the past. I hope that our other meetings this year will see much new equipment exhibited by members of the association.

EDWARD B. COOPER, *Chairman*

COSMIC RAYS

Address by REV. JOHN A. TOBIN, S.J.

The discovery of cosmic radiation is a great tribute to the scientific method of observations, measurements, and logical reasoning. In all branches of science we try to train the student to observe the variations, measure the constants, and reason by induction to the laws of science. If the facts are not true, then all the good logic in the world cannot give a true conclusion. When the logic is faulty then all the good experiments and measurements cannot reach a true conclusion. The history of the discovery of cosmic rays gives us many examples of false conclusions that came from false facts and good logic, or from false logic and good experiments. In the history of cosmic rays one error came from stating a universal law from a small number of experiments. Within the limits of induction we may affirm or deny that which was affirmed or denied about the particulars under this universal subject. This was called the "Argument from Experience." The difficulty is practical rather than logical. The logical process is abstraction. A constant effect demands a constant cause. When we find the quality that is indispensable in causing the effects, it is not difficult to make the law. But the practical difficulty is the experimental elimination of all the other factors that do not cause the change. The history of the discovery of cosmic rays proves that this elimination is no easy matter. The great complexity of the order and the difficulty of making accurate observations offered many difficulties.

To understand what we mean by cosmic rays and what we mean by the difficulties of logical reasoning from the measurements it is helpful to know the history of the discovery, the four types of instruments that were used to measure the rays and the results obtained in these measurements.

The discovery of X-Rays in 1895 by Roentgen prepared the way for the discovery of radioactivity by Bequerel. In 1898 the Curies discovered radium. It was soon observed that the positive particles or alpha rays, and the negative particles or beta rays, or the radiations like X-Rays or gamma rays all had the common property of making gases electrically conductive. Ions of positive and negative electricity were formed in the gas and moved in opposite directions in an electric field. This current could be measured and the number of ion pairs formed per second in each cubic centimeter (q) could be determined. This gave the total intensity of all radiations coming into the ionization chamber. At first this was considered as caused by radioactive substances. But in 1901 C. T. R. Wilson in England, and Elster and Geitel in Germany proved that the stagnant air in a dustproof sealed vessel had the property of conducting electricity. So the cause of ionization was not the air in the vessel, as the radon and its decay products die out in time used to hold the air. Some other source than the enclosed air must be the cause. Three other sources were then known. The earth had radioactive substances, the metal of the ionization chamber had these radioactive substances and the air surrounding the chamber had these same substances. In 1903 Rutherford and Cooke, and McLennan and Burton in Canada observed that 30% of the ionization was cut off by a thickness of a lead screen of two inches. The air and the earth were removed as causes by making the measurements over the ocean. In 1905 A. S. Eve in Canada stated that the small amount of radioactive substances in the air would not be sufficient to account for the ionization found over water. From his measurements he computed that the radioactive substance in the air could only produce one-tenth of the effect produced over the water. If we represent the total ionization as q and the ionization caused by the earth as q_e and the ionization caused by the air as q_a and the residual ionization caused from impurities in the metal as q_0 then the equation read $q=q_a+q_e+q_0$ but there was still another amount called q_c. For example you find ten dollars in the cash drawer. In making out the accounts you find that there was three dollars (q_0) in the drawer for cash, one sale was four dollars (q_e) and another sale was one dollar (q_a). But there are still two dollars to be accounted for. This was the problem that Fr. Theodore Wulf, S.J. tried to solve. What was the cause of this ionization that did not come from the earth, the air or the metal. For example the capacity (c) of the apparatus was 34.6 cm. The volume (w) was 27,000 cc. Fr. Wulf used his own electrometer, but using a Lindemann electrometer the time (t) to pass five divisions (n) was found to be 89.7 secs. and the value of each division (s) was calibrated as 46 divisions per volt. From the general equation the value of total ionization was determined.

$$qew=\frac{c}{300}\times\frac{dV}{dt}\cdot \quad \text{But } \frac{dV}{dt}=\frac{n}{s\times t}=\frac{\text{volts}}{\text{per sec.}}\cdot$$

$$\therefore \quad q=\frac{1}{ew}\times\frac{c}{300}\times\frac{n}{s\times t} \quad \text{or} \quad q=\frac{1}{4.8\times10^{-10}\times27{,}000}\times\frac{34.6}{300}\times\frac{5}{46\times89.7}=5.4I.$$

In 1910 Fr. Wulf determined the ionization at the foot of the Eiffel Tower, after subtracting the residual as six Ion pairs per sec. per cc. or ($6I$). At the top of the Eiffel Tower he found 3.5 I where there should have been none, as the air should have absorbed the radiations from the earth. Fr. Wulf constructed his own apparatus and his own electrometer. He observed and measured. Then he reasoned logically that either there was another source of radiation in the upper atmosphere or the absorption of gamma rays by the air was smaller than given at that time.

Dr. Victor F. Hess, now Professor of Physics at Fordham University, and Nobel Prize winner in 1936 for the discovery of cosmic rays, writes, "After reading the account of Fr. Wulf's experiment, I decided to attack the problem by direct experiments of my own." Dr. Hess removed the second suggestion of Fr. Wulf by measuring the absorption of gamma rays in the air and found that they were completely absorbed in 500 meters of air. So then Dr. Hess tested the second conclusion. He made ten balloon flights and found the following interesting facts. At 500 meters altitude there were $2I$ less than on the ground, at 1500 the same as on the ground, at 3500 there were $4I$ more than on the ground and at 5000 there were $16I$ more than on the ground. In 1912 Dr. Hess concluded that the observed effect could only be interpreted by assuming that a very penetrating radiation of extra-terrestrial origin exists. He called them "Weltraumstrahlung." A. Gockel in Switzerland had made three flights with Fr. Wulf's electrometer but instrumental errors had masked the results. The practical difficulty of removing sources of errors was studied and in 1913 and 1914 Kohlhoerster went up to 9300 meters and verified the observations of Dr. Hess. Since that time many measurements have been made and they are so clear that reason demands some new and very penetrating radiation that comes from the ground. Here we can note from the altitude effect a bit of poor logic. Millikan and Bowen in Texas noted this altitude effect but their measurements were different from Dr. Hess. The conclusion that Dr. Hess was wrong was not true. In 1930 J. Clay observed a new effect, the latitude effect. So both measurements were correct for their own latitude. Another false induction was noticed at this time. Observers who measured the intensity from 40° to 80° North did not observe the latitude change. Their conclusion that there was no latitude effect was false. It is noticed from 40° to the equator. The World War stopped the work but in 1925 Millikan and Cameron proved from their observations at great depths in snow-fed lakes that these rays are very penetrating. In 1932 both Compton and Millikan made a study of these rays all over the earth and verified the altitude and latitude effects. As the rays were deflected in the earth's magnetic field as noticed in the east-west asymmetry effects it was reasoned that they must consist mostly of charged particles that would be deflected into these fields. These facts removed some of the false conclusions that came from very fine logic but on the foundation that the rays were electromagnetic radiations. It is now universally admitted that these particles originate outside the earth's atmosphere. When we realize the practical difficulties of removing 80% of the radiation that comes from the earth and the instruments, and the great difficulties of measuring the cosmic rays at high altitudes, then in deep mines and then in the open ocean, and the work of coordinating results all over the world, it is interesting to note how the instruments proved the logical conclusion of Fr. Wulf that there was a new radiation of greater energy and penetration than we have on earth.

There were four methods used in the experiments on cosmic rays. The first was the ionization chamber and electroscope. The discharge method allows the current to leak off from the charged electrometer. In the charge method there is a flow to the electrometer. To avoid large chambers the small chamber is used at high pressures. To avoid recombination as much as possible argon gas is used. Compton used three concentric lead shells to cut out the radiations from the earth. In high altitude work this lead shield is not necessary as the air absorbs the rays from the earth. This instrument gives the intensity of ionization but not the number of rays or the nature of the rays.

The direction of the rays and the number of rays are determined by the counter telescopes. A single Geiger-Miller counter responds to rays in all directions. But when three counters or more in a line are actuated simultaneously, and the pulses from these counters are fed into a recording system that *only* registers when *all three* are actuated simultaneously then the direction of the counter shows the direction of the rays. As only cosmic rays have the energies to pass through all the counters, the counter telescope does not respond to any other rays, and we can measure the number of the rays. The Geiger-Miller counter consists of a Pyrex glass tube containing a copper cylinder about 20 cm. long and 1 cm. in diameter. This copper cylinder is connected to the negative terminal of a high potential of about a thousand volts. Through the center of the cylinder runs a small tungsten wire that is connected to the positive of the high potential through a high resistance (10^9 ohms). The electrodes are held in place by a glass envelope that is sealed when filled with a mixture of 94% Argon and 6% Oxygen at a pressure of a tenth of an atmosphere. The passage of a cosmic ray causes ions in the counter, and these ions collide and cause other ions and precipitate a discharge across the electrodes. The negative ions move to the positive thin wire and cause an excess of electrons on the condenser plate in series with it. The other plate becomes positive and makes the grid of a 57 tube negative. The pulse through this tube is then amplified by the usual methods. The discharge in the counter tube is not continuous but intermittent. When the counter is exposed to known and constant sources of radiation and the number of pulses are plotted against the applied voltage, the curve shows the threshold voltage, the plateau voltage where the counting rate is independent of the voltage, and the glow discharge. The tube is operated at some voltage in the plateau voltage region. If a cosmic ray should actuate the tube at the instant that the tube is recovering, or in the time that the recording device is recovering there is a source of error. This error is corrected by the Laws of Probability. Another error could creep in from the chance that three different rays from three different directions could actuate the three counters simultaneously. To avoid this error, duplicate sets of counters are placed in the walls and so connected that the recording apparatus does not register when these independent rays actuate the counters. These cosmic rays telescopes proved that cosmic rays were electrically charged particles, as photons could not actuate the three counters simultaneously. By these telescopes the altitude and latitude effects were studied. A beam of particles is like an electric current, and a current in a magnetic field has a thrust on it the same as the thrust on the wire in the armature of a motor. As the rays that are bent in the magnetic field of the earth have to pass through more atmosphere, they are absorbed near sea level. It is found that the intensity is 10% greater at Vancouver than at the equator. Since more rays move perpendicularly to the earth's magnetic field at the equator than anywhere else, fewer charged particles should get through in that region, and Clay found the decrease from 40°S to the equator and likewise 40°N to the equator. At an altitude of 40,000 feet however Swann and Locher of the Barthol Research Foundation found many rays that were horizontal. These counters then tell us the direction of the rays and their number.

The third method is used to study the nature of these rays. The Wilson cloud chamber makes visible the ion path by means of droplets that condense around the ions. When the cloud chamber is placed in a strong magnetic field the particles are bent into curved paths according to the nature of their charge and their mass. Anderson detected the positron as it had the same mass as the electron but an opposite charge. The energies of these cosmic rays were studied as the energy in electron volts could be measured by the product of 300 times the radius of curvature and the strength of the magnetic field. A most interesting combination of counters and a cloud chamber was used to study cosmic rays. If a cosmic ray actuated the counters above and below the cloud chamber, then that ray could be photographed in the cloud chamber. The pulse in the counters was used to actuate the plunger in the cloud chamber and also at the proper time to photograph the tracks that were visible. In this way there were pictures of cloud tracks on the film. In these pictures the cosmic ray showers were studied and the existence of a particle that was 200 times heavier than the electron was discovered. These particles called mesotrons have great penetrating power. This third method gives facts about the nature and the energies of these particles.

The fourth method was developed by Wilkins in Rochester. He made a study of tracks in the silver bromide of photographic plates. By determining the grain spacing and the number of particles per cc. that have been blackened by the path of the cosmic rays, he determined the types of particles and their energies. This method verified the results about the nature of the particles studied in the cloud chambers.

From the history of the discovery of cosmic rays and the use of the above four methods in the measurements, we have the following results. The intensity of these rays vary with the altitude. These rays also vary with latitude. There is the east-west asymmetry of 10% more positives than negatives. The intensity varies with changes of pressure and changes of temperature. There is a monthly change which indicates a 27.9 day period. There is a daily period with a maximum at noontime. Then there are variations due to magnetic storms. There is need of more experimental evidence for a complete induction about these daily, monthly, and irregular variations of cosmic ray intensity. It can be understood from articles in the *Physics Review* for 1941 (e.g. Oct. 15) how our knowledge of these variations is still incomplete.

Not only these variations in intensity, but the nature of the particles have been studied in the last ten years. Rossi in 1932 showed an arrangement of three counters in a vertical plane with as much as a meter of lead between them that about 40% of the charged particles coming down vertically at sea level are able to penetrate through this material. These must be particles as photons cannot pass through. When cloud chambers were interposed between the thicknesses of lead these cloud chambers operated by the coincident pulses from the counters the density of ionization showed the paths to be those of fast and penetrating electrons. The mass of some of the particles was found to be two hundred times that of the electron. These particles were called mesotrons. The Rossi curves showed a maximum of counts through about two centimeters of lead. As the thickness increased the number of counts then decreased. This hump in the curve is also noted in the altitude intensity curves. So besides the penetrating particles there are less penetrating ones. From these particles come showers that were photographed. The counters can be arranged so that a photon cannot cause the pulse in the first counters and we know the showers are charged particles. This cascade process can be explained by the *primary* electron striking non-radioactive matter and sending out a *primary* photon as in the x-ray tube. Then this primary photon in striking an atom sends out an electron pair. These *secondary* electrons of the pair can cause *secondary* photons. These *secondary* photons then produce the *tertiary* electrons in pairs. The low energy of these electrons dies out in collision and they are easily absorbed. This low energy part of the cosmic rays explains the hump on the Rossi curves and the increase in ionization due to altitude up to 16 kilometers and then the decrease. The high energy electrons entering the atmosphere cause this shower effect and the increase in the intensity. However after the equivalent of 2 cm. of lead the thickness of the atmosphere absorbs these low energy electrons and the intensity decreases down to sea level. Many false conclusions came from the study of these low energy electrons that come from the showers. If you merely study this part of the energy spectrum then the incomplete induction about the nature of cosmic rays is clear, as the penetrating electrons and mesotrons are omitted.

From photographs in the Wilson cloud chambers we find that the earth is being bombarded by high energy particles that measure up to 20 billion volts. This is a thousand times higher than any source that we have on earth. Hundreds of these particles go through our heads every minute. A particle that has an average energy of a billion electron volts will pass through a thickness of 10 cm. of lead in a straight line. These particles have unit charges, are almost equally divided, with a slight excess of positives. Protons have a mass 2000 times that of the electron and neutrons have this same mass but are not deflected in the magnetic field. These neutrons are detected when they bombard parafine and send out alpha particles that ionize. This gives us the cosmic ray family of electrons and positrons of small mass, mesotrons of intermediate mass, and protons and neutrons of large mass. At present the great work is to study the energy of these particles. Mesotrons are not stable and have a mean life time of 2 microseconds or one-millionth of a second.

From the history of cosmic rays we see how the careful measurements of Fr. Wulf, S.J. and his logical conclusion that some other agency then unknown must have been the cause, and the careful work of Dr. Hess in searching for this unknown cause of ionization led to the great work in this study. It is an object lesson in both the scientific method and logic. The difficulty was practical. Nature only whispers her secrets and the scientist must listen carefully and realize that his mind is finite and must be humble and not generalize from some few facts. We do not know how these high energy particles are sent out, and we do not know where they come from in the universe except it must be far out in space and free from matter.

(The above lecture was illustrated by many slides)

WARTIME GASES

Address by LOUIS R. WELCH

I find myself today in the unique position of a speaker who sincerely hopes that his talk will never be of any practical use to his audience.

The scientific aspects of modern warfare have never been given much consideration in our secondary school classes. We understood that there was to be no more war. Consequently, the curriculum makers and the textbook writers made little mention of the military or naval applications of scientific principles. It was felt that these would be of little interest or value to boys or girls of high school age.

Now all is changing. World history, in the making during the past two years, is forcing us to revise many of our cherished ideas. Many authorities now ruefully admit that it has become expedient for our high school students—for all civilians of all ages—to receive at least a basic training in certain fundamental defence measures against possible aerial attacks.

The part of this training that has to do with gas warfare is of great importance. People as a whole know least about this type of fighting and look upon it with undue fear and horror. As a result of this ingrained fear, the use of gas upon untrained troops or civilians, quickly lowers their morale to the verge of panic. This is not true with trained groups who realize that with proper precautions the number of casualties resulting from a gas attack will be surprisingly low. The science teacher should be able to answer intelligently questions concerning gas, to take the mystery away from gas attacks, and to dispell much of the horror with which gas fighting is viewed. It is not necessary or advisable that this instruction be of a highly technical nature. Formulas or scientific names need not be stressed or even mentioned. It is merely necessary in such a basic course, to consider the general characteristics of gases likely to be encountered, to outline the necessary protective measures, and to indicate the proper treatment for gas casualties.