the feasibility of a commercial system. An important adjunct to these experiments was measurements of radiation in outer space, which added a great deal to our knowledge of the Van Allen belts. In May, 1963, a second TELSTAR satellite was launched to continue the researches of the first one.

On December 13, 1962, NASA launched its active communications satellite, RELAY, another product of New Jersey communications research. The RELAY satellite, similar to the TELSTAR satellite in many respects, was designed and built by RCA engineers at the Defense Electronic Products Division in Princeton. ITT's space communciations center at Nutley is the primary ground station for the RELAY satellite tests on the east coast, while the Bell System station in Maine is used in overseas television transmission. The Nutley facilities conducted the first transmission via active communications satellite with South America, and Nutley was the originating station for a variety of transmissions to Europe.

It may not always be practical to use big antennas with complicated receivers for world-wide communications via satellite. Because of this, Bell Laboratories and ITT engineers developed simultaneously, but independently, compact transportable ground station equipment. The ITT equipment is a 12-channel voice terminal which has been used in Rio de Janeiro for the southern link of the North and South American experiments via RELAY.

In 1959, Signal Corps scientists conceived, developed, and sent into orbit via Vanguard II an experiment designed to send back crude information about the earth's clouds. This 21-inch sphere was the forerunner of a series of meteorological satellites called Tiros. Under the management of the National Aeronautics and Space Administration and the technical direction of the Signal Corps Laboratories, RCA has developed and produced orbiting satellites whose primary objective is the observation of the earth's cloud-cover by means of television cameras. Carrying both a wide- and narrow-angle lens camera each of the eight satellites launched since April, 1960, has given scientists a broad view of the circulation of the atmosphere. In addition to providing pictures of cloud formations with the subsequent advantage of aiding in weather forecasts, the cameras have given scientists new knowledge of the infrared radiations given off by the earth.

Space is a wonderful frontier. It affords a variety of opportunities. One may use it unimaginatively to imitate the voyages of past centuries, or ingeniously to blow his neighbors to dust. New Jersey scientists and engineers were first to find things to do in space that are useful as well as exciting. Score, Courier, Echo, TELSTAR, RELAY, and Tiros presage a new age—they do not merely reflect the past.

XII

RESEARCH IN HUMAN BEHAVIOR

IN HIS EFFORT TO UNDERSTAND the world in which he lives, scientific man has accumulated an enormous amount of information about energy and matter and the extraordinary process of life. Yet he has far from complete knowledge of the physical and biological world. And he is even less informed about his own mind—how he thinks and feels, and how he responds to his environment. The science concerned with this—the science of psychology—is a relatively young one. But it is growing rapidly because man has come to realize the interrelation between his physical and mental welfares.

Princeton University has had a Department of Psychology since 1920. In 1924 this department moved into Eno Hall, the first building in the world devoted exclusively to psychology.

Some of Princeton's earliest research in this field began in 1930 with the discovery by E. G. Wever and C. W. Bray that minute electrical pulses are produced in the inner ear as the result of sound stimulation. This discovery formed the nucleus of continuing research in the auditory responses of animals and human beings and has brought about changes in the theory of how the ear operates. The work has added to our understanding of how information is coded in terms of frequencies and of which parts of the ear are stimulated by various signals.

This psychological research has provided physiological information. The theory of what happens in otosclerosis in humans, for example, has been worked out by inducing the effect in animals and measuring their responses both before and after the hardening of the ear tissue.

Modern electronic equipment has been invaluable in many psychology studies. In auditory research, for example, the signals to be measured are as small as one-millionth of a volt. In measuring the electric potential of a nerve fiber Wever and his associates use a wave analyzer to pull the signal out of the background "noise."

Princeton psychologists are interested in interpersonal relationships, the comparison of polar extremes in personality, and the complex learning processes in human beings and in animals. They have studied the little understood phenomena of perception. Aesthetics—perception diffused with mood and emotion—is being studied in an attempt to understand how music and visual art seem to have moods as well as sound and color.

Mathematics and the computer play a large part in the psychological research at Princeton, particularly in measuring and "scaling" of data. Mathematical techniques have been applied to the description of learning, to methods for measuring subjective psychological quantities such as color or hue, and to the measuring of human preferences such as the factors involved in a man's choice of his friends. The computer is necessary to handle the inordinately large amount of interrelated data which evolves when subjects are compared in every conceivable way.

Measuring the responses, rather than just counting them, represents a sophisticated approach to data gathering. In this connection, Princeton's J. A. Notterman and his colleagues use analogue voltages to measure force, time duration, and time-integral of force. For example, the ubiquitous white rat is fed food pellets in accordance with how hard and how often he presses on a bar. The interrelation between force and time provides meaningful data. Some of the results of these studies suggest that neither the psychological principle of "reinforcement" nor of "least effort" alone is sufficient to account for behavior. Both must be present, with some additional motivation as well.

It has also been discovered that the force of response goes up with increased drive. A really hungry rat will press the bar with much greater force even though he "knows" it will not avail him additional food. Ordinarily, the rat will not work harder for more—he will not press even a little bit harder to get two pellets rather than one. Such information is useful in the study of energy distribution patterns in various animals as well as in humans.

At Bell Laboratories in Murray Hill there is a laboratory which is not concerned with chemistry, physics, or electronics, but rather with the science of human behavior. This is the Behavioral Research Laboratory—a diverse group made up primarily of experimental psychologists, but also including physicists, mathematicians, electrical engineers, and a sociologist. These researchers are trying to learn how people react under controlled circumstances and also how people learn. The Behavioral Research Laboratory has spent much time studying the reaction of people to their environment and to one another. This study of the machinery of human nature has led to new ideas about training, personnel policy, and communciations processes. Electronic equipment plays an important part here too. In a study of conflict of interest, for example, an electromechanical bargaining game was built which established a hypothetical situation involving two truck drivers, a single-lane road, and a complex of gates. The study revealed the different approaches people take to conflict and compromise.

Behavioral scientists have also worked with Bell Laboratories librarians on the study of retrieval and automatic dissemination of information. This has led to computer-produced "permutation indexes" of technical memoranda and other material.

Recently a number of studies have been made on the learning processes, specifically what is called discrimination learning and partial reinforcement.

Some research in the Behavioral Research Laboratory, and a good deal in the Acoustics and Speech Laboratory, lies in the areas of speech and perception. If communications technology is to be efficient, it is necessary to know just how much fidelity is necessary for a satisfactory telephone conversation or a television program. Getting and analyzing people's reactions to things such as "speech compression" or transmission distortion is a job for the psychologists.

The Human Factors Research Department is another department at Bell Laboratories concerned with human reactions. It also employs both physical and social scientists. This group uses simulation techniques to determine if proposed communications services would be useful or desirable to users before those services are provided. For example, some years ago this group conducted an experiment in "voice" dialing. A number of people dialed the numbers they wanted by speaking into the telephone. A silent operator performed the connections, giving the illusion of an automatic system. The test panel generally preferred this method of dialing but, in addition, an interesting piece of psychological information was gained. Several people who stuttered were included in the panel. Over the test period, after they began to forget they were talking to a person and began to believe they were talking to a machine, they stopped stuttering during "dialing."

A Human Factors group was involved in the training of the Project Mercury astronaut team. Specifically, the group was responsible for coordinating the work on a simulation system used to train the flight controllers at the Project Mercury control center at Cape Kennedy. In designing the equipment, these engineering psychologists kept in mind the need for the most realistic situations possible. The compelling effect of realism admitted by the participants is a measure of their success.

XIII

CENTERS OF RESEARCH

So far throughout the story of research in New Jersey we have seen a concentration of advances in science and technology in industrial and university laboratories. In some cases there has been a great deal of cooperation between industry and university, and such cooperation has been exceedingly fruitful as it was in the case of streptomycin. Some industrial organizations have deliberately and admittedly established their laboratories near Princeton or near Rutgers to take advantage of the university climate.

There have also been overt attempts on the part of industry and the university to get together on long-range projects. One example is the 15-million-electron volt tandem Van de Graaff accelerator built at Rutgers for use by Rutgers and by Bell Laboratories. Sharing the cost of the two-and-one-half-million-dollar facility, both organizations will use it to do basic research in nuclear physics.

University Centers

At Rutgers the Institute of Microbiology and the Chemical Research Department form the nucleus of a Science Center in Piscataway Township, across the Raritan River from the main campus. Recent buildings in this Center include one for biology, the Nelson Biological Laboratories, built in 1961. This houses the Bureau of

Biological Research whose specialty is research in protein metabolism. Nelson Biological Laboratories will also conduct instruction in basic medical services for the proposed two-year medical school. In 1961 ground was broken for buildings to house the Physics Department and departments of the engineering school, and the following year construction of the Van de Graaff accelerator began. Another building in this Center is the "Gamma Greenhouse" where agricultural scientists will conduct radiation experiments on plants.

In the spring of 1962, with the aid of a federal grant, work was started on a Rutgers Psychopharmacology Laboratory. This represents expansion of continuing research in tranquilizing drugs. Studies are also conducted on the sensation of taste—one of the least explored fields of human reaction. In 1962 Rutgers took over a research program that had been going on at Yale University for 41 years, the new Center of Alcohol Studies. This center, with the help of annual grants from the National Institute of Mental Health, will study problems created by the excessive use of alcoholic beverages.

The Stevens Institute of Technology in Hoboken is a monument to the engineering feats of the Stevens family. It was incorporated in 1870 on land and with money bequeathed by Edwin A. Stevens. Today this engineering and science college has contracts from government and industry for research program amounting to several million dollars. To carry out these programs 130 research personnel work full time on 172 different projects. For example, there is a research program for the Esso Research Laboratories on "Dynamic Plastics Deformation," and one for Picatinny Arsenal on "Conversion of Explosive Energy." In physics, experiments are conducted on controlled thermonuclear energy; in chemistry, on the effects of the molecular structure of chemicals on physiology; in metallurgy, on the fundamental differences between the shiny and the dull surface of a metal.

Stevens research is best known, however, for the work conducted in its Davidson Laboratory. The Laboratory was established in 1935 as the Experimental Towing Tank by K. S. M. Davidson and A. B. Murray, who pioneered in the study of hydrodynamics with emphasis on the performance of sailing yachts.

The genesis of this research was a program supported by the Esso Research Corporation and the United States Steel Corporation of small-scale model testing in the jury-rigged swimming pool at Stevens. During World War II the United States Navy expanded the facilities, and the Experimental Towing Tank became a major design test-center for hydrodynamic studies.

Today the Laboratory is used for the study and evaluation of phenomena associated with the operation of various modes of water transport, particularly on the ocean. The most basic study is on the "decay" of ocean waves. Since waves affect the erosion of shore lines, research might help to tell, for example, how strong waves generated in storms some distance offshore will be when they reach the beach. Core of this research in the Laboratory is a wave channel—a shallow concrete tank 250 feet long, 3 feet wide, and 9 inches deep.

One of the best known accomplishments of this Laboratory has been the testing of the hulls of contenders for the America's Cup. This yacht race was first brought to American waters through the efforts of Edwin Stevens. Both the 1962 rivals, the Australian *Gretel* and the winning American boat *Weatherly,* were tested at the Davidson Laboratory.

The Davidson Laboratory operates along two major lines of research. The Transportation Research Group investigates hydrodynamics as a basic science and studies the development of ships and yachts. The Applied Mechanics Group studies fluid physics, high-speed craft, propulsion, and the behavior of underwater weapons.

At Princeton, the James Forrestal Research Center was established in 1951 to relieve the acute shortage of laboratory space and facilities on the University campus. These shortages were slowing down certain research programs, chiefly in plasma physics and aeronautical engineering. In addition to the Princeton-Pennsylvania Accelerator and the Plasma Physics Laboratory, discussed earlier, the Research Center houses work in aerodynamics and jet propulsion, in applied mathematics, and in the chemical sciences. Here the scientists and engineers are studying extreme conditions—high speeds, high temperatures, high pressures, and high energy levels. These extreme conditions appear on the surface of airfoils at supersonic speeds, in the chambers of rocket engines, or in the heart of a nuclear reactor.

Much important knowledge has been gained at the Research Center in Aeronautical Engineering, the only teaching department of Princeton with headquarters at the Center. This department operates a gas dynamics laboratory which uses wind tunnels capable of simulating speeds up to Mach 20, or 15,000 miles per hour at sea level, to study supersonic aerodynamics. A subsonics laboratory is operated for low-speed studies, a flight mechanics laboratory deals with aerodynamic concepts leading to improved performance of helicopters or air-cars—new types of vehicles which ride on a cushion of air. The jet propulsion laboratory deals with combustion processes, ignition studies, and the problem of heat transfer in rockets. Nuclear and ion-propulsion experiments are also studied there.

The Newark College of Engineering, active in education for many years, established the Newark College of Engineering Research Foundation in 1959 with a $500,000 pledge of support from Thomas M. Cole, president of the Federal Pacific Electric Company of Newark. The Foundation provides a unique service to research in a formal program designed to encourage the engineering profession both actively and tutorially.

Major objectives of the Research Foundation stem from a national need for highly qualified graduate scientists and engineers, as well as the need for adequate numbers of qualified teachers in engineering colleges and the need for the highest possible quality of science instruction in the secondary schools. Specific objectives are the professional development of the Newark College of Engineering teaching staff, the attracting of capable young engineering graduates to Newark College, and the establishment at the College of programs to assist secondary school teachers in science and mathematics in their professional development and training.

For example, during the 1960-1961 academic year 34 Newark College of Engineering faculty members were engaged in 36 research projects. During the same period the Foundation supported 10 fellowships for engineering teachers. The National Science Foundation and the Victoria Foundation support a program at the Newark college known as the "in-service institutes"—one-night-per-week seminars in basic sciences for high school teachers. During these sessions teachers are brought up to date on new developments and ideas which have not yet reached the high school textbooks. Outstanding high school teachers also can participate in a program of summer research under the direction of its faculty. This program is underwritten by the National Science Foundation, which also supports a program in which outstanding high school students study in a five-week science training program.

A more direct attempt on the part of the university and industry to exchange ideas is the Princeton University Conference, a program designed to let ideas flow between members of the Princeton faculty and representatives of industry. The charge of this program is to narrow the gap between the academic and nonacademic worlds, thereby shortening the time lapse between the development of new basic knowledge and its use by society.

The Princeton University Conference conducts formally organized two-day meetings once or twice a year on broad-gauge topics and periodic meetings on topics narrower in scope. Those present come from businesses, foundations, government laboratories, labor organizations, and universities. Between 1956 and 1962, 49 major meetings were held with over thirty-three hundred men from industry and other areas discussing problems of mutual interest with three hundred members of the Princeton faculty. Some of the scientific meetings scheduled indicate the variety of topics considered: Polymer Science and Engineering, in 1956; The Physics and Chemistry of Radiation Damage, and Problems of Low Speed Flight, in 1957; Industry and the Future of Basic Research, and Energy Transfer in Gases, in 1958; Plasma Physics, Game Theory, and Active Centers in Heterogeneous Catalysis, in 1961. The list of participants is long and diverse, covering the fields of chemicals, communications, aircraft, textiles, petroleum, banking, steel, and transportation.

Industrial Centers

The attempt of New Jersey universities to divorce physically the large areas of research from the teaching campus seems to be a sign of a trend in the way in which research is being organized. Some of the industries whose work was discussed in earlier chapter have also found advantages in setting up separate research centers for the discovery and study of new knowledge in science and engineering.

Chief among these in New Jersey is Bell Telephone Laboratories—the research and development organization of the Bell Telephone System. Bell Laboratories evolved in 1925 from the Engineering Department of the Western Electric Company located in New York City. In 1934 the Development and Research Department of American Telephone and Telegraph joined the group and since that time communications research and development in the Bell System has been centered at Bell Laboratories. Today the organization has large facilities at Murray Hill, Whippany, and Holmdel, and a small laboratory at Chester.

The geographical division of Bell Laboratories within the State keeps over twelve thousand people from being massed in one area, but the cohesiveness of its organization is still maintained. Most of the research in the fundamental sciences is conducted at Murray Hill. Holmdel has taken on, in addition to its historical work in radio, switching and telephone-set development and work on data transmission. Whippany carries the largest share of the load of research and development emanating from government contracts on defense projects assigned to the Western Electric Company. And the Chester Laboratory concentrates on the testing of telephone poles and other equipment used outdoors and exposed to the weather.

The concept of separation of research and development from the manufacturing and operating aspects of communications does not mean that the researchers at Bell Laboratories are aloof from telephone problems. On the contrary, there is very close cooperation among the divisions of the Bell System. Bell Laboratories exists, not just to invent things, but to invent things needed by communications technology. In the final stages of the development of new systems Laboratories engineers, telephone company engineers, and Western Electric Company engineers work closely together. A current example is the work going on to prepare Succasunna, New Jersey, for installation of the Bell System's first full-scale commercial Electronic Central Office in 1965. Putting this new system in harmony with existing telephone switching systems requires the engineering skills of men from Bell Laboratories, Western Electric, and the New Jersey Bell Telephone Company.

Another telephone research center is the Engineering Research Center which Western Electric opened near Princeton early in 1963. The Research Center was established apart from all manufacturing facilities to free engineers from the exigencies of specific production commitments. At the Research Center, Western Electric engineers are looking for fundamentally new and better ways to make things—its primary activity is research concerning "engineering for manufacture." This encompasses design of tools, machines, processes, and production systems. Today we cannot wait until manufacturing techniques are desperately needed to devise them. They must be envisioned for the future electronic device or system. In addition, it has become evident that research in this area requires special talents, special facilities, and a special working environment.

At the Western Electric Engineering Research Center, research and development are concentrated in mechanization, processes, and systems. An example of research in mechanization is the search for a mechanized device that will automatically select a wire from a cable by its color-coding. Research in systems includes mathematical and statistical techniques and computer technology. Western Electric is attempting to establish a sophisticated ordering system to forecast requirements and order the manufacturing or procurement of parts at the proper time in the manufacturing schedule.

The Radio Corporation of America built a research center southeast of Princeton in 1942 to accommodate research groups from the Camden and Harrison manufacturing plants. After World War II the Princeton Center, renamed the David Sarnoff Research Center, began to concentrate on fundamental sciences and today is strong in research in areas such as the behavior of the electron and also in the study of new materials.

Most of the applied research and development is conducted by Radio Corporation of America scientists and engineers at the various product divisions. There are, however, affiliated laboratories at the David Sarnoff Center which help to bridge the gap between research and the needs of the market. The research program of RCA in general is conducted in six major areas—materials, electronics, acoustical and electromechanical, system, computers, and microwaves.

Expansion of the Standard Oil Development Company led to the establishment in 1948 of a separate research center in Linden. And when further expansion was deemed necessary ten years later, the then named Esso Research and Engineering organization broke off its process research and set up the Florham Park Laboratory

—a center engaged in the design and development of refining processes.

There are many examples in New Jersey of industry's trying to separate research from other departments and divisions. Cities Service set up its Research and Development Laboratories in Cranbury. Celanese has two centers of research—one in Summit and one in Clark. Socony-Mobil divides its research six ways; three facilities are in New Jersey, at Paulsboro, Princeton, and Metuchen.

A Unique Center

No separate facility for research, either academic or industrial, is quite like the Institute for Advanced Study in Princeton. The Institute is a research center for eminent scholars doing advanced work in their own fields. It has no formal connection with the problems of university departments, industry, or the government.

The Institute was founded in 1930 through a donation of five million dollars by Louis Bamberger and his sister Mrs. Felix Fuld. In 1921 Bamberger and Mrs. Fuld had met and talked with Abraham Flexner—an American educator who had headed the General Education Board of the Rockefeller Institute for many years and was instrumental in directing the philanthrophy of a number of important trusts towards education.

Flexner traveled in Europe to exchange ideas with educators there and to obtain their opinions of the type of institute that might be most useful. He decided the first "school" in such an organization should be devoted to mathematics. First, this subject was fundamental. Second, it required almost no material investment. Third, it seemed to be a field easy to find a staff for, and mathematicians were generally agreed on the outstanding figures in their respective fields. Since the donors felt obligated to the citizens of New Jersey and since the Princeton University faculty was rich in renowned mathematicians, the Institute was established near the Princeton University campus.

The Institute for Advanced Study was originally conceived as a graduate school whose faculty would have no undergraduate obligations. It was to use the facilities of Princeton University but remain a completely separate organization. Flexner intended it to be primarily intellectual in character, to be small and flexible. In view of the fact that the world's important universities were becoming big and organized, the Institute was to be kept free of the world's immediate problems, free to pursue any issue it liked.

Abraham Flexner served as the first director of the Institute from its opening in 1933 until Frank Aydelotte took over in 1939. In 1947 the present Director, Dr. J. Robert Oppenheimer began his administration. Men like Oppenheimer, John Von Neumann, Oswald Veblen, and, of course, Albert Einstein have helped the Institute gain its reputation as a fountain of basic knowledge in mathematics and theoretical physics. In addition to mathematics, there is a School of Historical Studies.

The Institute has pretty much kept to its original form —a small organization for thoroughly trained basic scientists who can ignore the world while they concentrate on the problems of their field. No degrees are awarded there because the members are as far advanced academically as possible when they arrive. There are about forty long-term members, half of whom comprise the faculty, and about one hundred temporary members who remain between one and two years. Admitted by faculty vote, most members have been invited to attend, although some who apply on their own are accepted.

XIV

RESEARCH 1964

THE ENVIRONMENT of science and technology has changed spectacularly since the days of John Fitch and his contemporaries. The inventor no longer works in a technological vacuum, unaware of the major achievements of men in other lands or even in his own. True, modern science is extremely complex; discoveries by the hundreds of thousands of scientists and engineers throughout the world are countless; and it is impossible for any one man to keep up with the tons of technical literature published each year—or even to determine what part of it is worth reading. But the organizations—the industrial laboratories, the universities, and the institutes and professional societies with which an engineer or scientist is associated—help to keep the researcher informed concerning the scientific achievements in his field. Thus, not only can he build on the technological foundations laid down by his predecessors, but also, he is less likely to duplicate the work of someone else. Moreover, our patent system, which we traced back to the efforts of New Jersey's John Stevens, has been a powerful influence for the publication of technological information.

We see less of the solitary inventor. Today the inventor is ordinarily associated with others of complementary abilities in some large organization. Fitch could design a steamboat by himself because it was really a simple piece of machinery. Stevens' operations were slightly more complicated, and thus he was forced to call upon the skills of foundrymen and others to build his successful boat. Likewise, men like Boyden and Hyatt became involved in technology that called for skilled specialists in several fields and thus had to set up programs involving many people. Edison had learned as he went along that not only was it necessary to employ men with fine hands, but also men with fine brains who contributed the basic understanding that hastened the ultimate success of an electric light or a phonograph.

Sharing Knowledge

For most of the twentieth century, science and technology have progressed by sharing skills and information. Thus in New Jersey today we have research laboratories operated by industry—Bell Telephone Laboratories, the David Sarnoff Research Center, the Merck Laboratories —which are separate from the main body of the corporation and staffed and administered by professional technical people. Today there are many technical aspects to any one industry. Bell Laboratories employs engineers, physicists, chemists, mathematicians, and even people with degrees in the biological sciences in its research in communications technology. The pharmaceutical firms employ specialists in every conceivable field in the biological sciences and some in the physical sciences as well. Merck, for example, employs people in 35 different fields.

According to Max Tishler, President of Merck, Sharp and Dohme Research Laboratories,

> the research team in today's pharmaceutical laboratory is a team of individual scientists, each preserving the autonomy of his field but relying on the interplay of chemistry, biology, and medicine. These teams recognize the individuality of the scientists, the independence of the science, and the interdependence of all sciences in the solutions of problems facing mankind.

New Jersey universities have followed a similar pattern in organizing research departments staffed in a variety of technical disciplines.

Part of the reason for this approach to research is that each project has so many different facets. The design of a Nike anti-missile missile system or of a communications satellite system, or the search for a new plastic or a disease-resistant plant calls for varied skills. Moreover, it has become practical for organizations to pool their facilities when vast machines are needed to simplify and speed up the work of research; machines such as a computer, or a Van de Graaff generator such as shared by Rutgers and Bell Laboratories, or an atomic reactor in Plainsboro, used for fundamental researches in nuclear energy and shared by ten corporations.

Within universities, with their departmentalizing, the individual research scientist remains a distinct and sometimes rather isolated entity. The man who is engaged in group research does not necessarily lack the individual creativity of a Stevens or an Edison, but he does live in a far more informative and responsive environment than such men knew. Although the pool of knowledge of a group may be necessary to the overall success of a research project, some single man in a group must be responsible for the idea that leads to a new drug or a new electrical circuit. Nevertheless, there is a reward in carrying out a good idea successfully, just as there is in having the idea in the first place.

Large laboratories can have a stimulating effect on research. A specialist in an area needs a number of able associates to keep him sharp professionally. Moreover, scientific creativity tends to flourish in the presence of a judicious mixture of disciplines. But basic new scientific ideas must still come from the individual scientist. "Manpower," whether it be a group or a committee, cannot create.

Technological research has had a stimulating effect of another sort. It has led us to fields of activity unknown only a few years ago. The "engineering for manufacture" type of research carried out at Western Electric's Research Center in Princeton is one example. Another is the intensive program of quality control which is so important to the reliability of components for a communications satellite or a weapons system. A third is the concept of "systems engineering," which brings together an understanding of available technological resources, needs, and economic considerations in planning complex systems which are at once realistic, useful, and economically sound.

As an example, systems engineering has been essential at Bell Laboratories in planning and building a new type of telephone switching system using electronic components instead of the conventional electromechanical ones. The problem of making the new work with the old, compatibility, is one of many that must be solved in a systems approach. Most modern weapons, such as the Nike systems, are complex combinations of interacting gear, and acute systems planning is as necessary for their success as is the proper functioning of individual components. And this technological approach is indispensable to other complex military systems in which New Jersey laboratories have had a part—the DEW Line, BMEWS, or the SAGE communications system.

In an effort to comprehend and profit by research, the New Jersey Council for Research and Development was established in 1962 to define and study the problems facing research and development in New Jersey and to recommend methods to promote its growth. The Council is composed of scientific, educational, commercial, and industrial institutions throughout the State.

As outlined by the Council, some of its specific aims are:

an exchange of scientific and technical information of mutual interest to members, a fostering of appropriate legislative aid for the promotion of research and development, a survey of the needs, feasibility, coordination and development of training programs to provide large numbers of skilled techniques, and a program for the advanced training of scientists.

Financing Research

One of the most important questions concerning research is: where does the money come from? Research money is certainly easier to come by today than it was for John Fitch. John Stevens was shrewd enough to take on a partner with money. Seth Boyden, although he seemed to care little for making a fortune, took out of each of his projects enough capital to start a new one. Edison discovered early in his career that the inventor whose success was well publicized would easily find funds to carry on his work.

Today, the federal government pays nearly two-thirds of the research and development costs in the United States. The government's interest in fostering science is not a latter-day phenomenon. The Smithsonian Institution was created by Congress in 1846 and the National Academy of Sciences was formed in 1863 to furnish advice and support on technical matters to the federal government. Today's well publicized National Aeronautcis and Space Administration (NASA) has its roots in the National Advisory Committee for Aeronautics, established in 1915, whose laboratories contributed much to both civilian and military aviation. And the National Research Council was organized as part of the National Academy of Sciences in 1916. The years during and immediately after World War II spawned a host of technological agencies such as the Office of Naval Research and the Atomic Energy Commission, both set up in 1946.

The federal portion of support of research and development projects is channeled through these agencies and the Departments of Defense, Agriculture, and Health, Education, and Welfare. A more recent (established 1950) federal institution, the National Science Foundation, supports "nonmission oriented" research through research grants and fellowships, similar to the way private philanthropical foundations operate.

The influence of the federal government is felt keenly in New Jersey, not only in the number of defense contracts let to New Jersey firms, but also through help from agencies such as the National Institutes of Health and the Atomic Energy Commission, which have made available funds to carry out a variety of research projects. In addition to supporting academic and industrial organizations the federal government conducts research in its own laboratories—for example, at the National Bureau of Standards or the Naval Research Laboratory, or, in New Jersey, at the Signal Corps Laboratories at Fort Monmouth.

Although it is the largest source of funds for research, the federal government is really only one of a triumvirate of three major sources: the others being private industry and nonprofit institutions including colleges and universities. Large corporations finance much research out of profits. Universities depend on fund drives and endowments to supplement the help coming from government agencies and contracts. Foundations, such as the Carnegie Institute and the Rockefeller and Ford Foundations, are responsible for a great deal of important research work in many areas of the United States. Rockefeller grants, for example, have been made chiefly to institutions doing advanced research in the fields of its interests. In New Jersey, Princeton University over the years has been the chief recipient; most of the money was granted for studies in geology and in population research, and to Princeton's Center of International Studies.

Sometimes several sources of funds support a research program. We have seen several examples in New Jersey of work shared by government and industry, government and university, industry and university, and industry and industry. The sharing of knowledge, of funds, and, perhaps most important, of goals has become an important mode of operation in seeking scientific knowledge.

The trend of organizational support of science and technology can be read off the expenditure sheets. For example, federal expenditures for research and development increased from 3 billion dollars in 1953 to an estimated 15 billion dollars in fiscal 1964. The Department of Defense alone will spend about 7.6 billion dollars in 1964. Industry is following the trend. American industry spent 4.5 billion dollars on research and development in 1962, twice the amount spent in 1959.

Part of this rise is due to the rise in research and development costs. The National Science Foundation has estimated that in 1964 it costs an average of $34,000 a year in equipment and salary to keep a professional researcher at work. This figure represents a 34 per cent increase over the cost in 1960.

Despite today's seemingly widespread and liberal support of research in many fields, the support and successful execution of research still pose serious problems. Some American industries are technologically backward. While research might help these, an industry in financial difficulties, or an industry consisting of many small companies, will find it hard to establish a well-staffed and effective research laboratory and to support it through an initial period of low productivity. Agricultural research financed by the state and federal governments has helped small farmers and backward farmers, but how can science be brought to bear on the problem of small or backward industries?

Another problem is that of the huge government expenditures on space and defense programs which add little to our general scientific and technological capability. Such programs compete for personnel with industrial, university, and foundation research. Is there any remedy in comparably huge government expenditures in other fields, or in smaller expenditures on some aspects of space and defense?

However much government action may help or hinder research, the success of research depends on the individual research worker. What drives a man? What usually interests him? Here we have a problem of aligning the interest of the able scientist or engineer with what society wants, a problem that W. O. Baker, at an American Association for the Advancement of Science symposium on basic research, held in 1959, called the "paradox of choice." Baker pointed out that tackling the problems of a practical field in too narrow a manner may preclude the very discoveries that would have the most practical value. Henry de W. Smyth of Princeton University said at a National Science Foundation conference in 1960 "research has two functions—to widen man's knowledge and to apply this knowledge to his needs and longings." It seems, no matter how much the purists declaim on the beauty of research "for its own sake," that all roads traveled by astute investigators lead eventually to some utility. As J. Robert Oppenheimer puts it, "Manifestly not every finding leads straight to invention; but it is hard to think of major discoveries about nature, major advances in science, which have not had large and ramified practical consequences."

These words could describe Waksman's interest in the micro-organisms of the soil, which led to streptomycin; or Claude Shannon's theories on information transmission, which led to new sorts of communications systems; or the fundamental studies of the solid-state that led to today's huge semiconductor industry. Science and technology in New Jersey have often had "large and ramified practical consequences."

And yet, it would be blindly optimistic to believe that somehow in New Jersey astute investigators will travel on roads worthy of their journeying regardless of the nature of their education, the condition of our society, or the way in which the State and the Nation finance science and technology. Our welfare depends in a large degree on research, on science, on technology. We need to understand these things if we are to foster them wisely. This history may add something to a general understanding.

BIBLIOGRAPHICAL NOTES

Ideas on how to organize this book came primarily from the *Outline History of New Jersey* (Rutgers University Press, 1950); and John T. Cunningham, *Made in New Jersey* (Rutgers University Press, 1954). These two volumes pointed out the diversity and magnitude of technical industry in New Jersey and suggested the areas of research so important to an industry that is to grow successfully.

Much of the information on the universities and industrial organizations was provided by them in the form of brochures, reports, reprinted articles and speeches, internal publications, and letters in answer to specific questions. Other useful sources were the printed proceedings of various symposia and conferences by technical societies and material from federal and state institutions.

CHAPTER I

Of the several volumes used to cover the work of John Fitch, Thomas Boyd's *Poor John Fitch* (New York, 1935) is the most comprehensive. Other pertinent information came from William E. Schermerhorn, *The History of Burlington, New Jersey* (Burlington, 1927) and A. P. Hulbert, *The Paths of Inland Commerce* (New Haven, 1921). Additional details were obtained from *Federal Writers Project—Stories of New Jersey* (1938) and *The Dictionary of American Biography* (New York, 1936).

Background on the development of steam engines and steam boats was obtained from E. A. Allcut, *An Introduction to Heat Engines* (Toronto, 1945); and Carl D. Lane, *American Paddle Steamboats* (New York, 1943).

For further information on New Jersey's early contributions to railroading see Wheaton J. Lane, *From Indian Trail to Iron Horse—Travel and Transportation in New Jersey, 1620 to 1860* (Princeton, 1939); William Starr Myers, *The Story of New Jersey* (New York, 1945); Thomas F. Gordon, *A Gazetteer of the State of New Jersey* (Trenton, 1834).

CHAPTER II

For more on Seth Boyden see *Federal Writers Project—Stories of New Jersey* (1938). This is also a source for the work of Alfred Vail. New light was shed on the relationship between Vail and Morse in *Newsweek* (December 17, 1962) concerning the "Morse Code." For a discussion of farming in New Jersey see Carl R. Woodward, *Development of Agriculture in New Jersey, 1640 to 1880* (New Brunswick, 1927); Hulbert G. Schmidt, *Rural Hunterdon, An Agricultural History* (New Brunswick, 1945). Details on early farm instruments developed in New Jersey came from *Harpers Encyclopedia of U.S. History* (New York, London, 1902).

CHAPTER III

The most readable and comprehensive modern biography of Thomas A. Edison is by Matthew Josephson, *Edison* (New York, 1959). Other useful works include F. L. Dyer and T. C. Martin, *Edison, His Life and Inventions* (New York, 1929); Francis Jehl, *Menlo Park Reminiscences* (Dearborn, Mich., 1937); D. D. Runes, *The Diary and Sundry Observations of Thomas Alva Edison* (New York, 1948).

CHAPTER IV

For further reading on New Jersey agriculture see John Cunningham, *Garden State—The Story of Agriculture in New Jersey* (New Brunswick, 1955); Ingrid Nelson Waller, *Where There is Vision* (New Brunswick, 1955).

CHAPTER V

See Donald G. Cooley, *The Science Book of Wonder Drugs* (New York, 1954); Fred Reinfeld, *Miracle Drugs and the New Age of Medicine* (New York, 1957). See also *Fortune,* August, 1958, and May, 1960, and *New Jersey Business,* October, 1961.

CHAPTER VI

See *Chemical and Engineering News,* January 25, 1944, and *World Petroleum,* November, 1944, for history of oil technology. For specific industries see *Fortune,* June, 1958, December, 1959, and December, 1962.

CHAPTER VII

For a description of the particle accelerators at the James Forrestal Research Center see the *Princeton Alumni Weekly,* April 18, 1958.

CHAPTER VIII

See W. R. MacLaurin, *Invention and Innovation in the Radio Industry* (New York, 1946); Donald McNicol, *Radio's Conquest of Space* (New York, 1949); Orrin E. Dunlap, Jr., *Radio's 100 Men of Science* (New York and London, 1944); George C. Southworth, *Forty Years of Radio Research* (New York, 1962); *The Age of Electronics,* Lincoln Laboratory Decennial Lectures, Edited by C. F. J. Overhage (New York, 1962).

CHAPTER IX

For accounts of RCA's trials with color television see *Fortune,* October, 1962.

CHAPTER X

See Orin E. Dunlop, Jr., *Radar* (New York and London, 1946); A. E. Harper, *Rhombic Antenna Design* (Princeton, 1941).

CHAPTER XI

See *The Age of Electronics,* Lincoln Laboratory Decennial Lectures, Edited by C. F. J. Overhage (New York, 1962).

CHAPTER XII

An account of early work in psychology at Princeton is given in the *Princeton Alumni Weekly,* December 5, 1958.

CHAPTER XIII

For the history of the Institute of Advanced Study see Abraham Flexner, *I Remember* (New York, 1940).

CHAPTER XIV

See "Proceedings of a National Science Foundation Conference held in Washington, D.C., May 20, 1958" (Washington, 1958); and "Proceedings of a Symposium on Basic Research," sponsored by the American Association for the Advancement of Science and the Alfred P. Sloan Foundation, edited by Dael Wolfe (Washington, D.C., 1959).

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