necessary to bring its output of electron energy from 500,000,000 to greater than 1,000,000,000 electron volts. Operation at the new level is expected this fall.

It has become apparent that the time has arrived when the Institute must have on campus a major digital computing laboratory. It is necessary to assist in a variety of computing programs in all the divisions; it is vital as an educational asset and as a tool to prosecute research into the design and use of electronic computing equipment. Funds for this purpose are being sought.

At many points around the Institute research programs of great importance are in progress. About 530 scholarly papers were published this year. The various research-supporting agencies of the Federal Government are contributing about $2,000,000 annually to these research activities. Since these agencies submit all proposed research projects for careful review by leading experts, the many grants and contracts now in force here are an impressive tribute to the quality of the Caltech research program. The very substantial support from private sources—foundations, corporations, and individuals—is an additional tribute.

RESEARCH HIGHLIGHTS

IN THE Annual Report of the Institute, published this month, the various divisions summarize their research activities for the year 1954-55. From these voluminous reports we have extracted the following highlights from each division.

Biology

FROM THE SUBMICROSCOPIC viruses to the largest mammals, every living creature known to man contains, as components indispensable to its structure and function, the two classes of giant molecules known as proteins and nucleic acids. Every living cell in the human body contains myriads of molecules of these types. Proteins come in thousands of varieties. The one found in muscle, for example, is responsible for our movement. Many of our hormones—like ACTH—are protein in nature. The thousands of enzymes that make possible the chemical reactions responsible for life processes are proteins or contain them. Proteins protect us against disease and they are responsible for many of our allergies.

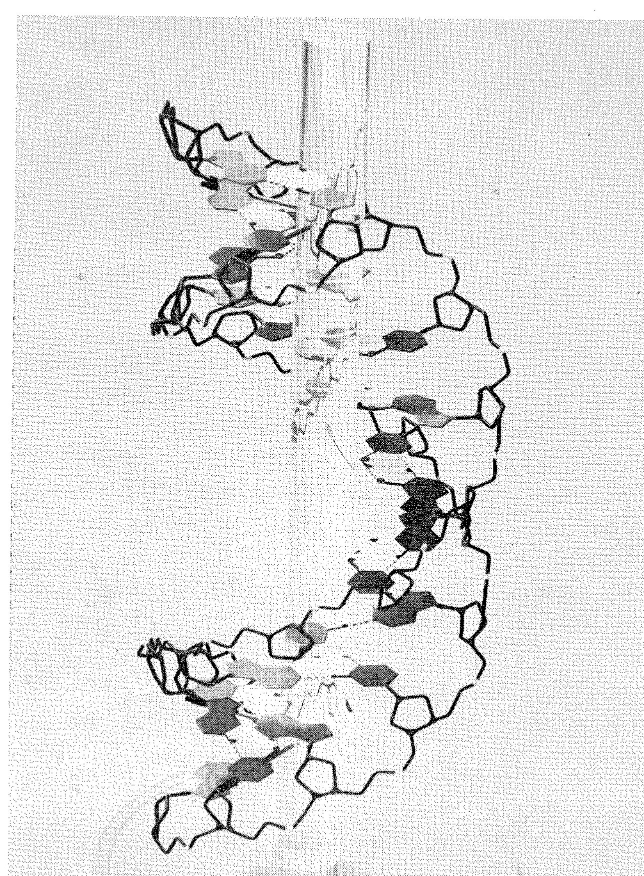
In brief, almost every activity of a living organism is concerned with proteins. Nucleic acids are closely related to proteins. It is natural, therefore, that much of the activity of the Institute's Division of Biology should center around the structures, functions and manner of formation of these remarkable substances.

Members of the Division of Chemistry and Chemical Engineering, as well as those of the Division of Biology, have contributed significantly to our understanding of the structure of proteins. A biologically attractive hypothesis as to the detailed structure of the nucleic acid of hereditary material was formulated at Cambridge University a few years ago. Since then, much attention has been given by Institute workers to problems connected with the reproduction of this type of nucleic acid, and the manner in which it transfers information to a second type of nucleic acid and to cellular proteins.

Molecular structure chemists, biochemists, geneticists, immunologists, and workers in many other related fields are beginning to reach agreement on a working hypothesis as to what these interrelations are and how they are brought about. It is believed by many that units of heredity—genes—contain information in the form of one kind of nucleic acid called DNA.

DNA is thought to be capable of duplicating itself systematically with each cell division, and of serving as a model or template from which a second nucleic acid, known as RNA, is constructed.

RNA, in turn, is believed to serve as a jig or template against which specific proteins are constructed from free amino acid building blocks. On completion of these



A model of the proposed structure for DNA, the nucleic acid of hereditary material.

Bruce H. Sage and William N. Lacey, joint directors of Caltech's chemical engineering laboratory.

specific protein molecules, they are peeled away from the nucleic acid template, and at the same time folded or turned into the shapes characteristic of enzymes and other specific protein molecules.

Wide agreement on a hypothesis of such general significance to biology as this, coupled with many advances in related branches of the field, suggests that the prospects for increasing our understanding of basic life processes have never been brighter.

Chemical Engineering

THE PAST YEAR has seen the essential completion of an extraordinary program of research in the field of chemical engineering—a basic study of the thermodynamic properties of hydrocarbons, which has provided a great amount of fundamental information for the petroleum industry.

Chemical engineering is a complex subject; it incorporates into one field the complexities of both chemistry and engineering, and for this reason many chemical engineering problems have had to be solved in a superficial way. It is clear, however, that these problems should be subjected to fundamental attack, and a program of fundamental research was begun in the Caltech chemical engineering laboratory over twenty-five years ago by Dr. William N. Lacey and Dr. Bruce H. Sage.

This program involved the determination of thermodynamic properties of hydrocarbons. One part of the work was completed sixteen years ago, and summarized in the monograph *Volumetric and Phase Behavior of Hydrocarbons,* by Sage and Lacey, which was published in 1939 by the Stanford University Press. The second, and essentially final stage in this program has now been completed. All of the equilibrium measurements on the volumetric and phase properties of pure hydrocarbons and hydrocarbon mixtures that have been made during the past quarter of a century in the Institute laboratories have now been reduced to a systematic tabular and graphical form, and published by the American Petroleum Institute in two volumes. The second of these two volumes appeared in the spring of 1955, as the book-length monograph, *Some Properties of the Lighter Hydrocarbons, Hydrogen Sulfide, and Carbon Dioxide,* by Sage and Lacey.

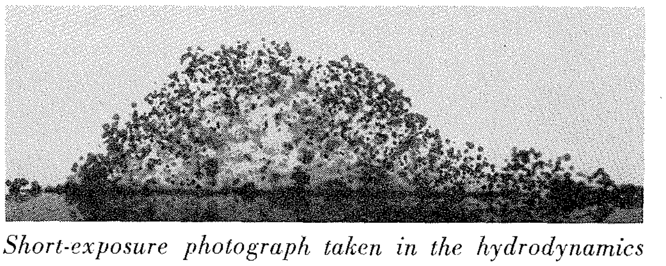
Dr. Lacey, and Dr. Sage, and their associates in chemical engineering have now extended their interests to more complicated properties that do not relate to states of physical and chemical equilibrium; in particular, problems of the transport of momentum, material, and energy in materials in turbulent flow, and the properties of materials, such as diffusion coefficients and thermal conductivities, that depend upon molecular transport.

Another extension of the program of fundamental studies in chemical engineering, in which Dr. William H. Corcoran is especially interested, involves the study of the kinetics of chemical reactions, both at atmospheric pressure and at elevated pressures and temperatures. It is expected that, through investigations along these lines, the workers in chemical engineering at the Institute will be able to make further important contributions to the basic principles of this subject, comparable to those that have been made through the investigations of the thermodynamic properties of hydrocarbon systems.

Engineering

CAVITATION, vapor bubble formation, and collapse due to pressure fluctuations in moving or stationary liquids, has been a subject of continuing interest at the Institute for its hydrodynamic effects and for the material damage which cavitation bubbles cause.

Drs. Albert Ellis, Robert T. Knapp and Milton S. Plesset, in particular, have been concerned with the material damage problems and, through theory and different experimental means, have sought basic under-



Short-exposure photograph taken in the hydrodynamics laboratory shows cavitation bubble at point of collapse.

standing of the mechanism by which cavitation damages materials exposed to its action.

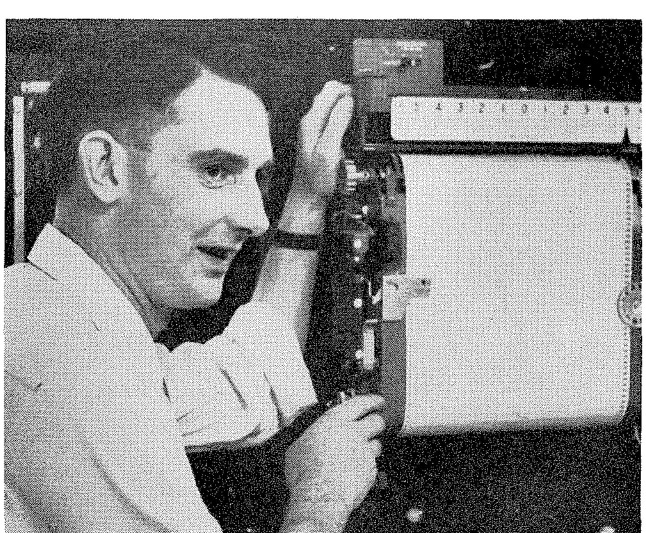
Much evidence points to the collapse of a cavitation bubble at the surface of a test specimen of a material, such as steel, striking an impulsive blow of microscopic size but of high unit stress. Repetitive action of this sort in continuous cavitation appears to be responsible for the surface changes observable by metallurgical and X-ray techniques long before the occurrence of the gross damage characteristic of cavitation in hydraulic machinery. Only recently, through techniques developed by Dr. Ellis, has it been possible to observe in a direct and quantitative manner the collapse of a single microscopic bubble and the impact stress produced in a test specimen.

Dr. Ellis and Dr. George W. Sutton (PhD '53), then a graduate student, developed ultra-high-speed photographic methods using polarized light to show the propagation of stress waves in an impacted plastic piece. These pictures are taken at the rate of approximately one hundred thousand a second and show a sequence of stress patterns from a single impact. By adaptation of these methods to a small cube of plastic about two millimeters on a side, the impact of a single bubble collapse and the stress pattern it produces have now been photographed and the magnitude of the stress determined.

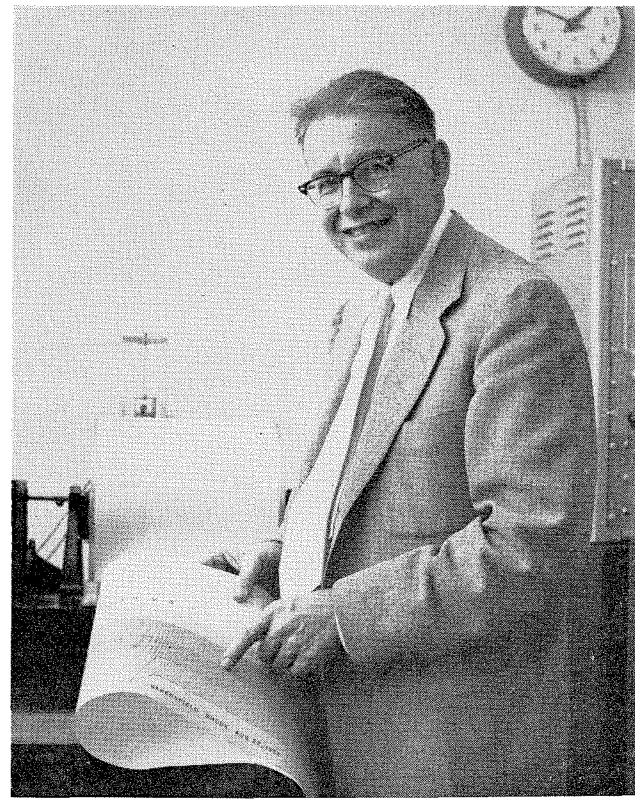
This is a unique accomplishment which is a direct experimental observation of a mechanism which until now has only been inferred from gross behavior. These results should yield new evidence on which to build an understanding of the basic cause of cavitation damage.

Geology

A MAJOR CONTRIBUTION from Caltech's Seismological Laboratory is the magnitude scale now in world-wide use for describing and classifying earthquakes. This scale is based upon empirical relations



John G. Bolton heads up the Institute's new program of research in the field of radio astronomy.



Charles F. Richter checks on the recently revised formulas relating magnitude to energy in earthquakes.

always subject to revision and refinement as more data become available.

A recent revision of the formulas relating magnitude to energy in earthquakes shows that the energy released is many times smaller than earlier calculated. In an earthquake of magnitude 6, for example, the energy released is less than 1 percent of what it was once thought to be. However, even this greatly reduced quantity is more than sufficient to cause widespread disaster. It makes no difference to earthquakes that man in his ignorance has formerly calculated their energy to be much greater than it really is. Earthquakes will go right on creating havoc and destruction until our knowledge is such that we can successfully cope with this menace.

An interesting facet of the new calculations is that they show the energy released by all earthquakes in the world during a single year to be less than the energy represented by the heat conducted to the surface from the interior. In other words, more than sufficient energy to cause all earthquakes exists within the body of the earth.

Physics

IT HAS BEEN KNOWN for some time that radio waves come to the earth from outer space, but recognition of the unusual objects in the sky which are strong sources of radio waves has depended heavily upon cooperation with the staff of the Mt. Wilson and Palomar

Observatories. For several years attempts have been made to establish the origin of strong radio sources.

It has recently become clear that work in the field of radio astronomy will provide additional information to our knowledge of the structure of the universe, and it is toward this end that a program of work in radio astronomy has been started at Caltech. John G. Bolton, who discovered the first six "radio" stars in 1948 while at the Commonwealth Scientific and Industrial Research Organization in Sydney, Australia, will direct the work, which will consist mainly of detailed investigations of the so-called radio stars, including accurate determinations of their positions, angular sizes, radio frequency spectra and, perhaps, distances. In cooperation with the astronomers at Mount Wilson and Palomar, it is hoped to secure further identification of radio stars with visual objects.

Work has already started on the fabrication of electronic receiving equipment and the development of specialized devices. The antenna system is now being designed and will probably consist of two steerable devices about 80 feet in diameter, to be mounted on a system of rail tracks. A search is being made for a suitable location free from radio interference.

Jet Propulsion Laboratory

DURING THE PAST YEAR the story of the Jet Propulsion Laboratory's participation in the development of the Corporal Guided Missile was released by the Army. The Corporal is a long-range supersonic guided missile for use against surface targets. It was announced as the Army's first missile of this type to go into production. It was also announced that Corporal units have been sent to Europe.

The development of the Corporal missile has absorbed approximately half of the Laboratory's effort for the last five years. It has required the Laboratory to carry out an extensive testing program at White Sands Proving Ground and also to establish a rocket motor test facility at Edwards Air Force Base. Much of the growth of the Laboratory during this period has been associated with the Corporal project.

Now that the Corporal is in the hands of the troops, the Laboratory is withdrawing from active participation in the program as rapidly as practicable.

The successful completion of the Corporal is an accomplishment in which the Laboratory can take considerable pride. The Army Ordnance Corps has expressed itself as more than satisfied with the short time scale and modest funds expended by the Laboratory, and with the capabilities of the resulting weapon.

Astronomy

SEVERAL MAJOR PROJECTS were brought to completion at the Mount Wilson and Palomar Observatories during the year 1954-55.

The concept of the expanding universe originated in the announcement by Dr. Edwin P. Hubble, in 1929, of linear relationship between the velocity of recession and the distance of the galaxies. Since that time the observatories have had in progress an extensive program to extend the measurement of velocity and distance to a large number of objects, including several at the extreme limit of observation with the 100-inch and later the 200-inch telescope.

Dr. Milton Humason has now completed the observation of velocities of 620 galaxies and has found velocities ranging up to about 60,000 km/sec or one fifth of the velocity of light. A parallel program, started in 1947 for the photoelectrical determination of the magnitudes of these same galaxies, has also been completed by Dr. Edison Pettit. These velocities and magnitudes provide the observational data for a critical study of the velocity-distance relationship now being carried out by Dr. Humason, Dr. Allan Sandage and Dr. Nicholas Mayall of the Lick Observatory.

A second project has been the establishment of a precise photoelectrically determined magnitude scale. This project, initiated in 1947 by Dr. Joel Stebbin and Dr. A. E. Whitford of the Washburn Observatory, with the 100-inch telescope, has been completed by Dr. William Baum, using the 100-inch and 200-inch telescopes. With the aid of the photon counter, which Baum developed, he has been able to extend the measurements beyond the 23rd magnitude in two selected areas and to the 21st magnitude in six other areas.

Since the faintest stars that can be photographed with the Hale telescope are of about the 23rd magnitude, this project has made available standards of magnitude extending throughout the range of the instrument. These standards are of great importance to many other projects, since many of these, including "the scale of the universe problem," depend on precise determination of the magnitude of faint objects for their results.

A third major project completed this year has been an investigation of the properties of the stars of the greatest absolute brightness, most of which are variable. For this project Dr. Walter Baade has taken, during the past five years, a long series of plates with the Hale telescope of each of four fields in the Andromeda Nebula. The light curves of approximately 700 very bright variable stars found on these plates have been determined by Dr. Sergei Gaposchkin of Harvard College Observatory and Miss Henrietta Swope.

In a parallel investigation, Dr. Halton Arp has obtained a long series of photographs with the 60-inch telescope of several fields of the Andromeda Nebula. In this two-year study, 30 novae were found and their light curves measured. These investigations provide, for the first time, precise information about the properties of these intrinsically very bright stars which are so rare as to prevent satisfactory study in our own galaxy. The results are of great value for other observatory projects since these stars are the indicators used to fix the distances of galaxies and other distant objects.