WHAT IS BASIC RESEARCH?

A worker in basic scientific research is motivated by a driving curiosity about the unknown. When his explorations yield new knowledge, he experiences the satisfaction of those who first attain the summit of a mountain or the upper reaches of a river flowing through unmapped territory. Discovery of truth and understanding of nature are his objectives. His professional standing among his fellows depends upon the originality and soundness of his work. Creativeness in science is of a cloth with that of the poet or painter.

Vannevar Bush, in *Science the Endless Frontier,* says with great authority and validity:

> Basic research is performed without thought of practical ends. It results in general knowledge and understanding of nature and its laws. The general knowledge provides the means of answering a large number of important practical problems, though it may not give a complete specific answer to any one of them. The function of applied research is to provide such complete answers. The scientist doing basic research may not be at all interested in the practical applications of his work, yet the further progress of industrial development would eventually stagnate if basic research were long neglected.
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> One of the peculiarities of basic science is the variety of paths which lead to productive advance. Many of the most important discoveries have come as a result of experiments undertaken with very different purposes in mind. Statistically it is certain that important and highly useful discoveries will result from some fraction of the undertakings in basic science; but the results of any one particular investigation cannot be predicted with accuracy.
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> Basic research leads to new knowledge. It provides scientific capital. It creates the fund from which the practical applications of knowledge must be drawn. . . .
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> Today it is truer than ever that basic research is the pacemaker of technological progress. . . .

Despite this apparent unconcern for practical ends every great scientist has a profound faith that knowledge is an essential value of life. He believes that greater understanding will lead to the greater well-being of mankind. Time and again this faith has been justified. The history of science affirms the fact that basic research, though seeking no practical ends, is by no means "impractical" research.

Basic research, in terms of its immediate utility, is a game of chance. In the search for oil, many a dry hole is drilled, but statistically the eventual output far out-weighs the cost. So it is with research.

From another point of view, basic research is an investment in which, if wisely planned, the proceeds from a small portion not identifiable in advance more than pay for the total outlay.

The essential difference between basic and applied research lies in the freedom permitted the scientist. In applied work his problem is defined and he looks for the best possible solution meeting these conditions. In basic research he is released of such restrictions; he is confined only by his own imagination and creative ability. His findings form part of the steady advance in fundamental science, with always the chance of a discovery of great significance.

In our colleges and universities basic research is a necessary ingredient in the training of scientists. One of the primary missions of the National Science Foundation is to support basic research both in the cause of progress in science and of the training of scientists. But what of organizations looking for practical utilization of science, such as technical industries and many Federal agencies? For them extension of knowledge and new ideas in a special area of science may often be critically needed for a particular development. It follows that the support of basic research by an organization with practical goals is justifiable and important in areas of science closely related to the operations of the agency.

SCIENTIFIC METHODOLOGY

Many students of science and human affairs have studied the methods and procedures found effective in scientific research. It is questionable whether there is a unique, all-purpose method for attacking research problems. Different problems and different investigators require different approaches. Several observations about the working habits of scientists, however, are of interest.

One of the outstanding characteristics of science is the objectivity of its findings. Each individual researcher is trained to observe, to experiment and to analyze in as objective a manner as possible. Wishful thinking has no place in his work. He realizes that his findings will not become a permanent part of the structure of science until they have been challenged and confirmed by other investigators. Thus, science is a highly democratic process. Anyone can question a "law" of science and if he can establish his objection by proof convincing to his colleagues, it will stand. The strength of science and its power rests therefore largely upon the thorough testing of its structure at all points, and upon an interesting combination of collaboration and competition on the part of its workers, upon their independence and their integrity.

The term research covers many activities. The following paragraphs will describe some of the common activities of scientists in making their inquiries. These will be illustrated by examples taken from the research currently supported by the Foundation.

OBSERVATION AND DESCRIPTION

Careful observation and description of an event is required at an early stage in understanding and explaining it. The point seems too obvious to dwell upon, yet for hundreds of years science failed to advance because men did not see what took place before their eyes. They described nature as they thought it should behave and not as it did behave. In 1543 the publication of an atlas of anatomy by Vesalius proved a milestone in scientific thought because Vesalius based his anatomical studies upon actual dissections of human bodies. The Greeks had also done this, but for a millennium and a half the practice was discontinued and almost no further advance was made in knowledge of the human body and in the competence of surgeons. Careful observation is still a vital scientific requirement.

For example, the patient exploration, collection, classification, and description of the hundreds of thousands of species of plants and animals is the bedrock upon which our present knowledge of life and living forms is built. Two centuries ago such studies revealed the wonder and diversity of nature and sharpened man's desire to know and understand the world around him. They led directly to the formulation of important biological theories, such as those of evolution and genetics. Moreover, the practical implications of systematic biology rival the purely scientific. New plants contribute to progress in agriculture and medicine. The relationship of plants and animals to environment, soils, and climate, particularly in little known regions, anticipates extension of agriculture into such regions and the successful management of forest reserves, grasslands, and watersheds.

New York Botanical Garden

Bassett Maguire of the New York Botanical Garden has a Foundation grant to explore the botanical resources of the Guayana Highland of British Guiana. The geographic isolation of the area makes it an excellent natural laboratory in which plant evolution may be studied on a grand scale.

University of Utah

Stephen D. Durrant of the University of Utah has undertaken with Foundation support a study of mammals on the Aquarius Plateau and in the Henry and Abajo Mountains of Southern Utah. Many of the animals in this remote, isolated area are unlike related species in other localities and there is little chance for crossbreeding with species outside the immediate area. The animal populations are relatively small. Nature has in effect provided ideal conditions for experiments in evolution and the development of species. Under these unique circumstances the scientists hope to learn much about the rate and amount of change that can take place in a population in a few generations.

University of California at Los Angeles

Another type of exploratory research is being undertaken by Theodore H. Bullock of the University of California at Los Angeles. He is studying the pit organ of pit vipers, a class of poisonous snakes including rattlesnakes, copperheads, and water moccasins. The pit organ, located between the eye and the nostril, is unusually sensitive to infrared or heat radiation. The mechanism is perhaps similar to that of the heat sensitive receptors in human skin, but it is far more highly developed, both for sensitivity and rapidity of response. One of the interesting characteristics of the pit organ is its resemblance to certain man-made electronic mechanisms. The nerve fibers connecting the pit organ to the central nervous system carry a steady stream of relatively constant impulses. The impulses to the brain are modulated by changing temperatures, somewhat as a radio carrier current is modulated by sound.

American Museum of Natural History

Human behavior is probably determined in part by the instinct or the biology of the individual and in part by his training or experiences after birth. Not all psychologists agree, however, upon the relative importance of instinct as against experience, nor upon the aspects of behavior for which each is primarily responsible. A great deal can be

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learned from painstaking observation of lower animals for which controlled conditions can be established.

T. C. Schneirla of the American Museum of Natural History has a Foundation grant to study the development of behavior patterns in lower animals. He is particularly interested in those aspects of behavior resulting from the relationships between mother and young as well as between litter mates from the time of birth to young adulthood. A series of studies will be conducted on the behavioral development of young cats raised with normal access to the mother. The results will be compared with the behavior of animals raised in isolation from birth.

TOOLS AND INSTRUMENTS

One of the outstanding achievements of modern science lies in the extension of the powers of observation by the development of better tools and instruments. Although micro-organisms were postulated in ancient times, they became observable biological entities only with the invention of the microscope. Physical theories are based upon the restricted range that has been observed. It is dangerous to try to use them beyond the range of observation without testing them experimentally. The classical theory of moving fluids, for example, worked very well at speeds up to the speed of sound. At that point and beyond no theory existed. Further theoretical development, needed to describe jet and rocket behavior, required improved instruments and facilities, such as the highspeed camera and the transonic and supersonic wind tunnel.

Illinois Institute of Technology

Max Jakob of the Illinois Institute of Technology received a Foundation grant to study bubble formation, heat flow and other aspects of boiling. By means of a highspeed camera, he slows down the action permitting detailed observations and measurements to be made of bubble area and frequency which will in turn enable him to estimate heat flow characteristics of boiling liquids at the heating surface and the bubble surface.

Pennsylvania State College

At the Ionosphere Research Laboratory at Pennsylvania State College, J. J. Gibbons, A. H. Waymack and their colleagues are exploring the upper atmosphere. In this case radio waves are used to probe the unknown. For more than a quarter of a century the existence of ionized or electrified layers of particles in the upper atmosphere has been established. They are known to have a great deal to do with long-distance radio transmission and possibly with weather. The Heaviside layer—first to be discovered—ranges from about 8 to 12 miles above sea level. Many other higher layers have since been discovered. Within the past year, working on a Foundation grant, Dr. Gibbons has announced the discovery of a very high, heretofore unknown ionized layer more than 500 miles above the surface of the earth.

Harvard College Observatory

The Foundation has provided partial support to the Harvard College Observatory for construction and operation of a radio telescope, under the direction of Bart J. Bok. Radio astronomy is a comparatively recent field of study which deals with short wave radio waves generated by the stars or other heavenly bodies. Such studies promise to reveal much new information about the Milky Way, the galaxy to which the solar system belongs. Very little is known about several important sections of our galaxy, the Milky Way, because visible light from distant stars has apparently been absorbed by the "dark nebulae," immense clouds of gaseous material in between. The Harvard radio telescope will be used for a systematic study of the range of frequencies from 300 to 1650 megacycles per second. This range is of particular interest because it will provide a means of identification of hydrogen and deuterium and yield information about the temperature, densities and turbulence of these gases in interstellar space.

MEASUREMENT

Measurement is another step in research. Many scientific problems are well along toward solution when a scientist knows what to measure and how to measure it. This was expressed emphatically by Lord Kelvin:

> When you can measure what you are speaking about and express it in numbers, you know something about it, and when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind.

The development of physics from the time of Galileo is one of the great achievements of mankind. Much of the progress of physics has been due to its success in finding the proper things to measure. Mechanics progressed hand in hand with the recognition of the measurable concepts of momentum, acceleration, and energy, and the advance in thermodynamics awaited the discovery of measureable ideas like pressure, temperature, and heat. As measurements become more precise, discrepancies previously hidden come to light and suggest the need for better physical theories. The complexity of living organisms and social organizations has prevented the easy formulation of measurable concepts in these areas which in turn has hampered biologists and social scientists. What metric does one use for aging, for example, or insanity, or happiness?

Of the projects supported by the Foundation a number are concerned primarily with precision measurements and quantitative studies in both the physical and biological sciences.

University of New Mexico

On the experimental side many scientists are engaged in observing the behavior of nuclear particles and in making precise measurements of them. Cosmic ray studies are of particular value in this regard since the energy of many of the primary particles in cosmic rays far exceed energies that can be attained in particle accelerators.

V. H. Regener and John R. Green of the University of New Mexico, working on a Foundation grant, have been investigating an uncharged component of cosmic radiation called N-rays, believed to be mostly high-energy neutrons. They have been measuring the penetrating power of N-rays passing through ordinary water and heavy water by measuring the distance that the N-rays travel on the average before colliding with a nucleus in the water. Since water consists of hydrogen and oxygen, collision may occur with either type of nucleus. In the case of heavy water, heavy hydrogen replaces ordinary hydrogen but the oxygen atoms remain the same so that any observed difference in the distance of penetration should be due to the difference in the two types of hydrogen. Actually the observed difference was less than the uncertainty in the measurements. On the other hand, in both cases the penetrating power of N-rays was about four times the distance that would have been expected under the conditions of the experiment. This experimental fact has not yet been satisfactorily explained.

Duke University

Martin M. Block and Harold Lewis, of Duke University, are also investigating the action of cosmic ray particles, in this case charged particles. The analysis is complicated by the fact that the charged component of cosmic rays is a mixture of several kinds of particles and the first problem to be attacked is the separation of the various factors. This is done by measuring the mass and momentum of the particles. The problem is further complicated because some of the particles to be observed have a very short lifetime of the order of a billionth of a second.

USE OF MODELS OR ANALOGUE SYSTEMS

Creation of models or simplified systems imitating natural processes has greatly aided scientific inquiry. Some models may involve actual construction for measurement and operational studies. The testing of air-frame designs in a wind tunnel is an example. Here, measurements made on the actual model answer questions too complicated to handle mathematically. Other models, however, may be purely abstract and mathematical. They simplify the analysis and enable scientists to use the powerful tools developed by mathematicians.

Several research projects supported by the Foundation involve the design of suitable models for dealing with difficult problems.

Yale University

Wolf Vishniac of Yale University is one of a group of biochemists trying to unravel the mystery of photosynthesis, the chemical process by which plants convert the energy of sunlight into energy-containing foods and fuels. In essence, the process turns low energy compounds such as water and carbon dioxide into high energy compounds such as sugar and cellulose. The radiant energy of light is transformed into stored chemical energy. Chlorophyll, the green coloring material in plants, plays an important part in this energy transformation.

For a long time scientists tried to design a laboratory model of the process. Several investigators, including Vishniac, had successfully converted a solution of organic compounds into compounds of higher energy in the presence of light, but they could do it only when natural particles of plant material containing chlorophyll were added. During the past year Dr. Vishniac has been able to duplicate essential features of the process by exposing to sunlight a chemical solution to which pure chlorophyll was added. This development of a working model may be an important forward step in research on photosynthesis.

By controlled modification of the conditions of the experiment biochemists can now test and measure the effects of many hypotheses concerning the reaction. It is now possible to visualize production line or continuous flow processes in which high energy materials useful for food and fuel are created through the action of sunlight.

Johns Hopkins University

W. D. McElroy, of the Pratt-McCollum Institute of Johns Hopkins University, has received Foundation support for research into the nature of the biochemical reactions responsible for the luminescence of fireflies. As in the case of photosynthesis, luminescence is the result of a complicated chain of reactions, all but the last of which take place in the dark. Firefly luminescence is known as "cold light" because of the small amount of heat released in the reaction.

The light-making process of the firefly requires a fluorescent compound (luciferin), an enzyme (luciferase), a metallic ion such as magnesium or cobalt, oxygen, and a high-energy phosphate containing compound. Dr. McElroy is primarily concerned with the method by which luciferin is formed and with the role of the phosphate in the reaction. Much of his experimental material is obtained through purification of crude extracts of tissues from fireflies.

DEVELOPMENT OF CONCEPTS

One of the most difficult as well as one of the most creative aspects of research is the development of meaningful concepts. Much has been written about the creative process by which the mind working upon the raw materials of experience distills out the essences and recombines them into new, more revealing insights about the physical world. In this respect creativeness in science appears to differ little from creativeness in art or any other branch of thought.

In large part the intellectual excitement of science derives from the scope and boldness of its concepts. Their impact can be revolutionary as was the case with the germ theory concept formulated by Pasteur and Koch in which specific infectious diseases are traced to the action of specific organisms. Such a sweeping conceptual generalization not only clarifies our understanding of a host of observed natural phenomena but suggests a course of action—in this case methods for treating individual patients or for preventing epidemics.

University of Chicago

During the year the Foundation provided support for the work of Rudolph Carnap, a mathematician and logician from the University of Chicago, who is attempting to develop a new conceptual basis for probability. Probability may be defined as a measure of the likelihood of an event's occurring; but careful analysis reveals that the term actually covers two very different concepts. Both aspects of probability are highly useful in practice, and many persons feel that the two forms are closely related.

One type of probability may be called statistical or actuarial. In this case the probability assigned to an event's occurring is based upon the frequency with which it has been observed to have occurred in the past. The vast insurance business is largely built upon this concept as are many of the statistical techniques based on frequency counts.

The second type of probability is more theoretical in that an attempt is made to assign on purely theoretical grounds a measure of the probability of an event's occurring. Games of chance furnish the most obvious example. Assuming the wheel is true, the odds on roulette can be calculated. Of course, the calculated odds can then be tested by experience and if there is marked disagreement the careful player will re-examine his initial assumptions. The uses of this type of probability extend far beyond games. It has been applied by physicists to the kinetic theory of gases and by communications engineers to problems in telephone traffic.

Rational decision-making in any field is largely a matter of estimating the odds as to the possible outcomes of the decision. Depending upon the case at hand, we normally, as a basis for estimate, use one or the other of the two types of probability listed above. Carnap hopes to develop a single logical system incorporating the valuable features of both.

TESTING OF CONCEPTS

In order for science to be effective in helping us understand nature, it must be able to meet the test of experience. The testing of scientific ideas and concepts, therefore, is an important and essential research activity. It often requires great thought and ingenuity to devise suitable tests and to set up appropriate experiments.

University of Illinois

Among the fascinating mysteries of nature is the ability of living things to repair or regrow damaged tissue. In some lower animals the amount of damage that can be repaired is extraordinary. The salamander apparently can lose its tail with impunity because it is able to grow a new one. If a leg is lost, however, it is not so fortunate; it cannot normally grow a new leg. Biologists can induce growth of a new tail-like organ on the leg stump by transplanting tissue from the tail. Conversely, a tissue graft from the leg grafted to the tail stump will prevent growth of a new tail.

Evidence of this nature suggests that there are two types of tissue cells—youthful cells capable of growth and adult cells in which further growth is prevented. It further suggests that the difference in the two types of cells might be of a chemical nature and that the adult cells produce a growth-inhibiting substance. S. Meryl Rose of the University of Illinois has a Foundation grant to study regeneration of tissue and particularly to attempt to find a growth-inhibiting substance in the adult tissue. For his experiments Dr. Rose uses the hydroid, a simple animal related to jellyfishes, that lives in the sea. If one of the tentacles of the hydroid is lost, another will quickly grow out to take its place. An area of tissue near the mouth of the hydroid contains cells which inhibit the regrowth of the tentacles when transplanted to the stump. As a matter of fact growth can be prevented if large quantities of the growth inhibiting tissue is simply placed in the sea water in which the injured hydroid lives. Having obtained these results Dr. Rose is now attempting to isolate and identify the growth inhibiting factor.

Columbia University

Over the past decade the radioactive clock, developed by Willard Libby at the University of Chicago, has proved a most valuable tool for historians and archeologists. Scientists have long known that nitrogen atoms turn into radioactive carbon when bombarded by cosmic radiation in the upper atmosphere. The radioactive carbon mixes rapidly with ordinary carbon in carbon dioxide in the air and hence becomes a component part of all living plants and animals. With the death of the plant or animal, however, the mixing process stops and the radioactive carbon slowly decays while the ordinary carbon stays fixed. From the ratio of radiocarbon to ordinary carbon a scientist can estimate the age of the material being examined. Archeologists have used this method to assign dates to the remains and artifacts of early men. The radioactive clock is useful for dating organic material up to about 30,000 years old. Beyond that the amount of radioactive carbon remaining is too small to measure.

In order for the radioactive clock to be useful, however, it must run on time. This means that radioactive carbon must have been formed in the atmosphere at a constant rate over the past 30,000 years, which in turn means that the cosmic radiation has been constant for the same period. Scientists have generally assumed this, but during the past year J. Laurence Kulp, of the Lamont Geological Observatory of Columbia University, found a way to test the assumption. Dr. Kulp received a grant from the Foundation to measure the radioactive carbon content in sediments at the bottom of the ocean. In testing the assumption of cosmic ray constancy he compared the time-scale of radioactive carbon with that of ionium, another radioactive material found in ocean sediments. Since the presence of ionium has no connection with cosmic ray activity, the comparison was fair. Dr. Kulp showed that the two radioactive timescales have agreed for at least 30,000 years, and on other grounds he has reason to believe that cosmic radiation may have been constant for the past 500 million years.