showers; the number falls off to about five percent for thicker plates. A statistical treatment of the problem by Furry[8] predicts that over twenty percent of the electrons passing through five mm of lead will give showers, forty percent at one cm, etc. Since we have reason to accept the calculated probabilities of radiation and pair production, we are left with about half or two-thirds of the incident radiation behaving in an anomolous manner. This is more than can be explained by statistical fluctuations. We may assume either that electrons and quanta of extremely high energy do not react readily with nuclei, or that the radiation is composed in large part of particles which ionize like electrons, but which do not radiate quanta. Measurements of energy loss in heavy metals as found by Nedermeyer and Anderson[9] seem to indicate the presence of such nonradiating particles. Photographs taken by Street and Stevenson[10] indicate that these penetrating particles are not protons because they do not ionize heavily enough at the end of their range. In order to account for their great penetrating power and their low ionization, the existence of a new particle with electronic charge and the mass of 100 to 200 electrons has been proposed. Further experiments by Fussell[11] and experiments in progress at Berkeley on the specific ionization of cosmic-ray particles may shed more light on the question of the existence of such a particle.

The author wishes to express his gratitude to Professor Robert B. Brode under whose helpful guidance these experiments were carried out, and to Professor J. R. Oppenheimer for his continued interest in the problem.

[8] W. H. Furry, Phys. Rev. **52**, 569 (1937).
[9] S. H. Nedermeyer and C. D. Anderson, Phys. Rev. **51**, 884 (1937).
[10] J. C. Street and E. C. Stevenson, Phys. Rev. **51**, 1005 (1937).
[11] L. Fussell, Jr., Phys. Rev. **51**, 1005 (1937).

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The Latitude Effect in Cosmic Radiation at High Altitudes

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Measurements of cosmic-ray intensities in the equatorial and temperate regions are reported, and the instrument described. The apparatus consists of a single Geiger counter, the impulses of which are transmitted by radio to a ground station. The results are compared with high altitude electroscope measurements and are found to agree satisfactorily. Flights up to 70,000 feet were obtained in Peru. The results indicate that the intensity of cosmic radiation in the upper atmosphere in Peru is about half that at Washington. The component which produces about one-half the maximum total intensity of ionization at high altitudes over Washington is cut out by the earth's magnetic field and does not reach the top of the atmosphere in Peru. The energy of this component lies between 3 and 12×10^9 ev. Analysis of the data shows agreement with the Carlson-Oppenheimer curves. The ionization at high altitudes is shown to be in large part due to secondaries.

Introduction

The latitude effect in cosmic radiation has been one of our chief aids in determining the energy spectrum of the incoming radiation. It has long been realized that one of the most important parts of this study has been that of the latitude effect at high altitudes. Hitherto high altitude work has necessitated the use of recording equipment which depended upon recovery of the instrument after the balloon flight to obtain the record of the intensity. With the development of radio transmission of balloon-data, a new method, useful for this work, has made its appearance. It is clear that recovery of recording instruments presupposes an inhabited country and literate populace. Where the topography is chiefly desert or ocean, the radio method has proved especially useful.

Counters and Transmitter

In order to measure the total intensity of cosmic radiation at various altitudes, a single counter was used. Except for Cosyns[1] relatively few observers have used single counters for total intensity measures, and hence the details are described. It is clear that the method to be described may also be modified for coincidence counting; indeed such coincidence sets are already being reported on by T. H. Johnson.[2]

The desiderata for counter equipment for balloon work are: (*a*) Light weight; (*b*) strong pulse with minimum number of tubes; (*c*) a sea-level counting rate such that at highest altitudes the vastly increased rate will still be within the response time-constant of the relay, or whatever other device is the slowest in the circuit; (*d*) ruggedness; and (*e*) proper operation under conditions of varying temperature and pressure.

These desiderata determine the design of the instrument. Consider factor (*c*). Since, as will be detailed below, the entire equipment was found to work accurately at counting rates up to 200 per minute, and since the cosmic-ray intensity in temperate latitudes is known to be some 200 times more intense at the high point on the intensity-altitude curve, the counter should at sea level have a counting rate of less than one count per minute. The counter was therefore made small. The cylinder was made one cm long and one cm in diameter. The cross section of the counter to radiation from any direction was therefore between 0.75 and 1 square cm. Such a counter (see Fig. 1) will normally operate at sea level at less than one count per minute.

Considering factor (*a*), we see that the counter must operate at a low voltage in order to save battery weight. Two possible types of construction may combine to give low counter operating voltage. These are (*a*) filling the counter with helium, argon, or other noble gas, and (*b*) operating at a somewhat lower pressure than

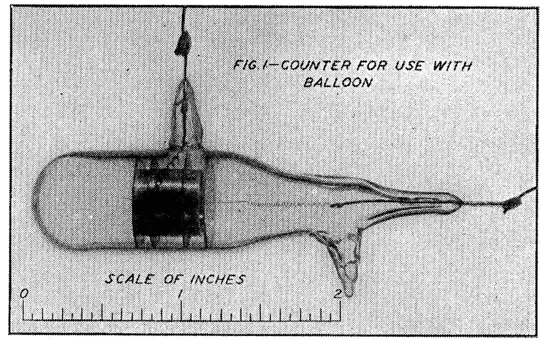

Fig. 1.

usual. In this work the counters were filled, some with helium, some with argon, at pressures from 2.5 to 3.8 cm Hg, and were found to have a stable operating plateau at between 350 and 550 volts, depending on the gas and pressure chosen. As we will see later the conditions were selected to meet various problems concerning the shape of the intensity pressure curve at high altitudes.

The counter circuit employed a single type 32 screen grid tube fed through a coupling condenser of 0.00005 mf. This tube was chosen inasmuch as it has a low filament current (60 milliamperes) and a high mutual conductance. The characteristic curve of this tube has a hump at low voltages and advantage was taken of this fact. The tube was operated at 135-volt plate potential, 2-milliampere plate current, 90-volt screen grid potential, and 3.5-milliampere screen current. The filament, rated at 2 volts, 60 milliamperes, was operated on a single cell, giving 1.4 volts over a period and supplying between 48 and 50 milliamperes. These several factors combine to produce the desired result. The circuit diagram is given in Fig. 2.

The tube is operated with a very high resistance grid leak or none at all, and with a plate load resistance of 25,000 ohms. In this condition, the plate current flows at its full (saturated) value. However, when a count occurs in the counter tube, the plate current shuts off entirely. As ions flow to the grid, the grid returns quickly to a normal potential and the full plate current flows again. As a result a cosmic-ray impulse causes a 2-milliampere deflection in the plate current of the first tube. This is a greater swing than can be obtained in the conventional manner. The output of this one tube was sufficient to

[1] M. Cosyns, Bull. Tech. de l'Assoc. Ing. sortis de l'École Polytech. de Bruxelles (1936).
[2] T. H. Johnson, Phys. Rev. **51**, 385–386 (1937) and J. Frank. Inst. **223**, 339–354 (1937).

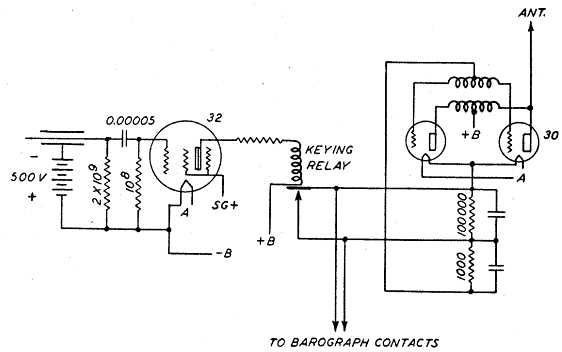

FIG. 2. Circuit of cosmic-ray balloon apparatus.

operate a Western Electric G-26 relay in the plate circuit which keyed the transmitter.

The counter and amplifier described above were put through the following tests to determine whether this arrangement was suitable for work under the conditions expected to be encountered.

(a) Counting rate

The counting rate was found to be 0.4 count per minute at sea level (ground level). An increase of a factor of 200 in the rate between the ground and the top of the flight was expected. Therefore it was necessary to ascertain that the apparatus would respond to 100 counts per minute.

The relay in the plate circuit was therefore connected to an impulse counter. The plate output was independently connected to a "scale-of-8" thyratron counter, which recorded one count for every eight pulses which the tube gave. A strong source of radium was then brought near the tube. The counting rate rose as the radium approached. The relay operated satisfactorily up to a rate of 250 counts per minute; that is, the mechanical counter and the thyratron agreed up to this point. As the rate was increased to 600 per minute, as measured on the thyratron set, the relay began to chatter, and only recorded 200. This was very satisfactory operation, since the maximum rate to be expected was something over 100, and the relay worked properly over 250.

(b) Time factor of counter and tube

A cathode-ray oscillograph was connected to the counter and amplifier tube to determine the the length of each pulse. It was found that the pulses lasted 0.005 second. The pulse was of the proper shape, starting fast, reaching a peak with less than observable lag, and falling off exponentially from this peak at the rate indicated. Thus it was established that the counter and the amplifier were not introducing any undesirable electrical characteristics, such as flat-topped pulses, which some circuits give, and that the slowest electrical part of the circuit did not introduce any delays which would result in missing counts when operating at a fast counting rate.

(c) Temperature effects on resistances

In order to determine whether the temperature variation during the flight would affect the counting rate by changing the resistances in the circuit, a high resistance, five times as great as the output resistance used, was introduced. The counting rate changed by less than ten percent. Similarly, changing the plate resistance by a large factor made small difference in the counting rate.

(d) Battery tests

For counter voltage the Eveready type X-180 battery was used. This battery weighs about 2 ounces and delivers 45 volts. It was tested by putting a resistance and meter across it, and was found to deliver 1.5 milliamperes for 4 hours with but a ten percent drop in terminal voltage. Inasmuch as this was far in excess of the load to be used, it was satisfactory. Moreover, it was found that an increase of 45 volts in the counter potential only changed the counting rate by ten percent, and thus the effect of possible temperature change on the rate due to changing battery voltage was negligible.

For filament supply an Eveready 935 single cell weighing 1.5 ounces was used. This cell was tested and delivered 50 milliamperes for 5 hours, or for five times the length of the ascending part of the flight.

For plate supply, General batteries type V-30-M were used. These deliver 45 volts, weigh about 6 ounces and have a capacity of about 65 milliampere hours.

The relay in the plate circuit of the type 32 tube was a Western Electric type G-26 telephone relay. The contacts of this relay directly keyed the oscillator, so that each time the counter counted the transmitter emitted a signal.

The transmitter was a simple oscillator, consisting of two type 30 tubes connected in push-pull. The circuit used was that described by Curtiss.[3] Effort was made to have all the oscillators identical. This oscillator, without batteries weighs 80 grams; and requires 135 volts for plate supply and 4 volts for filament power. The oscillator is overloaded and uses an instantaneous plate current of about 50 milliamperes. Since the pulse lasts but 0.1 second and long life is no object, strong signals are thus obtained.

Barograph

The altitude or pressure at which the instrument may be, is signaled by a barograph designed as a part of a radiometeorograph. This instrument is described in detail in a following paper. The models assembled by the American Instrument Co. after this design were found to work excellently, and operated without failure on all of the flights.

Receiver

The receiver used was the receiver portion of a transceiver, made by the Transceiver Corporation. The unit is of the superregenerative type. A tuned antenna of 5/2 the wave-length was extended vertically. The transmitting antenna was 1/2 the wave-length in length and also vertical. The frequency chosen was 58 megacycles. This frequency was selected considering the absence of reflections and interference, and was found satisfactory.

The output was taken from across the loudspeaker terminals, and passed through coupling condensers of 0.01 mf capacity to the grid of a 6*C*6. In the plate circuit of the latter was placed a telephone relay. This relay was then connected to a telegraph tape recorder.

The loudspeaker was left connected. The set was so adjusted that the regeneration "hiss" was heard. If the regeneration control was turned until the set was just regenerating, then when the signal came in the regeneration ceased. When regeneration ceased, the load across the 6*C*6 swung to a positive potential, and plate current flowed. The plate relay closed and the telegraph tape recorder registered a signal.

Noise has relatively little effect on a receiver of this type. A cathode-ray oscillograph was connected to the output and showed a broad noise pattern when the set was regenerating. As soon as regeneration ceased, the noise pattern collapsed into a flat horizontal line. In other words the signal resulted in the absence of regenerative noise. Other noise is merely added to the background noise and except for extraordinary bursts of static occasionally encountered in the tropics, also collapses and shows no effect when the signal comes in.

Observations

With the equipment described above, a series of flights was made. Balloons made by the Dewey and Almy Chemical Company were used. The entire single equipment weighed between 2500 and 2900 grams, depending on the batteries used. Altitudes of 50,000 to 70,000 feet (15 to 22 km) were obtained.

Four flights were made during March and April, 1937, at Washington, D. C., geomagnetic latitude 50°. The cosmic-ray counts per minute are plotted against pressure in Fig. 3. It will be noticed that a rapid increase in counting rate is observed at pressures below 400 millibars. As the instrument rises, the intensity rises to what we will call the main peak. This main peak lies at about 100 millibars. Above this elevation the intensity drops.

The instruments continued to work on the descent, and gave points approximately checking those obtained on the rise. These points are generally farther apart in terms of pressure since the descent was usually faster than the ascent. In flights 1 and 3 only a few points were so obtained since a high wind carried the balloons far enough away (estimated 150 to 200 miles) to attenuate the signals below workable levels.

Flight 2 gave an excellent proof of the reliability of the instrument. Both lifting balloons burst simultaneously and the instrument dropped in free fall from about 56,000 feet. The barograph-signals showed that the velocity attained was about 100 miles per hour at first, and this slowed down to about 60 miles per hour as the instrument entered the denser atmosphere below 15,000 feet. During all this time the cosmic-ray signals continued to come in. On the descent

[3] L. F. Curtiss and A. V. Astin, J. Aero. Sci. 3, 35–39 (1935).

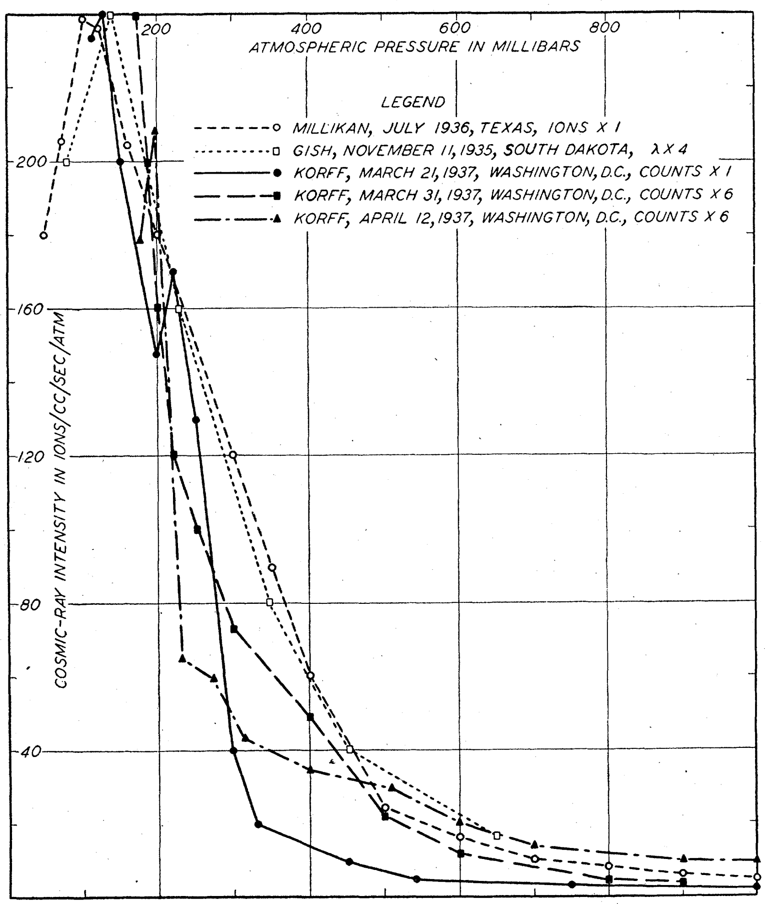

FIG. 3. Cosmic-ray counter results for Washington, compared with results of Millikan and of Gish.

the instrument accurately repeated the up-going curve, even to indicating a narrow secondary peak on the radiation.

The ascending and descending values obtained for each flight are averaged in Fig. 1, and the resultant curve is drawn through the points. The "plops" which the cosmic-ray counter gives can be plainly heard in headphones or loudspeaker and are quite unmistakable. Practice was always made to listen by ear to the signal and simultaneously watch the tape recorder.

The counting rates were adjusted to various rates initially, so that various final rates might be obtained. In one flight the rate was set quite high in order to obtain detailed information about the main peak. The maximum rate observed was as high as 250 per minute, a secondary maximum was 180, and the sea-level rate was about one. In the next flight, the rates were so set that the maximum was about 40 per minute at the top and about 0.2 at sea level. The resulting curve shows that the same observations are obtained with either rate, though obviously the faster rate allows a greater total number of counts to be gathered and therefore reduces the accidental scatter. In other words, fractions of a count being impossible, a small variation will show up more readily on a high rate than on a low rate, on which latter it might be confused with accidentals. By varying the rate by a factor of six, it was shown that the observed increase with altitude is not a function of counting rate. The repetition of the points on the downward curve indicates that the instrument is responding to radiation coming from outside.

A series of five flights was made in Lima, Peru, magnetic latitude 0°. The cosmic-ray intensities obtained in these flights are shown in Fig. 4. The intensity altitude curve is, essentially, the same shape as that obtained in Washington.

However, the maximum intensity over Peru is about half that over Washington. Moreover, this maximum intensity is attained lower down, that is, at higher pressures. The latitude effect, which is about eight percent at sea level between Washington and Peru, rises to 50 percent at about 45,000 feet.

Each point on the curves represents the average counting rate for periods of four to seven minutes. Since fewer counts were received from the lower portions of the flight, these lower points generally represent averages for a greater number of minutes than the higher ones. The counts per minute scatter more on the rapidly changing ascent portion of the curve between pressures of 400 and 150 millibars. At the top of the curve the scatter tends to diminish markedly. This same distribution of scatter is found by other observers. The vertical lines in Fig. 5 represent the amounts of this scatter. Those on Swann's curve are taken from his diagram. Those on the curve of the flight above Washington were averaged, as indicated above, every four to seven minutes. The vertical lines in this case represent the extent of the scatter, practically no points falling outside the limits thus set. The averages at the top of the flight are generally for four points, each representing the number of counts received in one minute. Toward the top of the flight the counting rate becomes high but quite uniform.

Discussion of the Results

(A) Comparison of the counter and electroscope techniques

These observations give us an opportunity to compare several different instruments and observing techniques. Four methods are considered. These are: The electroscope; the single counter; the coincidence counter; and the various devices for measuring atmospheric electricity.

In order to determine whether counters and electroscopes measure similar increases in radiation, the electroscope observations made up to 29,000 feet in Peru by Millikan and Korff[4] in 1935 are plotted on the same diagram as the counter-flight curves. Inspection shows that the two techniques yield similar results. Since "counts per minute" is an arbitrary scale, the different counter-rates are multiplied by constant factors from 1 to 4, to bring them to the same scale as the electroscope ordinate of ions per cc per atmosphere per second at a pressure of 500 millibars. This is essentially the procedure followed by Regener[5] in his comparisons of work with electroscopes and counters. It will be observed that satisfactory agreement can be obtained, and hence it may be concluded that the single counter can be regarded as an instrument capable of measuring the total intensity of cosmic radiation.

[4] I. S. Bowen, R. A. Millikan, S. A. Korff, and H. V. Neher, Phys. Rev. **50**, 579–581 (1936).

[5] E. Regener and G. Pfotzer, Physik. Zeits. **35**, 779–784 (1934).

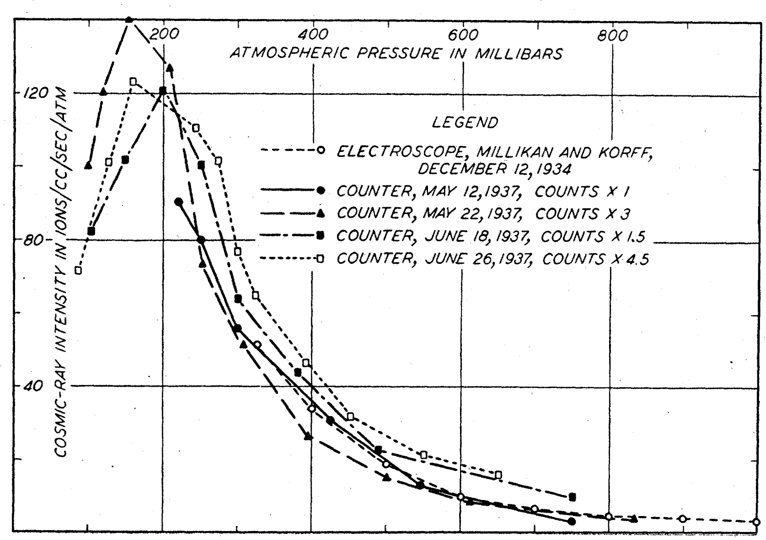

FIG. 4. Cosmic-ray intensity as a function of altitude in Peru; points obtained with electroscopes and with counters.

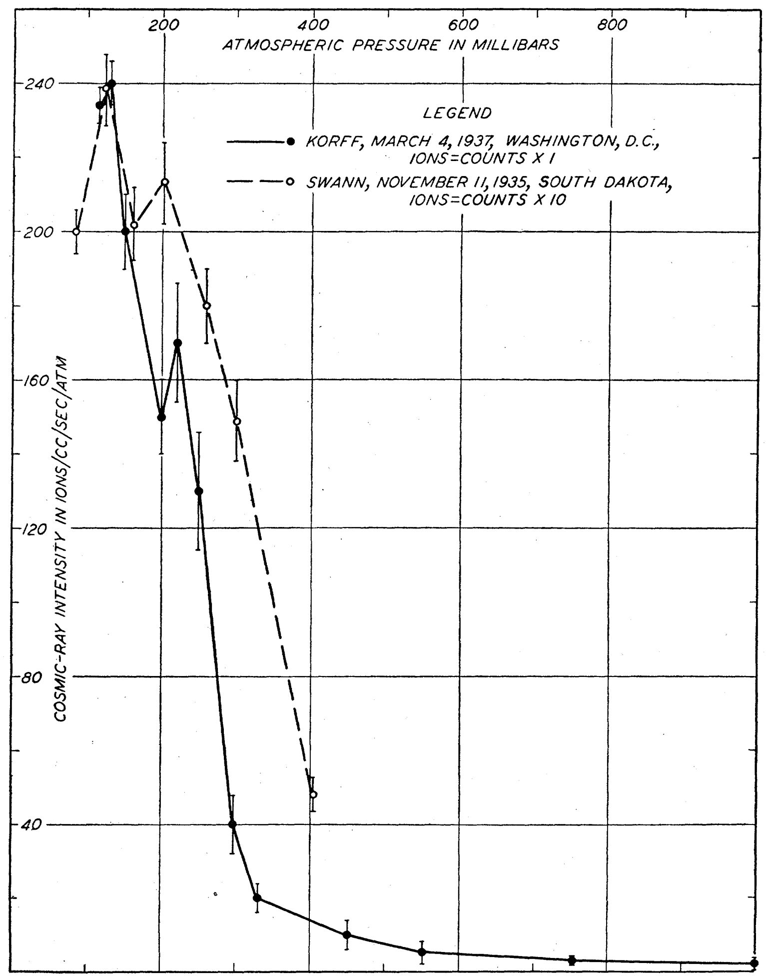

FIG. 5. Individual flight with single counter in Washington, compared with coincidence counter flight by Swann.

Similarly the counter observations at Washington are compared with the excellent results obtained by Millikan[6] in his balloon flights in Texas. In this case the curves can be compared right up to the top of the intensity rise. From this comparison it will be seen that the electroscope does not show small secondary dips as well as counters do. The electroscope tends to integrate over these dips, though they may be surmised from the readings. The counters, on the other hand, give a continuous record of the intensity between any two elevations.

Consider now the single counter as compared with the coincidence counter. In Fig. 5 are plotted the single counter rates obtained on a typical flight and the vertical coincidences obtained by Swann[7] on the manned stratosphere-flight. It will be seen that the coincidence counters tend to integrate somewhat more than the single counter does. Further, the departure of the coincidence curves from the single counter curves at lower elevations is in accordance with the theoretical analysis of Gross,[8] who shows that the vertical component of the radiation will fall off less fast than the total radiation. Minor secondary humps in the curve are also found.

Turning next to the problem of comparing the cosmic-ray results with those obtained in the atmospheric electric work, we find that if the

[6] I. S. Bowen, R. A. Millikan, and H. V. Neher, Phys. Rev. **52**, 81–88 (1937).

[7] W. F. G. Swann, G. Locher, and W. Danforth, Nation. Geog. Soc., Contrib. Tech. Papers **2**, 16–25 (1936); Phys. Rev. **51**, 389–390 (1937). (Points taken from Fig. 10, curve *A*, p. 22.)

[8] B. Gross, Zeits. f. Physik **83**, 214–221 (1933).

results of Gish and Sherman[9] be plotted together with the cosmic-ray intensity curves, the results will run very nearly exactly parallel. In Fig. 3 the results by Gish are plotted for positive air conductivity, his values of λ in units of 10^{-4} e.s.u. being multiplied by 4 to bring them onto the same scale as the cosmic-ray intensities. It will be seen that these results, which are for roughly the same latitude, agree well with the cosmic-ray curve. In the past comparisons have been made between the atmospheric electric curves and the ionization curves of Regener, which latter, in consequence of the latitude and longitude effect, have higher intensities at high altitudes. We may conclude that cosmic rays are the principal agent responsible for that ionization and conductivity in the upper atmosphere which Gish measures.

(B) Shift of peak

Inspection of the curves will show that the peak at which the maximum intensity is reached tends to move to higher pressures at low latitudes. This is due to the fact that the softer part of the incoming radiation is cut off by the earth's magnetic field and does not reach the top of the atmosphere at the equator. Those rays which produce ionization in the upper atmosphere at low latitudes are therefore harder and penetrate further into the atmosphere before they come into equilibrium with their secondaries.

The shift of the peak is also seen in the curves of Millikan,[6] where comparisons are made between the flights they made at Chicago, in Texas, and at Madras. It will be further seen that the curve which the senior author obtained in Peru fits in between those which Millikan obtained in Texas and India. This is to be expected since the longitude-effect operates between Peru and Madras, both of which places lie close to the magnetic equator, in such a way as to reduce the intensity at Madras.

Between Washington and Lima, Peru, the peaks shift by about one-half meter of water toward higher pressures. Since the earth's field will cut out all particles of energy less than 12,000 Mev entering at Peru, and about 4000 Mev entering at Washington, the shift of the peak may be interpreted as indicating that a group of rays of energy not less than 12×10^9 ev will reach equilibrium with their secondaries after penetrating about 0.5 meter of water more than is needed to bring those of 4×10^9 ev to equilibrium. This is in accord with the theoretical curves of Carlson and Oppenheimer.[10] They find a shift of peak owing to the production of multiplicative showers, by a difference in energy of 2700 Mev (lower limit of energy entering at northern latitudes) and 20,000 Mev (energy entering at Madras), of about 100 percent in abscissae of thickness of matter. The peak shift observed in the experiments reported on herein is just about half this, and the energy limit of the southern peak is also about half the second figure, or about 10^4 Mev, entering at Peru.

(C) Heights of peaks

The heights of the principal peaks of the intensity altitude curves determine the latitude-effect at high altitudes. Since the peak for Washington lies at 240 on the scale of ions per cc per atmosphere per second and the Peru peak at 120, or about half, we may conclude that one-half the radiation reaching the top of the atmosphere in Washington is cut off by the field and does not reach the atmosphere in Peru. This fraction of the radiation lies, according to the latitude effect calculations, between about 4 and 12,000 Mev.

However, it must be remembered that the interpretation of the latitude effect as directly indicating what fraction of the energy lies in any given energy band depends on the assumption that one cosmic ray, of whatever nature or energy, passing through the counter, produces a count. This behavior is true only for ionizing radiation. All cosmic-ray measuring instruments work on this principle. The agreement between the counters, the electroscope, and the other methods indicates that we are indeed measuring the ionizing component of the radiation plus the ionization due to secondaries. We must remember that non-ionizing radiation would not excite the counter. The glass and metal of the counter are equivalent to about one cm of water. Since the maximum secondary formation takes place after the penetration of about 100 cm of water, we

[9] O. H. Gish and K. L. Sherman, Nation. Geog. Soc., Contrib. Tech. Papers 2, 94–116 (1936). (Points taken from Fig. 4, curve B, p. 106.)

[10] J. F. Carlson and J. R. Oppenheimer, Phys. Rev. **51**, 220–231 (1937).

see that few ionizing secondaries will be formed in the counter itself. Regener's tests confirm[5] this conclusion.

The cosmic-ray intensity drops at very high altitudes below the maximum value, reached at about 50,000 feet. It is therefore clear that much of the ionization produced in measuring instruments at high altitudes is due to secondaries. In the Peru flights this drop was found to be about 30 percent of the total. Since the main peaks represent ionization primarily due to secondaries, the experiments show that the component of the primary radiation cut off by the earth's field was responsible for about half the total secondary production in the upper atmosphere. It does not follow that half the primary energy, or even that half the total number of incident rays, was involved. A large latitude effect proves that most of the incident rays are charged particles only if the same absorption law is followed by charged particles and by other forms of radiation, which we know is not true. We have tacitly assumed that the ionization in any measuring instrument is proportional to the amount of the incident radiation. Such an assumption would hold true only for a homogeneous radiation. It appears possible that the component of the radiation which is cut off by the earth's field is a powerful producer of secondaries, and that most of its energy is absorbed in the upper atmosphere. It is principally a more penetrating component which produces sea-level effects.

(D) Shape of curve

At high altitudes, beyond the primary peak, the intensity falls off sharply. In the flight of *Explorer II*, Swann finds a decrease[7] of about 20 percent between the maximum at about 0.8 meter of water and the top of the flight. Millikan[6] similarly finds a drop of about 25 percent between the maximum of his Texas flight and the top of his flight. Like results are obtained with the counter flights in Peru. Nor do any of these flights reach very high altitudes. The important question is: To what value will the measured intensity fall at the limit of the atmosphere? An extrapolation of the various curves to zero-pressure indicates that the ionization shown in a counter or electroscope may be quite low. This gives rise to the question of whether a component of the primary radiation may be perhaps only very slightly ionizing. Should Millikan's suggestion regarding a non-ionizing component of the radiation be substantially correct, this would be the effect we would observe. Photons or neutrons would excite the counter only if they knock secondary electrons out of the walls, the surrounding atmosphere being assumed absent. In other words, a counter is not capable of distinguishing whether a count was due to a primary ionizing particle or to a secondary electron ejected by the primary from the surrounding molecules of air or the counter wall.

By removing the surrounding air, that is, by attaining high altitudes, we remove the biggest source of secondaries. From these measurements at extreme altitudes we shall see whether the primaries are ionizing or not. As we will show in a following paper, preliminary high-altitude counter flights show a marked falling off beyond the "primary maximum," and that possibly some of the radiation is non-ionizing. The curve for dip of the intensity at extreme altitudes found in the flights in Peru shows that at least 30 percent of the total ionization at high altitudes is due to secondaries. This value is merely a lower limit. Further flights are being undertaken to settle this point.

Acknowledgments

The work described above was undertaken as a cooperative project. Thanks for financial support are primarily due the Cosmic-Ray Committee of the Carnegie Institution of Washington and to Dr. John A. Fleming, Director of the Department of Terrestrial Magnetism. Cooperation was received from Dr. Briggs, Director of the National Bureau of Standards. Advisory assistance with balloon-technique was received from the United States Weather Bureau. Work in Peru was greatly aided by Dr. G. A. Wagner, Chief of the Peruvian Meteorological Service, and from Dr. Santiago Bedoya of the Ministry of Foreign Affairs. For assistance in Panama the author is particularly indebted to Dr. James Zetek. Thanks are also extended to the many other persons who have helped the work, but whose names the limitations of space prevent listing.

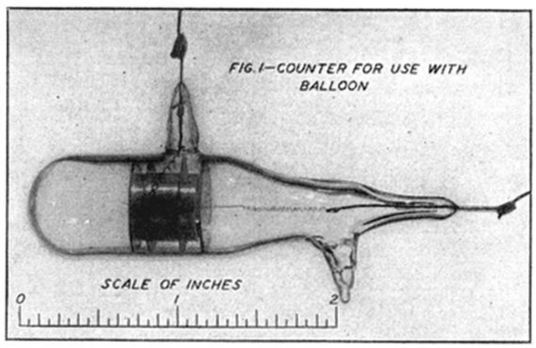

FIG. 1.