THINGS WE DO NOT KNOW

They may be the most important things about a university. Some comments on education and research

by L. A. DuBRIDGE

MANY PEOPLE ASSUME that the main business of a university is to deal with things that we know; that the main business of a professor is to know a lot. But some of the most important and exciting things about a university are the things we *don't* know; or possibly the things about which we know only a little and would like to know a little more. This suggests the basic truth—often forgotten—that the most valuable professor is not necessarily the one who knows the most (certainly not the one who *thinks* he knows the most) but the one who has the most consuming desire to know more.

And so it is that the most important thing about Caltech is that it contains a lot of people who realize how little they know about the physical world and are willing to spend their lives learning a little bit more.

Many an able scientist has worked all his life on things he didn't know—making slow but steady progress, yet never running onto anything earth-shaking. Others, through good luck or exceptional insight, or both, make many spectacular advances. But they never know ahead of time what their discoveries will be. That is the difficulty about exploring the unknown. It really *is* unknown; you just don't know what you will find—if anything. What we do know is but a tiny island in a vast sea of ignorance.

The ancient Greeks used to think that one could learn everything there was to know about the world by just sitting in a chair and thinking. So that is what they did. They thought up some pretty good ideas, too; but they also invented some real cock-eyed ones! And the trouble is, they did not know how to tell which were the good ideas and which were the bad. Not until Galileo came along 1500 years later and started doing *experiments* did anyone find out which Greek theories were right and which were wrong. Today we know that experiment and theory must go hand in hand in our quest for understanding the physical world.

With this introduction, let us look at some of the things going on at Caltech. Down in the basement of the Norman Bridge Laboratory of Physics we find Dr. Carl Anderson hard at work. Thirty years ago he was a student at Caltech and began working with Dr. Robert A. Millikan in his search for knowledge about cosmic rays. A few years later Dr. Anderson, in his cosmic ray pictures, identified a new kind of particle—called a positron or positive electron. It was a breathtaking discovery which earned him a Nobel prize. He has been taking pictures of the tracks of cosmic ray particles ever since and he and others have discovered several other kinds of new particles, too—mesons and V particles and K particles—and they have learned a great deal about their properties.

However, there is far more here that we don't know than we ever suspected. There is a whole array of new particles (we counted up 15 the other day) whose existence was quite unsuspected a few years ago and whose role in the scheme of things is still quite mysterious. Most of these particles are found in cosmic rays but they do not come in to the earth from outer space; they are created in our atmosphere or in the apparatus itself by other primary particles which do come in from outside. How are all these particles created? Still more puzzling—what happens to them?

Some of them exist for only a millionth of a millionth of a second and then they are gone. Where? We know about some of them; they simply blow up into other particles or vanish into radiation.

Some of these particles—mesons—clearly have some terribly important part to play in holding nuclei together. But just how? They do not have any real existence in nuclei. Yet they can be knocked out of nuclei!

To find out more about these questions, Dr. Robert F. Bacher and his colleagues have built a synchrotron in the big building where the 200-inch mirror for the Palomar telescope was ground and polished. This machine has been making half-billion-volt X rays; it will soon be boosted up to a billion. Such high-energy X rays are pretty good at knocking mesons out of protons.

The atomic nucleus

Now the proton—the nucleus of hydrogen—is the one particle that we used to think was a permanent elementary thing. Yet any number of mesons can be knocked out of it—leaving a neutron behind which promptly converts itself back into a proton! A mysterious process, indeed, in which energy is being converted into matter.

There are thousands of unknowns there. Maybe some day we will be able to learn how the atomic nucleus is put together. Right now all we know is how to make it fly apart. Just that knowledge will soon be the basis for a new power industry. But there is so much *more* to learn.

Even the astronomers are becoming nuclear physicists these days. We know that the sun is a kind of continuously operating H-bomb—deriving its energy from nuclear processes which, on a small scale, we can observe in the laboratory. Hence, we can hope some day to know more exactly what goes on in the sun and in the stars. Some of the stars are very different from the sun—are kept warm by a very different set of nuclear processes. Is the sun a sort of second or third generation star, descended from other types? Or are the other types descendants from stars like the sun? What is the evolutionary history of the stars? A quantitative study of the nuclear reactions which go on in stellar interiors—a long and very complex series of nuclear transmutations—is revealing the actual figures from which calculations can be made which will reveal the true story. Dr. W. A. Fowler and two visitors from England, Dr. and Mrs. G. R. Burbidge (*see page 17*), are making exciting progress on this problem.

Let us now cross the campus and look into the biology building. We have, as a matter of fact, just completed a new building there—the Norman W. Church Laboratory of Chemical Biology. In this laboratory, members of our Division of Biology join with the members of our Division of Chemistry for a joint attack on a whole series of unknown questions concerning the chemistry of living materials.

One of the most important living materials and one of the most interesting is that group of mysterious particles called viruses. A few short years ago almost everything about viruses was unknown. All that was known was that they were substances which caused diseases in plants and animals—but were too small to be seen in the most powerful microscope, and even too small to be filtered out in the finest filter. Nevertheless, ways were found for studying these viruses and the electron miscroscope now makes it possible to actually see them. There are many, many kinds of viruses—some shaped like cylinders, some like spheres, some like tiny hair-like snakes, some like tadpoles. These little objects constitute a kind of transition state between inanimate and animate matter. Each virus particle is actually a rather simple system made up of a few very complicated molecules. The virus substance can be crystallized, stored away, and kept in a bottle on a shelf for years like any other chemical. However, when the substance is put into the proper environment—the right living cell—the molecules suddenly come alive and begin to multiply.

Some types of viruses live only on bacteria and in living on them destroy them. Many of these are friendly viruses which could conceivably provide us with powerful tools for fighting diseases caused by bacteria. Other viruses, however, such as that of poliomyelitis, attack the nerve cells of animals; they may destroy them and therefore cause serious disease. We have an active virology laboratory at Caltech and in the new Norman Church building a suite of rooms has been provided with the finest equipment for virus research.

A few years ago Dr. Renato Dulbecco and his colleagues discovered a completely new technique for studying animal viruses—a technique which now enables them to make 100 experiments in the time and at the cost for a single experiment a few years ago. As a result, information is now being rapidly collected on how these creatures behave, what substances they live on, and how they grow and multiply.

Viruses and genetics

As with more complicated organisms, each generation of viruses inherits the characteristics of its parents, but there are frequent mutations and new genetic strains develop. The study of the genetics of the viruses has a double value: (1) It sometimes happens that a new strain will be developed which is relatively harmless and yet it will cause the animal tissue to develop antibodies which will kill the other harmful strains; thus vaccines against harmful viruses may be developed. (2) At the same time the virus, being a simple creature, has simpler genetic properties than, say, human beings and hence we can learn much more about the mechanics of the inheritance process.

As a physicist, I have never understood the complex subject of inheritance. All I know is that the unit of all inheritance, the gene itself, is also one of these particles that lie at the transition zone between the living and the dead. Like the virus, it is also a large and complex molecule, and in recent years important progress has been made in learning about the structure of the molecule. The extraordinary thing about these gene molecules and the virus molecules is that, when placed in the proper environment, each can serve as templates or molds to form or build up other molecules just like themselves. This suggests that the basic process of reproduction in all living things is that of complex molecules serving as a pattern to form, out of surrounding material, other molecules precisely like the originals.

Yes, biology is a fascinating and important subject—full of interesting unknowns.

But let us turn to our laboratory of geology.

The research worker in geology is usually thought of as a person equipped with a pair of high boots and a hammer who hikes into the mountains to bring back interesting rocks—especially rocks which might contain gold or uranium.

Well, of course, geology does deal largely with the earth's crust—which is largely rock—and so depends heavily on detailed exploration of the earth's surface. But new tools and techniques have been added in recent years—the tools of the nuclear physicist and of the isotope chemist, for example.

A primary interest of the geologist is the history of the earth—how it was formed, how the mountains and seas came into being, something about the rise and fall of various forms of life which have left their fossil remains—and also the processes now going on, such as volcanic activity, changing climate, the building of coral islands in the sea.

The earth

There are lots of things we don't know about the earth. We do not even know the answer to such a simple question as whether the earth as a whole is getting cooler or warmer. Of course, we know as we go down deep in a mine or an oil well that the temperature rises, which means that heat is flowing up to the surface and escaping into space. In the old days, this was regarded as quite adequate evidence that the earth is cooling off. But with the discovery of radioactivity it was realized that there was a source of heat in the earth—uranium, radium and other radioactive materials are slowly decaying, losing a part of their mass, which is transformed into heat. It turns out that quite a lot of heat is generated in this way. We still do not know whether the rate of heat generation is greater than the rate of loss—that is, whether we are getting hotter or colder.

Modern chemistry has provided a new tool for learning something of the temperature history of fossil shells as found, for example, in sedimentary rocks. It turns out that the ratio of abundance of the two isotopes of oxygen—O^{16} and O^{18}—contained in most living material depends on the temperature at which the material was formed. Thus we are able to determine the temperatures which existed hundreds of millions of years ago. We already know from examining the animals in the La Brea tar pits that less than 100,000 years ago southern California was both wetter and hotter than it is now. As yet, however, there is no decisive evidence that the earth two billion years ago was either much hotter or much colder than now.

It has been recently determined from the ratios of lead isotopes in meteorites and materials of the earth's crust that the earth is just about 4½ billion years old—that is, it has been solidified in its present form for that long. The astronomers now believe that the universe is only about 5 billion years old—so if the earth did much cooling off after it was formed it must have done it pretty rapidly!

Hotter or colder?

Actually, since the half-life of uranium is only about a billion years, there was much more of it on the earth 4½ billion years ago than now. So the earth might have been formed cold—then been slowly heated up for a billion or two years by the uranium and then gradually cooled off as the uranium disintegrated. We don't know whether we have already passed, or not yet reached, the maximum temperature. Professor Harrison Brown is directing a group of geochemists in the attack on such problems.

The Division of Geological Sciences is also the place where they study earthquakes. (Our Seismological Laboratory is, in fact, one of the best equipped—probably *the* best equipped—in the world.) Earthquakes are interesting to southern Californians for obvious reasons. For example, over in the Engineering Division our structural engineers apply synthetic earthquake-vibration patterns to simple model structures—like buildings and bridges. They can then tell you how to design a building so that it will not fail in a severe earthquake. That's one thing they *do* know.

But earthquakes are interesting geological tools, too. Seismologists are very much pleased when a quake occurs for these disturbances serve as probes to explore the interior of the earth. Indeed most of what we know about the earth—down below the 4 or 5 miles you can go with an oil well—has been learned from earthquakes, either natural ones or man-made ones. The waves from an earthquake which occurs, say, in Borneo will travel clear through the center of the earth and come out in Pasadena. In fact, a whole series of waves will bounce off various discontinuities in the earth, be reflected back from the surface and give rise to the most complex patterns of wiggles on a seismological instrument. Dr. Beno Gutenberg and his colleagues have learned how to sort out these wiggles and can tell which ones are waves which came through—or bounced off—the earth's core.

Other earthquake waves travel along the surface through the earth's crust—and from the speed with which they travel, the way in which they are reflected, and the differences in travel time between waves of different frequencies one can learn a great deal about the structure of the earth's crust, about the formations which are inaccessible under the bottom of the sea and about the structure of the roots of the mountain ranges.

There are, of course, two kinds of research which go on at Caltech: pure research, which is the discovery of new knowledge about nature; and applied research, which is the application of this knowledge to develop devices or techniques of practical use to men. Many people think of Caltech as the home of pure research—the search for knowledge for its own sake. We are indeed glad to have and even to promote this reputation, for we are proud of the achievements in pure research of the Institute over the many years since Dr. Millikan's pioneering work here, beginning in 1921.

Practical matters

However, it is very unfair to a large segment of our campus to pretend that there is no work of a practical nature under way—no attempt to apply the knowledge of science to things that are beneficial and directly useful. Our Engineering Division makes it its business to carry on research in the various fields of engineering and to apply scientific knowledge to the development of such things as chemical processes, design of machinery, the study and development of metals and alloys, the study of the behavior of turbines and pumps with an eye to improving their effectiveness and efficiency, studies in the best design for various types of structures—including the work I have already mentioned in earthquake resistant structures—a study of high-speed aerodynamics with an eye to the design of supersonic airplanes and guided missiles, and the study of materials useful in the structure of aircraft and of jet engines.

Some of the first wind-tunnel tests on large models of aircraft ever made in the United States were made in the old wind tunnel of the Guggenheim Aeronautics Laboratory at Caltech in the late twenties, and these tests plus the succeeding wind-tunnel work which went on there in the early thirties did much to build and strengthen the aircraft industry of southern California. The modern wind tunnels at Caltech, instead of operating at speeds of 180 miles an hour, operate at speeds of from five to ten times the speed of sound. There is even one small experimental wind tunnel using helium instead of air which for short periods can attain speeds of twenty times the speed of sound.

The work done in the High Voltage Laboratory by the electrical engineers on the problem of the transmission of electric power over great distances resulted in the development of high voltage transmission techniques which made possible bringing electric power from the High Sierras and from the Colorado River to Los Angeles.

In the Hydrodynamics Laboratory there are water tunnels which serve for water-borne craft and undersea craft the same function that wind tunnels serve for aircraft.

Throughout all the engineering departments there is work going on which has made possible the design and building of more effective equipment, machinery and devices now being manufactured by American industry.

But it is not only in engineering that work of practical importance is done. An able biochemist, Dr. A. J. Haagen-Smit, a few years ago began to get curious about the chemical nature of the Los Angeles smog. Up to that time, it was actually unknown what particular chemical materials were responsible for the objectionable effects of smog, such as eye irritation, the cracking of rubber and damage to plants. Some thought the irritating substance was black smoke; others thought it was sulfuric acid formed from sulfur and others thought it was fumes from synthetic rubber plants. Actually, the irritating substances turned out to be materials formed in the air by the action of sunshine on the vapors of unburned oil and gasoline and the oxides of nitrogen. The oxides of nitrogen, it turns out, are formed in any combustion process. The raw gasoline and oil vapors are emitted into the air in a variety of ways — through evaporation of gasoline from tanks, from filling stations and from cars, as well as through the emission of unburned hydrocarbons from the exhausts of cars, from the stacks of oil-burning fires of many kinds. The problem of eliminating smog, then, is the problem of stopping the emission into the air of hydrocarbons and of the oxides of nitrogen. To reduce by a large amount the emission of either of these types of substances is not an easy problem; but whether it is easy or not, that is the problem which we must solve if air pollution in Los Angeles is to be reduced.

Research and education

There are, of course, many other things of interest that are happening on the Caltech campus. The field of the unknown is a vast one and the attacks on it are going forward on many different fronts.

Nevertheless, I should like to emphasize that, with all the research going on, Caltech is primarily an educational institution. Our major function is to select young men who have exceptional talents in the fields of science and engineering; to assist them in developing their talents to the maximum degree; and to help them prepare themselves for careers of exceptional usefulness in extending the bounds of scientific knowledge, or in applying such knowledge to the satisfaction of human needs, or in becoming teachers to carry on the education of the next generation. Since a large fraction of our students will be going into research, development and engineering work, it is obviously necessary that their professors be actively engaged in such work. Our research work therefore is an inherent part of our educational program and vice versa. At Caltech education and research are not two unrelated activities but they are heads and tails of the same coin.