COSMIC RAY RESEARCH

By PROF. WILLIAM H. PICKERING

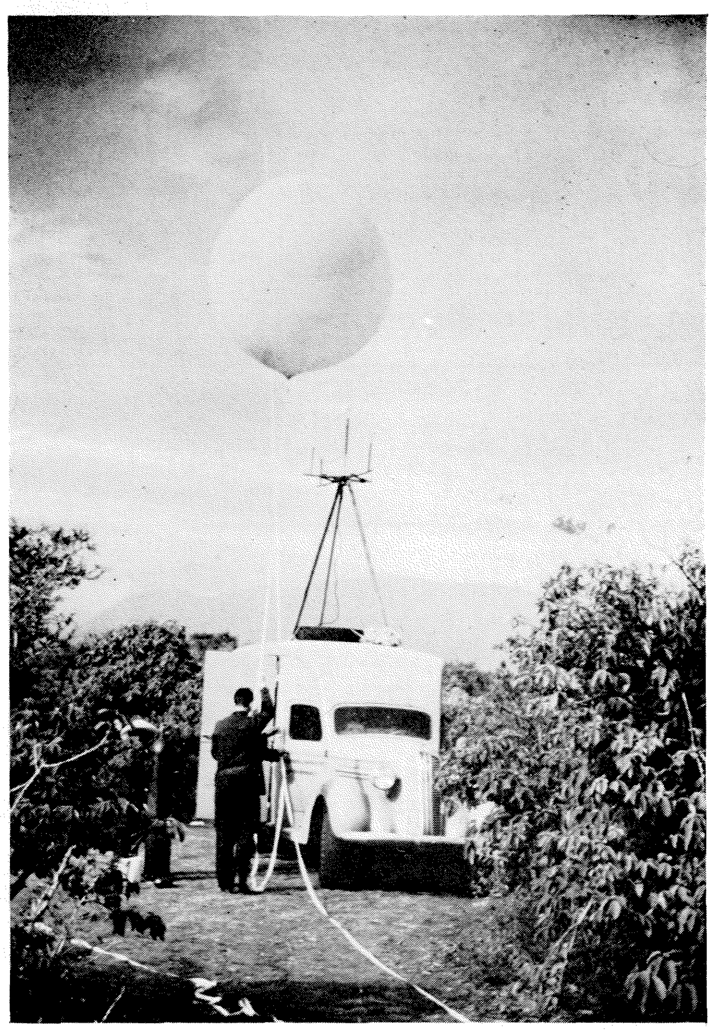
Many of us have wondered about the nature of cosmic rays and the equipment used in studying them. Dr. Pickering presents a qualitative answer in the following article.

For the past ten or fifteen years physicists in all parts of the world have shown a great interest in research and study of the cosmic ray. Here at the Institute, under the leadership of Dr. R. A. Millikan, a large and active group have contributed many important discoveries in this field. One phase of the work is described in the following article:

First, a few lines on the question, "What are cosmic rays and why have physicists devoted so much effort to these investigations?" Briefly we can say that cosmic rays are rays of somewhat the same nature as x-rays or the radiations from radium, which are continually bombarding the earth from outer space. They differ from these mundane radiations in that they have enormously greater energies. Thus the radiations from radium have energies of about a million electron volts; that is, they correspond to the radiation produced by a million-volt x-ray tube. Other artificially produced radiations might have energies reaching up to a few tens of millions of volts. The cosmic ray energies, on the other hand, are measured in the billions of volts. Because of this enormous energy, much of the radiation can penetrate through the earth's atmosphere down to sea level and even beyond. The atmosphere, of course, is equivalent to 76 centimeters of mercury, or about 30 feet of water, and so no ordinary x-ray can penetrate very far through it.

Cosmic ray investigations might conveniently be divided into two categories. First, the rays provide the physicist with a natural source of radiation possessing an energy much greater than any other source, either natural or artificial. Hence, by a study of the passage of this radiation through matter, the physicist can extend the realm of his nuclear studies into a region far beyond the limits that can be reached by any other means. Secondly, the physicist and the astrophysicist together have an interest in the nature and origin of the rays. How can such tremendous energies be generated? Why are the rays so constant in intensity between day and night, winter and summer? What is the actual nature of this radiation? Is it a high energy, very short wavelength electromagnetic radiation, or does it consist of charged particles? In both of these categories much has been learned, many questions have been answered, but much remains to be solved. The particular investigations that we are discussing deal with the problem of the energy spectrum of the primary rays incident upon the earth's atmosphere. They also permit the testing of an hypothesis as to the origin of the radiation, for clearly a knowledge of the energy spectrum of the radiation will give considerable information about this important point.

One might well ask how the energy of these rays can be measured when this energy is so tremendous. The principle is very simple. We all know that a magnetic field exerts a force on an electric current. Here the electric current is the incoming



Above — A view of the traveling laboratory, showing a balloon about to be released.

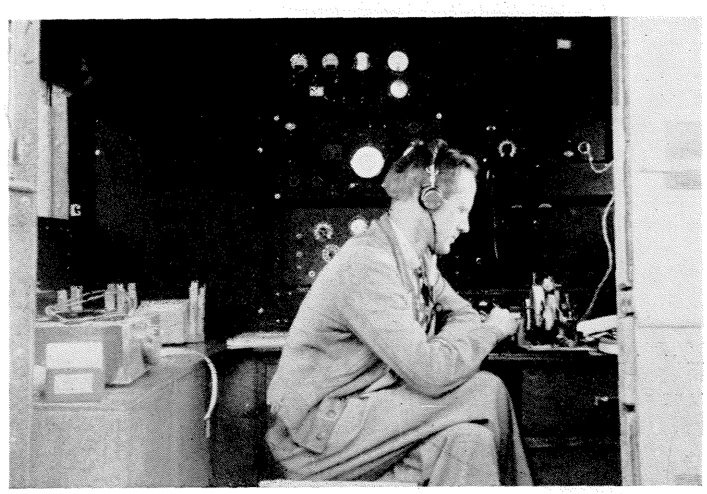
Right—The compact detector and radio transmitter unit ready to be sent aloft.

Another view of the truck laboratory.

stream of cosmic ray particles, the magnetic field is the field of the earth itself, and the force exerted on the particles bends their straight path into a gigantic spiral. Calculations show that there is a definite relationship between the energy of a cosmic ray particle and the latitude at which it strikes the earth. Only the most energetic particles are able to reach the equator, while all particles can reach the magnetic poles. Hence, if we can find out how many particles are reaching the earth at different latitudes, we can deduce the energy spectrum of the incoming radiation, or at least the spectrum of the charged particle component of the radiation. The problem then reduces to measuring the amount of incoming radiation at different latitudes. This requires that we measure the radiation present at the top of the atmosphere or, since that is unattainable, at the very highest altitudes possible.

Two methods have been developed for doing this. Both involve sending an instrument aloft by means of balloons. In the first method the instrument is an electroscope and an arrangement to make a photographic record of its rate of discharge. In order to get a sensitive record at all altitudes it is recharged every four minutes, this being done by a contact mechanism which connects it momentarily to a charged condenser. The discharge rate gives a measure of the ionisation present, and thus of the cosmic ray intensity. In addition to this record, a barometer and temperature record are also placed on the film so that a correlation between cosmic ray intensity and barometric pressure is obtained. Flights with these instruments require the recovery of the instrument in order to obtain the record. Since an average flight will travel about 100 miles from its starting point, there are not many places where 100 per cent recovery can be expected. The second method avoids this trouble by using radio to send the information back to the starting point while the flight is actually in process. This method involves using a different type of detector for the radiation than an electroscope, because of the obvious difficulties of connecting an electroscope to a radio transmitter. The detector used is a Geiger counter. This useful little device is essentially a copper cylinder with an axial wire. It is placed in a partial vacuum and a high voltage connected between wire and cylinder. When an ionizing particle passes through the counter a momentary breakdown takes place and a relatively large voltage pulse is obtained. This can then be amplified and made to run a loudspeaker, or a relay, or ring a bell, or do anything else that an electric current is able to do. In our apparatus we make it operate a radio transmitter. Then, on the ground, we receive a pulse and have this recorded on a moving paper tape. Barometer and temperature signals are also radioed to the ground station by a method similar to one used in a radiometerograph. Another advantage of the Geiger counter is that it can be connected into an electric circuit, which will respond only to simultaneous pulses between two or more counters. Thus, we can connect up two Geiger counters in a vertical line and only record those particles which operate both counters simultaneously. Such particles, of course, must be shooting in a vertical direction. This selectivity enables us to make a much more accurate study of the energy spectrum of the radiation than can be done with the electroscope, which responds to rays coming from all directions. The reason is that the energy which a particle arriving at the earth will require, is dependent not only on the latitude but also on the direction of arrival. By recording only the vertical particles, we then know exactly what minimum energy is possessed by the rays we are counting.

This radio and Geiger counter instrument, the cosmic ray radio-sonde, as we call it, has been used for observations at several different latitudes during the past three years. At the



Dr. Pickering receiving signals from one of the balloon units.

end of 1939, flights were made in India, in order to obtain information near the magnetic equator. Last year the equipment was mounted in a truck to form a completely self-contained traveling laboratory, and in December observations were taken in Mexico. In April of this year some additional data were taken in Utah and Idaho. The series of flights made so far give a fairly good picture of the variations in the radiation at latitudes extending from about 50° to the equator.

Now that the traveling laboratory is being used, the procedure in making a flight is somewhat as follows. First, a good location is chosen. This requires a spot completely out of sight of any automobile traffic or power lines, because of the danger of electrical interference on the receiver. It also requires a reasonably good horizon, so that when the balloon is near the end of its flight it will not be hidden behind some mountains. At the very short wavelength used for the radio, the signals only travel in straight lines. If the balloon was below the horizon it could not be heard on the radio. In Los Angeles county, at least in prewar days, good locations were very scarce, as we have found to our sorrow. We finally found a good spot about fifty miles from Pasadena. The next step is to prepare the instrument for the flight. It is placed in a bamboo cage for protection, and then wrapped up in cellophane for thermal insulation. The cellophane is partly clear and partly black. We have found that it is possible to keep the temperature inside the basket to within about 10 degrees of the ground temperature during the whole flight. To lift the instrument two balloons are generally used. They are inflated equally with hydrogen to a diameter of about five feet. This gives a total net lift of about 4800 grams. The instrument weighs about 3500 grams so that 1300 grams upward pull is available. This will give a rate of rise of about 1000 feet per minute. A good flight will go up for about 80 or 90 minutes, then one balloon will burst, and the remaining balloon will lower the instrument to the ground at about the same rate as the ascent. Since we use about 100 feet of tape between balloons and instrument, the remaining balloon makes a pretty good marker after the landing and we hope that some of the local inhabitants will have their curiosity aroused and retrieve the instrument for us. We offer a suitable reward to help the process along.

In India we were rather surprised to get about three-quarters of our instruments back. It took a long time, but eventually they arrived in Pasadena. The Indian Meteorological Service provided us with a suitable reward notice with instructions in three different languages. Even in the remote villages of the tribesmen on the northwest frontier it seemed that someone could read at least one of the languages. One instrument that was released at Peshawar was recovered and returned very promptly. It seems that the tribesmen saw the balloon drifting down to earth in the late afternoon sunshine. They approached the instrument, only to hear an ominous buzzing sound. This confirmed their worst suspicions, and they gathered at a respectful distance to watch the inevitable exposion. Soon the whole village was waiting hopefully, and so, far into the night . . . The next morning some of the bolder ones decided it was a dud; after a few exploratory stones had been hurled at it, they investigated in detail. The reward notice instructed them to turn the instrument over to the nearest government official, in this case a British Army office a mere thirty miles away, and what is a thirty-mile walk when a silver rupee is at the other end! Early the following morning we had our instrument again, as the Army officer, with a commendable scientific curiosity, drove the sixty miles to Peshawar to find out what it was all about.

Our Mexican experiments were performed at Victoria and at Acapulco. To date we have not received any of our instruments back from Mexico, although we have had a report that two of them have been located. Probably they will be back "mañana."

Because of the press of other work, the observations taken in Mexico and in this country have not yet been calculated in detail. However, they do seem to give support for the hypothesis of the origin of the cosmic rays which has been put forward by Millikan, Neher and Pickering. This hypothesis starts with the experimental fact that the cosmic rays seem to be uniformly distributed in space. The implication is that they do not have their origin in either the sun or the stars, but that they are formed in interstellar space. We know that there is a very small density of atoms in interstellar space so the hypothesis is made that these atoms can, by a process of self-annihilation, convert their mass energy into kinetic energy of two cosmic ray particles. Two particles are needed to give conservation of momentum in the process. Although no direct evidence for such a process has been observed, nevertheless we do know from experiments in nuclear physics such as those of Lauritsen and Fowler at the Kellogg Radiation Laboratory, that a part at least of the mass energy of an atom can be changed to kinetic energy of a pair of electrons. The extension of this process to the conversion of all of the atomic mass into kinetic energy is not unreasonable. If this process is the cause of the cosmic radiation, then it follows that the cosmic rays should have only certain definite energies corresponding to the annihilation of certain definite atoms. Each kind of atom would give rise to particles of a definite calculable energy. Now observations of the stars, and particularly Bowen's observations on the ring nebulae trillions of miles away from the nearest star, and therefore presumably giving a fair picture of the conditions in interstellar space, show that there are only six kinds of atoms that are very abundant in space. All the rest are relatively rare. Hence, on the above hypothesis, most of the cosmic ray particles should have energies corresponding to the annihilation of one of these kinds of atoms. The lowest energy particles would correspond to hydrogen and would be so low in energy that they could not get past the magnetic field of the sun to reach the earth. The next atom is helium which would give rise to two billion volt rays, then come carbon, nitrogen and oxygen to give a band of energies between 6 and 8 billion volts. The last is silicon with an energy of about 13 billion volts. This is the theoretical energy spectrum according to the hypothesis. Experimentally the evidence for the 13 billion volt energy is excellent. The 6 to 8 billion volt band has been known for some time and the most recent data appears to give added strength to the hypothesis by confirming that there is essentially no energy in the spectrum in the regions between these bands. However, until the data is completely evaluated, we cannot put a definite figure on the actual energies in the various parts of the spectrum.