COSMIC RAYS

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C. H. C.

Cosmic Rays

Preface

> Here is the story of the modern Argonauts. But the Golden Fleece which the scientific Jasons of the world have been seeking appears to be a new universe, a universe of electrified particles driving through the vast realms of space with enormous energies, energies undreamed of by the physicists of even recent years, a space not visioned by our farthest-gazing astronomers. It is the story of Cosmic Rays.[1]

The highly penetrating and mysterious waves or particles that bombard us from outer space are called cosmic rays. A name that was first given to this radiation in 1925 by Millikan and his colleagues.[2] But the true discovery of such a radiation goes back some two decades before this.

From this simple beginning we find the opening of a field of study that has covered the world from pole to pole and crossed the seven seas. In the following pages will be found the history of the discovery and the attempts that have been made to understand these radiations.

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[1] G. F. Hull, Modern Physics, p. 277.

[2] R. A. Millikan, Electrons (positive and negative), p. 308.

CONTENTS

Chapter 1

History of Cosmic Rays

Several important discoveries in rapid succession preceded the discovery of cosmic rays. In 1893 a noted physicist said that it was probable that all the great epoch-making discoveries in the field of physics had been made.[1] Two years later Roentgen discovered the new penetrating rays now called x-rays. Becquerel discovered the radioactivity of uranium in 1896. Two years later Mme Curie separated the highly radioactive radium from uranium.[2] These discoveries of highly penetrating rays led to careful study of their penetrating powers.

A simple electroscope is the classical instrument to determine the presence of an electric charge upon the rod leaf system. If the electroscope is charged either negatively or positively the gold leaves will diverge from one another taking the shape of an inverted V. If ions are in the air surrounding the instrument, those of opposite sign to the charge will be attracted to the electroscope and thus neutralize it. As a result the leaves will slowly collapse.[3]

According to the theory of the electroscope, if charged the instrument should remain charged, but as early as 1901, Professor C. T. R. Wilson, of Cambridge, and others found that an electric charge in an electroscope, even when tightly sealed up in a case, somehow leaked out. This phenome-

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[1] H. G. Garbedian, Major Mysteries of Science, p. 170.

[2] R. A. Millikan, Op. cit., p. 301.

[3] H. B. Lemon, Cosmic Rays Thus Far, p. 33.

non of the natural discharge of an electroscope caused many scientists to wonder and to start investigations.[4] Rutherford and Cooke, of Montreal, in 1903 found this ionization

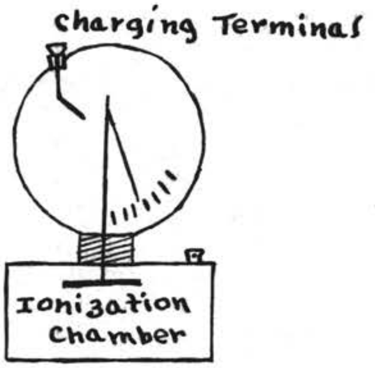

Fig. 1 [5]
Electroscope

to decrease some, but not wholly, by screening the ionizing chamber of an electroscope with a brick wall.[6] McLennan and Burton, of the University of Toronto, in the same year, lowered an electroscope in a tank of water, thus screening it with the water.[7] But this electroscope still showed the loss of charge. This phenomenon was first called the penetrating radiation of the atmosphere, and was at first quite naturally attributed to radioactive materials in the earth or air, which is in fact the origin of a large part of it.[8] It has been shown since, that in each cubic centi-

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[4] H. G. Garbedian, op. cit., p. 173.

[5] J. A. Eldridge, The Physical Basis of things, p.306.

[6] R. A. Millikan, op. cit., p. 302.

[7] Ibid., p. 302.

[8] Millikan and Bowen, Physical Review, vol. 27,(1926), p.353.

meter of normal air some 10 ions are formed per second. Of these, 5 are due to radioactive emanation in the atmosphere, 2 to radium in the soil and 3 to cosmic rays.[9]

Along about 1907, Eve a well trained worker in radioactivity took an electroscope to sea. His findings there caused him to think that the discharge was caused by some new radiation in the atmosphere.[10] Also McLennan continued his studies by surrounding improved electroscopes with layers of lead and carrying them out on the frozen surface of Lake Ontario. Thus he was getting away from any effect of radiations from substances in the soil. His experiments showed a discharge of the electroscope.[11]

In 1909 all the work that had appeared in this field up to that date was reviewed by Kurz and careful consideration given to each one of the only three possible origins of the observed electroscope discharging effects, namely: (1) the earth, (2) the atmosphere, and the regions beyond the atmosphere. The last two were definitely discarded and the article stated that half a mile of atmosphere would absorb all these radiations.[12]

Professor Theodore Wulff, a Jesuit Priest, took his instruments to the top of the Eiffel Tower and he found the effect less than on the ground but not as much less as the physicists had supposed. Professor Gockel, a Swiss physicist,

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[9] J. A. Eldridge, op. cit., p. 342.

[10] H. B. Lemon, op. cit., p. 49.

[11] H. G. Garbedian, op. cit., p.174.

[12] R. A. Millikan, op. cit., p. 303.

went up in balloons in 1910 and 1911 to make observations on these radiations. On one of these flights he rose to 4500 meters and reported the rays were weaker at first, but that they grew stronger with altitude.[13] This definitely indicated that these radiations were not given off from the earth. This was indeed a great discovery and the first to show that the earth was not the source for all the rays effecting electroscopes. These results left two possibilities of the origin, namely: the outer atmosphere and the regions beyond.

In 1911 Dr. V. F. Hess repeated several of these experiments to check the results as found by previous trials. Hess sent up several unmanned balloons with automatic recording instruments to heights over 5200 meters, and discovered that these puzzling rays were very strong there. In 1912, he found during the course of some balloon voyages, that the rays got stronger as he went higher, reaching several times larger values at four miles than at the surface of the earth.[14] These findings caused Hess to postulate an origin outside the planet. Naturally, he and a few others suspected our nearest heavenly bodies and especially the sun as the source. Observations by de Broglie in 1912 during the total eclipse of the sun, showed no change in the discharge of the electroscope, thus showing that the rays did not originate in that luminary.[15] This must have passed unnoticed, for several of the physicists still thought that the source of the rays must

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[13] H. G. Garbedian, op. cit., p. 174.

[14] Ibid., p. 175.

[15] H. B. Lemon, op. cit., p. 57.

have been the sun.

McLennan established a precedent, later followed by others, by taking his electroscopes on a long journey from Toronto to England and up into Scotland. Averages of 9 ions over land and 6 over sea were obtained from observations with the same set of instruments.[16]

In 1913 Kolhörster began making experiments on mountain peaks. Using three much improved types of electroscopes simultaneously for precision, he confirmed previous observations that the intensity increased several fold at high altitudes. Gockel, working lower down on the mountains, made his observations out on large glaciers away from any effect of radioactive materials in the soil. From his results he was convinced that the source of these rays was not some radioactive substance.[17]

In the same year and the following year Kolhörster carried the observations higher in the atmosphere. He pushed the records of altitude effects to 9000 meters and found a twelve- or thirteen-fold increase in discharge rate at that height over that at sea level.[18] But with these observations before them many scientists believed the source to be the upper part of the atmosphere.

In 1914 the World War broke out in Europe and drew most of the civilized nations into deadly warfare. With the coming of this war most of the activities in this field of Phys-

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[16] Ibid., p. 58.

[17] Ibid., p. 63.

[18] R. A. Millikan, op. cit., p.305.

ies were stopped.

In March and April of 1922, Millikan and some of his collaborators, sent four pairs of balloons aloft with recording instruments, at Kelly Field near San Antonio, Texas. Each pair of balloons carried a specially constructed recording machine. Each machine contained a barometer, thermometer, electroscope, three sets of motion-picture films and a driving mechanism. But with all of this each was built so compact that it weighed only seven ounces. The action of the leaves of the electroscope was recorded on the film. As the balloons rose the pressure of the atmosphere on the outside of the balloons became less and less, causing the balloons to become larger. Finally one of the balloons would burst and the remaining balloon would lower the instruments safely to the earth. Because of the wide publicity given the flights people for miles around were on the lookout for the instruments, and three out of the four were found. The maximum height reached by any of the balloons was 15,500 meters. The results showed an increase in intensity with altitude, but was only 25 per cent of that recorded by Hess and Kolhörster.[19] From the results obtained from this experiment, Millikan concluded that the apparent absorption coefficient went through a maximum before reaching the top. This would be consistent with hypothesis number 2 of Kurz, so these results left them still in doubt about the place of origin of the rays.[20]

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[19] Millikan and Bowen, Physical Review, vol.27,(1926),p.355.

[20] R. A. Millikan, op. cit., p.307.

Table number 1 shows results of a long series of airplane flights made by Otis in 1922 at Marsh Field (near Riverside) and in 1923 at Rockwell Field (near San Diego). In this work Otis would gain the desired altitude, remain there thirty minutes and then drop down to the next desired level. He could usually obtain about three sets of readings a day at this work. We see in the table that the intensity of the penetrating radiation at first decreases to a minimum after which it increases continuously with altitude.

Airplane observations by Otis[21]

Altitude	Excess over ground
500 meters	-2.1 ions/cc/sec
760 "	-2.7 "
1200 "	-2.7 "
1750 "	-1.9 "
2500 "	-0.1 "
3400 "	2.4 "
4200 "	4.6 "
5200 "	7.4 "

Table 1

Not long after this Millikan and Otis took their instruments to Pikes Peak. Combining their studies there with airplane observations at about the same altitudes over Pasadena, Millikan was convinced that there existed perfectly definite evidence for the excessively hard radiations found with the balloons.[22]

In 1923 Kolhörster[23] worked at the problem of measuring directly the penetrating power of these rays. To do this he

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[21] Millikan and Otis, Physical Review, vol.27, (1926), p. 651.

[22] H. B. Lemon, op. cit., p. 74.

[23] R. A. Millikan, op. cit., p. 308.

took readings, first on top of a glacier in the alps and second, in a crevasse in the glacier where, if local rays from the surrounding mountains and from glacial dirt were assumed to be absent, all the ionizing rays had to pass through a known thickness of ice. He thus obtained an absorption coefficient of the same order of magnitude as that obtained later by Millikan and his colleagues.

In August, 1925, Millikan, Cameron and Otis began several experiments on the absorption of cosmic rays. Two sealed electroscopes were lowered in Lake Muir (altitude 11,800 ft.). The water of the lake formed the absorbing material about the electroscope and, being snow fed, the water was free from radioactive impurities which would produce ionization in the electroscope.[24] The sinking of the electroscope in Lake Muir showed an ionization decreasing steadily with depth from 13.3 ions/cc/sec. at the surface to 3.6 ions at fifty feet below the surface, below which there was no further decrease.[25] Next these experimenters sunk their instruments in Arrowhead Lake, California (altitude 5100 feet). They found that each of the readings in this lower lake was identical with a reading in the upper lake six feet lower under the surface of the water. This six feet is the water equivalent of the absorption of the air between the two elevations. These two experiments settled the question for these physicists as to the source of the radiation. The first showed that the rays had ample penetrating power to come from the outside and the

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[24] G. E. M. Jauncey, Modern Physics, p. 384.

[25] Millikan and Cameron, Physical Review, vol. 28 (1926), p. 851.

second showed that the sources were not distributed throughout the atmosphere, for the difference of 3,700 feet of air showed no effect on the intensity of the rays except absorption.[26] As a result of this proof we find cosmic rays receiving their present name and the source of these rays was soon accepted by most physicists to be beyond our atmosphere.

From these data and other records obtained, Millikan boldly set forth his views about cosmic rays. In a later chapter we will discuss these views more fully, but at present we briefly state them: (1) the radiation in the air was complex, of four different degrees of penetrating power, the hardest having 18 times the penetrating power of the hardest known gamma rays, (2) the radiation was cosmical in origin, (3) the radiation was of photon nature and could be accounted for only on the assumption that heavy atoms were being created out of hydrogen in the vast regions of outer space. This last seemed to be a bold statement without enough evidence to convince most of the physicists.[27]

Along about this time several physicists suggested that this penetrating radiation might be due to high voltage electrons originating in remote thunderstorms. Partly to answer this, Millikan and his colleagues chose Lake Miguilla near Caracales, Bolivia (15,000 feet altitude), for sinking electroscopes.[28] This lake was surrounded by high

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[26] R. A. Millikan, op. cit., p. 308.

[27] G. F. Hull, op. cit., p. 279.

[28] Millikan and Cameron, Phy. Rev., vol. 31,(1928), p. 163.

mountains which completely screened the lake from hypothetical rays generated in thunderstorms. Readings were also taken at the surface of Lake Titicaca (altitude 12,500 feet) and on shipboard continuously on the trip from Los Angeles to Mollendo, Peru. These readings agreed closely with the readings previously given for the northern hemisphere and sea-level observations taken in the midst of powerful thunder storms showed no influence of these storms upon the electroscope readings.

During this same voyage they made tests for the effect of the milky way. From these observations they concluded, that if there is any effect whatever of the milky way upon the cosmic radiations, the rays coming to us from its direction cannot be 6 per cent greater nor less than those coming from the portion of heavens at right angles to the milky way.[29]

Two Russians,[30] Myssowski and Tuwim, contributed some work in this field by sinking electroscopes in the river Neva. Their greatest contribution was probably the suggestion that the cause of disagreement of readings over the earth's surface was that scientists were not taking into consideration the difference in barometric readings. In other words the pressure of the air has effect on the absorbing qualities of the atmosphere which must be considered.

With many experimenters entering the field, observations were made for the relation of cosmic rays with deflection,

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[29] Ibid., p. 170.

[30] H. B. Lemon, op. cit., p. 75.

sideral time, diurnal variation, variations with latitude, and many others. At first all of these showed very little if any effect upon cosmic rays. But in 1927 and 1928 Clay, during a series of measurements taken on a ship enroute from Genoa to Java, first succeeded in obtaining positive evidence of a change of intensity for different latitudes. The cosmic radiation showed markedly lower intensity near the equator than at higher latitudes.[31] At first these observations were given little attention. In fact about this time most of the physicists, and especially Millikan, had found very little difference because of latitude. Since then Millikan has agreed that there is a latitude effect on the incoming radiations.

Not long after this Bothe and Kolhörster first introduced a new and powerful means of studying cosmic rays, the Geiger-Mueller counter.[32] The details of this counter will be found in the next chapter.

The 1931 annual edition of the Americana Encyclopedia tells us that there was renewed interest in cosmic rays in 1930 because of several new and important discoveries. Bothe and Kolhörster found that cosmic rays were seemingly deflected by a magnetic field (some physicists say these are secondaries). Rossi says that the calculated speed of cosmic rays would require a potential difference of a thousand million volts.[33]

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[31] F. Rassetti, Elements of Nuclear Physics, p. 278.

[32] Ibid., p. 279.

[33] The Americana, 1931 Annual, p. 613.

In the last seven or eight years we find hundreds of investigators on the trail of cosmic rays. Instruments have been used in many ways and combinations; the earth's surface is being completely explored; and instruments have been taken far down into mines below the surface, hundreds of feet under water, and miles into the stratosphere. Many new instruments were made, old ones perfected, and new methods of technique introduced in these world wide studies. As a result of such studies we have a wealth of information before us, yet many of our questions can be only doubtfully answered.

Interest has spread so rapidly and so far we find a double page of a common magazine devoted to cosmic rays.[34]

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[34] Life, Dec. 6, 1937, pp. 18-19.

Chapter 2

Methods of Detection and Measurement

Kolhörster lists three ways by which cosmic rays may be investigated, namely: the electroscope, the cloud chamber, and the Geiger-Mueller counter.[1] We will discuss each of these three ways and also give some of the uses of combinations of two or three of these.

Electroscope.

Naturally the electroscope was the first instrument used in cosmic-ray investigations, because it was through the slow discharge of an electroscope that these new rays were discovered. In the previous chapter there is found a diagram of a simple electroscope with an ionization chamber, and also there is found an explanation of how it measures incoming rays.

As time went on the investigators improved their instruments and we find new and improved electroscopes being used. In using an electroscope to measure the penetrating radiation a charge of known potential is placed on the electroscope. Then the drop in potential of the insulated fibres in a given interval of time is noted.[2] With this data and known constants of the individual electroscope the number of ions per cc per second can be calculated.

The ionization chamber in electroscopes was at first

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[1] Nature, March 10, 1934, p. 387.

[2] Millikan and Otis, Physical Review, vol.27,(1926), p. 645.

usually filled with ordinary air at atmospheric pressure, but many tests were made using different pressures until now we find a common pressure used is thirty atmospheres. After experimenting with different kinds of gases it was found that argon seemed to give the best results when used in the chamber of an electroscope.[3] Figure 2 shows an electrometer using argon with thirty atmospheres of pressure.

The position of the needle or fibres of an electrometer may be read with a microscope or recorded by successive photographs. Neher developed a self recording electrometer which was used by Millikan in recording the radiations in deep lakes and at high altitudes at different parts of the world.

Rapid changes in the atmospheric radiations emphasizes the importance of using heavy shields about the instruments in making cosmic ray observations.[4] Lead shields are used in layers, and different numbers of layers are used to keep out local rays and to test the penetrating power of cosmic rays. In testing the intensity of cosmic rays from different directions, lead shields are made in parts so that four sides, top and bottom, are removable separately. In a number of observations on Pikes Peak and at Pasadena, Millikan used a shield of seven sheets of lead with a total thickness of 4.8 cm. and a total weight of 300 pounds. The shield was made so that the electrometer could be exposed to incoming rays from different directions, and thus study the directional effects.

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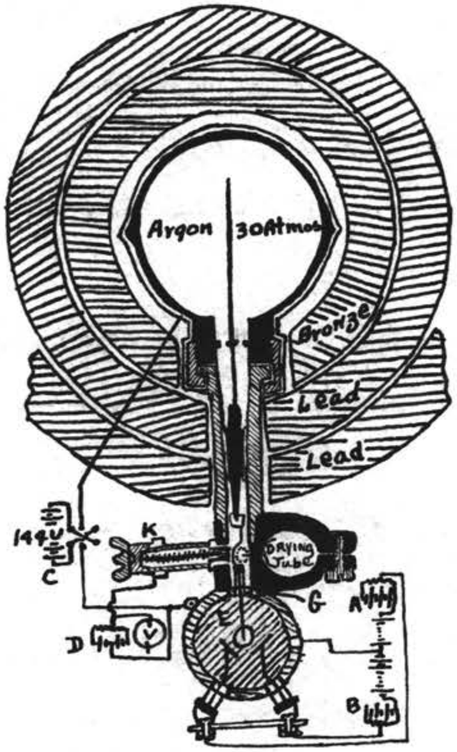
[3] Compton and Hopfield, Phy. Rev., vol. 41,(1932), p. 539.

[4] R. L. Doan, Physical Review, vol. 49,(1936), p. 198.

Figure 2 shows an electrometer as used in the world survey of cosmic rays (1931-1932), which was promoted by Dr. Compton. In this survey 7 sets of similar apparatus were made and used, and more than sixty physicists cooperated in the investigations.[5]

The steel bomb is separated from the metal rod and the heavily shielded case by excellent insullation. The rod may be connected to the electrometer needle by a fine spring, and be charged to the desired voltage. Below and to the right of E are windows through which, with the aid of a microscope,



ELECTROMETER [6]
Fig. 2.

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[5] A. H. Compton, Physical Review, vol.43, (1933), p. 387.

[6] G. F. Hull, op. cit., p. 280.

the position of the needle may be read. The bomb is filled with argon at a pressure of from 30 to 50 atmospheres and at the latter pressure the ionization is seventy times that for air at atmospheric pressure. The lead shields are each one inch thick and are used to cut out all earth radiation. The bronze shell is used to cut out any radiation that might come from the lead.[7]

In calibrating this instrument it was taken into a deep mine or tunnel to escape from the effects of such penetrating rays. After the instrument had been calibrated, the rate of drift of the needle gave the number of ion pairs produced per cc per second for normal atmosphere.[8]

The Cloud Chamber.

When the relative humidity of ordinary air is one hundred per cent, any lowering of its temperature will cause the moisture to form in very small droplets of fog or cloud. For this to occur readily there must be nuclei present on which the water may condense. Dust or smoke particles usually serve the purpose, but atmospheric ions may serve the purpose equally well. If nothing is present to be used as nuclei the clouds will not be formed unless there is a marked change in temperature. Thus a cloud chamber may be made as shown in figure 3. It consists of a glass cylinder containing water and air. This water and air is carefully made free of dust particles. The expansion causes a slight lowering of temperature which will cause tiny droplets to

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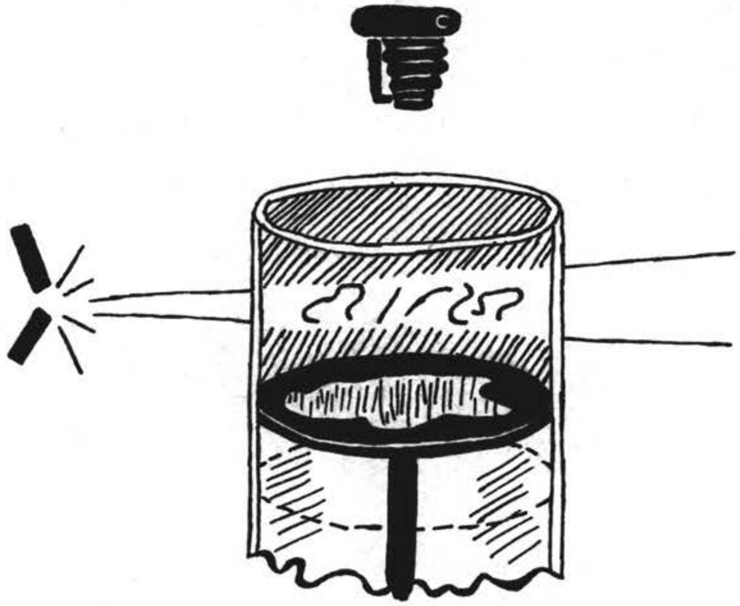
[7] Ibid., p. 280.

[8] Ibid., p. 282.

form if there are any ions present to be used as nuclei. Thus the path of an ionizing particle can be easily followed in a cloud chamber by the tiny droplets formed on the ions. Photographs are made of these pathways thus giving a means of studying the results of the experiments at any time.[9]

Through the use of magnetic fields of known strength these ion producing particles can be examined as to their speed, energy and whether positive or negative. Ordinary photons do not themselves produce tracks by forming ions but by collisions may release electrons which write their beaded paths. There are, however, photons associated with cosmic rays that smash atoms and cause other disturbances



A WILSON CHAMBER
Fig. 3.[10]

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[9] H. B. Lemon, op. cit., p.35.

[10] Ibid., p.36.

as shown in cloud chamber experiments. The appearance of the tracks identify the passing of an electron if the path is beaded, of the presence of a proton or alpha-particle if the path is continuous and heavy like.[11]

Lead screens are often placed in the cloud chambers to study the effect of the lead on the penetrating power of the cosmic rays and to study cosmic ray showers and bursts. A 6 millimeter lead plate will cause the particle to lose energy and because this does slow the particle down the direction of the particle can be found.

It was the study of cosmic rays in a cloud chamber that brought about a great discovery. While studying the action of charged particles, Dr. Anderson found paths of particles that showed all the characteristics of an electron except that they were bent in the opposite direction by the magnetic field.[12] After careful study to be sure it was a new particle Dr. Anderson announced his discovery. This new particle, discovered as a by product of cosmic rays, was given the name of positive electron or positron.

The Geiger-Mueller Counter.

Bothe and Kolhörster first introduced the Geiger-Mueller counter for the purpose of measuring cosmic radiation.[13] This type of counter usually consists of a hollow metal cylinder along the central axis of which is stretched a fine wire which is carefully insulated from the cylinder.

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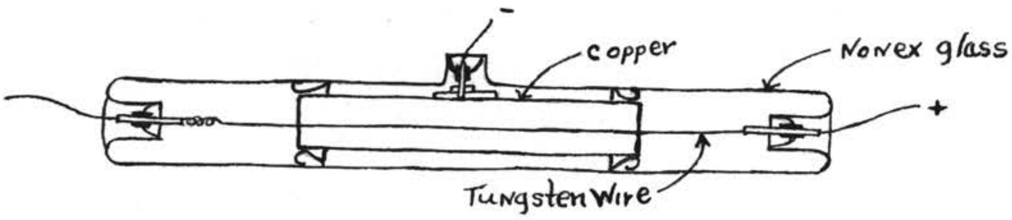
[11] G. F. Hull, op. cit., p. 284.

[12] C. D. Anderson, Physical Review, vol. 44, (1933), p. 406.

[13] F. Rassetti, op. cit., p. 279.

The tube is exhausted and baked out, after which it is filled with argon to a pressure of about 7 cm. of mercury. The wire and cylinder are highly charged with opposite kinds of electricity, almost to the point where a spark will flash between them.[14] In some tubes for cosmic ray work the potential difference is about 800 volts.[15] If by x-rays, radioactive emanations, cosmic rays, or any other cause ions are produced within the cylinder, they are attracted by the opposite charge on the cylinder or wire. Here they multiply themselves and cause the gas to become a conductor of electricity, thus discharging the device. By means of amplifiers, switches, etc., a cosmic ray counter device may be constructed or even an automatic recording apparatus can be made.[17]



Geiger-Müller Counter[16]
Fig. 4.

Two or three of these cylinders can be arranged in

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[14] H. B. Lemon, op. cit., p. 35.

[15] G. F. Hull, op. cit., p. 284.

[16] L. M. Mott-Smith, Physical Review, vol.39,(1932), p. 405.

[17] H. B. Lemon, op. cit., p. 35.

parallel (figure 5) in circuits so balanced that there will be no count unless both or all of these are triggered off at the same time. This occurs when cosmic rays pass through all G-M cylinders and then it is called a coincidence. The rays will be limited to the solid angle subtended by the cross-section of one cylinder at the mid-point between the top and bottom cylinders. If used like this they act as a telescope or direction finder for cosmic rays.[18] With groups of counters the number of rays coming in from a certain direction can be counted and thus the relation between intensity and direction can be found.

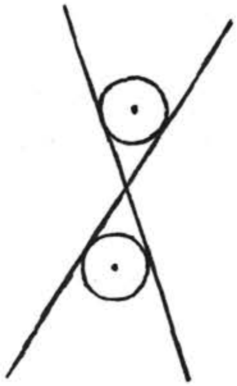

Fig. 5

A Cosmic Ray Telescope[19]

In the study of the latitude effect at high altitudes Korff, Curtiss, and Astin[20] used a single counter with a radio transmitter hook-up. With this apparatus they were able to send their devices aloft with smaller balloons and at the end of the flight they did not need to hunt the apparatus to

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[18] G. F. Hull, op. cit., p. 285.

[19] Ibid., p. 285.

[20] S. A. Korff, Physical Review, vol. 53, (1938), p. 14.

obtain their records. Instead they received their data by means of a short wave radio all during the ascent and descent. Such a method of studying cosmic ray effects in the stratosphere would be very valuable in desert regions, mountainous areas and other thinly populated localities. With such apparatus the experimenters would not have to depend on the return of their instruments for their data.

Many combinations of instruments have been used in the study of cosmic rays. One widely used combination, which has given good results, is that of a cloud chamber with a counter above and another below the chamber. Thus the paths of the rays that cause coincidences can be studied in the cloud chamber and the particles can be identified by their paths.

Chapter 3

Cosmic Ray Effects

This chapter will show how the cosmic rays are effected by altitude, latitude, longitude, direction, etc. Naturally such observations are more easily explained by certain theories than others and because of that we find theories growing out of these results. The theories that attempt to explain the following effects are left for a later chapter.

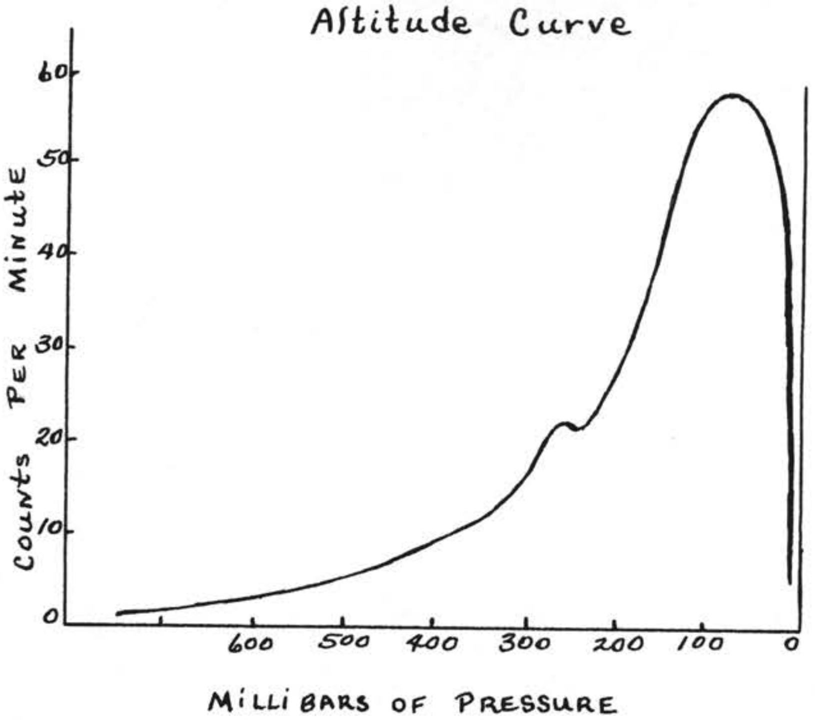

Fig. 6[1]

Altitude.

As has been stated in the history, cosmic rays were first shown to be different from rays coming from the earth by the increase in intensity with altitude. Further obser-

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[1] Curtiss, Astin, and Stockman, Physical Review, vol. 53, (1938), p. 27.

vations of altitude influence show that a maximum of intensity is reached at a height of 47.6 millimeters of mercury. These measurements were recorded by an automatic electrometer sent to a height of 92,000 feet by Millikan, Neher, and Haynes.[2] These results were duplicated by Regener about the same time.

Figure 6 shows an altitude curve drawn from results obtained by Curtiss, Astin, Stockman, and Boran.[3] In these flights the cosmic rays reached a maximum intensity and then decreased rapidly with altitude. As shown by the graph the number of counts at a height of 116,000 feet or 5 millibars of pressure was about the same as at 600 millibars of pressure. This phenomenon of reaching a maximum and then rapidly decreasing with altitude seems to show that most of the cosmic rays measured that near the earth are secondaries.

Latitude.

While traveling from Holland to Dutch India Clay found a drop in cosmic ray intensity as he approached the geomagnetic equator.[4] He made several such trips in 1927 and 1928 and confirmed his first observation, which showed about 15 per cent decrease of cosmic ray intensity from Holland to the equator. In testing these observations Millikan[5] went to Churchill, Manitoba, 730 miles due south of the north magnetic pole on the west side of Hudson's Bay. From

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[2] Millikan, Neher, and Haynes, vol.50,(1936), Phy.Rev.,p. 992.

[3] Curtiss, Astin, and Stockman, Phy.Rev., vol. 53,(1938), p. 23.

[4] H. B. Lemon, op. cit., p. 101.

[5] R. A. Millikan, Physical Review, vol. 36, (1930), p. 1595.

these observations Millikan found that the cosmic rays have the same intensity at Churchill (latitude 59) as at Pasadena (latitude 34). In 1931 Compton promoted a world survey to study the effects of latitude on the intensities of cosmic rays. The results show variations with latitude, with a minimum at or near the geomagnetic equator, and increasing intensity toward the north and south poles. At sea level the intensity at high latitudes is 14 per cent greater than at the equator. But with altitude the latitude effect increases rapidly, as shown at 4360 meters the intensity at higher latitudes is 33 per cent greater than at the equator.[7] These investigations seem to indicate that at least part of the incoming rays are effected by the magnetic field of the earth and therefore electrical particles.

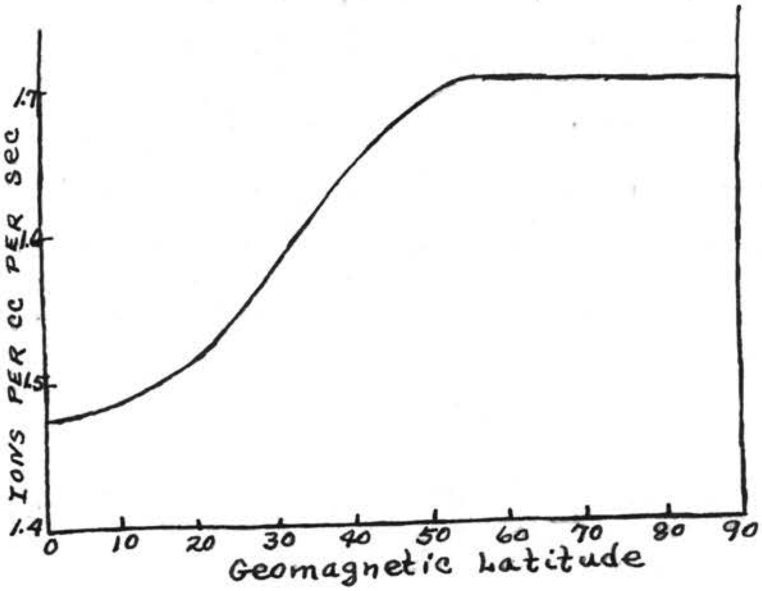

Fig. 7
Latitude Curve

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6 F. Rassetti, op. cit., p. 283.

[7] A. H. Compton, Physical Review, vol. 43, (1933), p. 387.

Longitude.

Neher and Millikan sent a self-recording electroscope on a world cruise in the captain's cabin on the Dollar Line ship President Garfield. This ship left Los Angeles, sailed by China and Singapore, up through the Red Sea and the Mediterranean Sea, out across the Atlantic Ocean to New York and back to Los Angeles. When the films were developed and the records studied the longitude effect was discovered, January 10, 1934. Other trips confirmed the observations of the first, showing an equatorial dip in intensity of 12 per cent in the region of Sumatra as compared to a dip of 8 per cent found on the west coast of South America.[8] Independently of this work Clay, von Alphen, and Hoaft found the intensity of cosmic rays was effected by longitude.[9]

Directional Effect.

In 1928 Millikan and Cameron made several tests to observe effects of direction on cosmic ray intensity. At that time they found no directional effect of any kind.[10]

In 1932 Johnson and Street, atop Bartol Laboratory in Swarthmore, Pennsylvania, found a possibility of greater intensity towards the south than the north.[11]

But by far the most important directional effect discovered is the East-West effect. By placing two G-M counters with their axes parallel to the north-south direction and

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[8] R. A. Millikan, op. cit., p. 439.

[9] M. S. Vallarta, Phy. Rev., vol. 47,(1935), p. 647.

[10] Millikan and Cameron, Phy. Rev., vol. 33,(1929), p. 266.

[11] Johnson and Street, Phy. Rev., vol. 41,(1933), p. 690.

by tilting the plane, which goes through their own axes, towards the west for the readings and then through the east, one can find from what direction the incoming rays are the greater.[12] Johnson and Street, Alvarez and Compton, Auger and Leprince-Ringuet, Rossi, and Elmert all reported finding a greater intensity from the west than the east.[13]

Diurnal Effects.

In 1931 Compton, Bennett and Stearns made tests for 240 hours near the top of Mt. Evans, Colorado, and found no variations in the intensity greater than statistical errors.[14]

In 1932 Mott-Smith and Howell investigated diurnal effects and found no significant increase or decrease in intensity with night even at the highest altitudes tested. No changes were recorded during the solar eclipse August 31, 1932.[15] Kolhörster reported in 1934 that periodic variations did not seem to effect the intensity of cosmic rays.[16]

After careful study and analysis of the long time continuous record of Hess and Steinmauer, Compton and Getting went on record to the effect that there seems to be a variation with sideral time that is ten times the probable error of the computations. These computations were confirmed by R. L. Doan who reported in 1936 that he had found a small diurnal effect.[17]

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[12] H. B. Lemon, op. cit., p. 112.

[13] T. H. Johnson, Phy. Rev., vol. 45,(1934), p. 570.

[14] Bennett, Stearns, and Compton, Phy. Rev., vol.38,(1931), p. 1566.

[15] Mott-Smith and Howell, Phy. Rev., vol. 43,(1933), p. 381.

Showers and Bursts.

From observations of cloud chambers and of cloud chambers in circuits with coincidence counters, the phenomenon of cosmic ray showers was found. If a thin piece of lead is placed in a cloud chamber the observer finds several paths leading from one point on the lead plate. It seems that a particle of very high energy can produce in a single process a large number of secondary particles. Anderson and his co-workers took 10,000 counter activated cosmic ray photographs on Pikes Peak. Results show that showers are more frequent and on the average larger than at sea level.[18]

Ordinarily a ray releases about 120 ion pairs per centimeter of path in an ionization chamber, but a few times a day there are released suddenly a few million. No present-day theory of the atom can account for this phenomenon.[19]

Other Effects.

Many other effects of cosmic rays have been studied but not enough evidence has been found in most cases to be convincing. Some of these other effects studied are sun spot cycles, terrestrial and solar magnetic storms, and the rotation of the galaxy.

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[16] Nature, vol. 133, March 1, 1934, p. 387.

[17] H. B. Lemon, op. cit., p. 123.

[18] Anderson, Millikan, and Neddermeyer, Phy. Rev., vol. 49, (1936), p. 204.

[19] M. S. Vallarta, Phy. Rev., vol. 47,(1935), p. 647.

Chapter 4

Electrified Particles or Photons?

From 1925 to about 1931 the majority of scientists seemed to favor the theory that primary cosmic rays were photons, but since that time we find them shifting over to the side of electrified particles. In the United States the two outstanding proponets in these fields are Dr. A. H. Compton (electrified particles) and Dr. R. A. Millikan (photons). In this chapter will be given a brief of the outstanding theories as they attempt now to explain the nature of cosmic rays.

The Photon Theory.

Most of these discussions are taken from explanations as presented by Dr. Millikan.[1]

In the study of cosmic rays one of the first things observed was their tremendous penetrating power. This suggested their kinship with gamma rays, since at the highest measured energies the gamma rays have a penetrating power of the order of a hundred times that of beta rays.

In 1927 and 1928 Hoffman and Millikan and Cameron observed that when the pressure in a given electroscope was increased from one atmosphere of air to 30 atmospheres, the multiplying factor of 14 was the same for the gamma rays of radium as for the cosmic rays.

From the study of thousands of photographs of cosmic ray tracks Millikan thinks that the immediate ionizing agent in

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[1] R. A. Millikan, op. cit., p. 404.

all cosmic ray ionization is either a free positron or negatron, and not protons, neutrons, or other heavy particles. Photons ionize only through the mechanism of free electron shots.

Between 14,000 feet and 50,000 feet there is an exponential rise of ionization and this is explained by the banded structure of the incoming photons.

As we shall see in the latter part of this chapter, the main arguments for electrified particles lies in the fact that cosmic rays are effected by latitude or the magnetic field of the earth. Millikan divides the rays into two groups, namely, non-field-sensitive rays and field-sensitive rays. The latter group is considered to be electrons, which are extra-terrestrial secondaries. When the primary photons are formed they travel probably millions of years through space before they reach our earth. When passing through rare bits of matter in space secondary electrons are produced by the collisions. These extra-terrestrial secondaries travel along with the primary photons, but they are effected by the magnetic field of the earth, thus accounting for the latitude effect. By records of investigations Millikan shows that about 7 per cent of the sea-level ionization in the temperate and polar latitudes above Los Angeles is due directly or indirectly to incoming electrons while about 93 per cent is due to non-field-sensitive rays.

Millikan sets forth several conclusions as a result of the study of collisions and energies of cosmic rays. Briefly these are: (1) secondary electron and photon rays account for

75 per cent to 85 per cent of all the ionization produced in the atmosphere by incoming electrons; (2) these secondary electron and photon rays are practically all low-energy rays; (3) but since the great bulk of cosmic ray tracks measured by both Anderson and Kunze have energies far above 100 million electron volts and about half of them are positive, it follows that they are not the effect of incoming electrons, because secondaries produced by high speed electrons are practically all negative; (4) since, as stated before, at least 75 per cent of the 7 per cent of field-sensitive ionization is due to secondaries produced within the air by incoming electrons, it follows that the number of incoming electrons found at sea level need be no more than 3 per cent of the total number of ionizing particles that produce the cosmic-ray ionization at sea level.

Because of the magnetic field of the earth, electrons, to enter our atmosphere near the equator, must have an energy of at least 10 billion electron volts. A few of the extra-terrestrial secondaries have this energy and this accounts for the longitude effect. Also these few electrons account for the east-west effect, which has been discussed in chapter 3. When this effect was discovered it was assumed that this showed there were a few more positive particles than negative entering this region. Millikan explains this by stating that the nuclei of atoms are more positive than negative, therefore in collisions in space the negatrons would be more easily captured by the nuclei than the positron, and thus leave more positrons. The magnetic field of the earth separates the incoming electrified particles, those of low energies entering the atmosphere near the poles, and those with only the highest energies entering above the equator.

In 1934 Millikan set forth a summary of his conclusions:[2] (1) practically all cosmic-ray ionization is due to the passage of positrons and negatrons rather than heavier particles; (2) more than 70 per cent of this ionization is due to secondaries produced within the atmosphere by incoming electrons and photons; (3) no evidence for more than 3 per cent of the ionization at sea level to be due to incoming electrons, but this number is responsible for the latitude, longitude, and east-west effects; (4) in general photons interact only with electrons whether in the nucleus or out of it; (5) the magnetic field of the earth separates low energy incoming secondary electrons from high energy electrons; (6) the greater part of the ionization of our atmosphere is due to photons of the energy of the order of 200 million electron volts.

At this point I wish to explain briefly what is meant by electron volts. Just as the energy of a bullet depends upon its mass and speed, and the speed can be expressed in terms of the distance the bullet would have to fall to acquire that speed, so the energy of a moving electron is given in terms of electron volts. Electron volts express the difference in potential between two points between which the electron would have to fall to acquire the energy it possesses.[3]

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[2] R. A. Millikan, Physical Review, vol. 46, (1934), p. 329.

[3] The World Book, vol. 3, p. 781.

Electrified Particles.

As has been previously stated Bothe and Kolhörster first started using coincident counters for the study of cosmic rays. In their studies they found the existence of ionizing particles having a mass absorption coefficient of the order of magnitude of the absorption coefficient of cosmic radiation.[4] This naturally caused them to identify cosmic rays as the ionizing particles and this was the beginning of the corpuscular hypothesis of cosmic rays.

When several G-M counters are placed in circuits to produce coincident counters the ionizing particle must pass through all cylinders in the circuit before it is recorded. Since photons cannot ionize the air the particle would be considered electrified, but many argue that it is probably a secondary particle. If four cylinders are arranged vertically and a piece of lead 10 centimeters thick is placed above, the number of counts can be recorded. If the thickness of the lead plate is increased to thirty-five centimeters the number of coincidences is reduced only a few per cent.[5] From the particle point of view this means that most of the particles at the top of the atmosphere have an energy of at least six billion volts.

Epstein, Lemaître and Vallarta, and Stoermer developed equations showing the influence of the magnetic field of the earth on electrified particles. This minimum energy for coming down through the blocking effect of the field was higher

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[4] F. Rassetti, op. cit., p. 279.

[5] G. F. Hull, op. cit., p. 287.

for lower geomagnetic latitudes, and required a drop in cosmic ray intensity when coming from higher to lower latitudes.[6] Such effects were later observed and confirmed as discussed in chapter 3. With this discovery of the latitude effect many scientists were convinced that this was sufficient proof that the primary cosmic rays are electrified particles.

The longitude effect and the east-west effect, discovered later, also show that the earth's magnetic field has an effect on incoming cosmic rays. Such effects on these rays seem to point rather definitely towards electrified particles entering the atmosphere.

In the study of high altitude observations and deep lake investigations three corpuscular components of cosmic rays are revealed. These groups are identified as separate groups by their range of penetration in the atmosphere and lakes below. From the absorption curve for the atmosphere Compton concludes that the great bulk of cosmic rays can be interpreted as particles of a certain range distribution and not photons. Compton divides these into groups according to the order of their penetration and calls them A, B, and C.[7]

Group A consists of the soft component predominant above 50,000 feet. The latitude effect at high altitudes overthrows the photon for this radiation, and the same effect seems to rule out the neutron, an uncharged particle. Electrons of as little penetration and energy as those of Group A could not pass through the earth's magnetic field. For this group the

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[6] H. B. Lemon, op. cit., p. 100.

[7] Ibid., p. 106.

possibilities left would be the protons and alpha rays. The alpha rays (doubly charged helium atoms) seem to be the choice for this group.

As analyzed by Compton, Group B covers a wide range of energies. Compared to the number of particles that enter the atmosphere, there are few of them able to penetrate all of the atmosphere. There seems to be a maximum at roughly one-half an atmosphere (36 centimeters of mercury) followed by a steep falling off down to a limit of 27 centimeters of mercury. Compton states that particles capable of penetrating thirty six seventy sixths of the atmosphere must have energies of 8 billion electron volts if they are alpha particles, 2.8 billion electron volts if electrons, and 2.1 billion electron volts if protons. From cloud chamber pictures at this altitude, proton tracks are extremely rare, and for this reason Compton says that Group B is most likely made up of electrons (positive and negative).

Group C contains the hardest of rays which penetrate the atmosphere and then hundreds of meters of water. According to Compton only protons seem to possess the necessary mass, charge (positive), and energy to produce the observed results in these connections.

As a summary, Compton identifies Group A with alpha particles, Group B with electrons, and Group C with protons.[8]

Thus we see that most of the scientists seem to agree that at least some of the cosmic rays that are entering our atmosphere are electrified particles. At a meeting of the

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[8] Ibid., p. 114.

American Philosophical Society at Philadelphia, Pennsylvania in April, 1935, the assembled men of science agreed that much of the incoming cosmic radiation consisted of electrified particles, but they differed sharply as to the exact percentage of corpuscular rays among the incoming rays. The estimates varied from 15 per cent to 99 per cent, the latter being Dr. Compton's figure.[9]

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[9] The Americana, 1936 Annual, p. 191.

Chapter 5

Speculations as to the Origin of Cosmic Rays

Many of the physicists that have been working in this field admit that there is not enough known about cosmic rays to even speculate as to their origin. But naturally the investigators have wondered where rays of such energies could have originated, and several have dared give us their hypotheses.

The partial or complete atom-annihilating hypothesis.

Millikan tells us that the existence of cosmic-ray bands, shown by different ranges of penetration, demands that cosmic rays originate in some nuclear act having sharply defined energy values translatable into spectral line frequencies.[1] According to Einstein's theory, mass and energy are interchangeable, and their relation is given by the formula $E = mc^2$. E is the energy in ergs, m is the mass in grams, and c is the velocity of light in centimeters per second. Using this equation as a basis Millikan advances the partial or complete atom-annihilating hypothesis.

It is believed by many scientists that the atoms of other elements are built up from atoms of hydrogen. But Aston found that the relative masses of the atoms of various elements are not multiples of the mass of the hydrogen atom.[2] From the measured masses of the atoms of various elements, using Einstein's equation and Planck's equation ($E = hv$), it

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[1] Millikan and Cameron, Phy. Rev., vol. 32,(1928), p. 534.

[2] The Americana, 1929 Annual, p. 593.

is possible to compute the energy released if these elements are formed by the union of hydrogen atoms. That is, if four atoms of hydrogen unite to form one atom of helium, there is a loss of mass equal to 4 x 1.008 (mass of hydrogen atom) minus 4 (mass of helium atom) which equals .032 atomic weight units.[3] It is supposed by Millikan and some others that this lost mass becomes radiant energy, which in this case equals about 28 million electron volts. The energy released by the sudden formation of an oxygen atom from 16 hydrogen atoms comes out 116 million electron volts; that released in the formation of silicon out of 28 hydrogen atoms is 216 million electron volts; of iron out of 56 atoms of hydrogen 460 million electron volts.[4]

From the study of the penetrating powers of cosmic rays it appears that the great majority of them have energies within the ranges indicated above, corresponding to the sudden formation of the elements, helium, oxygen, silicon, and iron from hydrogen. As far as known at the present time these are the most abundant elements in the universe.[5] It has been stated before that there are a few of the cosmic rays that have energies as high as 10 billion electron volts or higher. The sudden formation of uranium, our heaviest known element, from hydrogen would produce only 1,800 million electron volts.[6] Thus we see the partial atom-annihila-

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[3] G. E. M. Jauncey, op. cit., p. 385.

[4] R. A. Millikan, op. cit., p. 313.

[5] H. B. Lemon, op. cit., p. 96.

[6] R. A. Millikan, op. cit., p. 314.

ting process would not account for the most penetrating of the cosmic rays known. The complete annihilation of certain atoms would produce radiation with these energies. If the mass of a carbon atom was suddenly transformed into radiant energy the energy would be about 10 billion electron volts. Just such a transformation could not take place without violating the law of the conservation of momentum, but two 5 billion electron volt photons or electrons going off in opposite directions would overcome this difficulty. Two 8 billion electron volt photons might be produced by the annihilation of an oxygen atom.[7]

The Baade and Zwicky Hypothesis.

From the time it was shown that cosmic rays do come from outside our earth, it has been a favorite idea that certain events in stars are responsible for them. In 1934 Baade and Zwicky[8] advanced a theory placing the origin of these rays in super-novae stars. These are stars, which for unknown reasons, undergo a tremendous explosion accompanied by an increase in their brilliance. Novae within our own universe of stars are not at all uncommon and very brilliant ones are observed in other far distant universes. In 1935 an ordinary nova was discovered in the constellation of Hercules. Kolhörster set up cosmic ray coincidence counters and found an increase in cosmic ray intensity when the light from the nova fell on the cosmic ray telescope. The increase was two per cent, which was four times the experimental er-

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[7] Ibid., p. 452.

[8] H. B. Lemon, op. cit., p. 115.

ror. If these reports are confirmed by other data another independent clue to the fundamental nature of cosmic rays may be obtained.

If these rays are photons they would travel with the speed of light and would reach here at the time we see the explosion of the nova, but if they are electrified particles they would lag behind one another.[9] That is the various charged constituents of the ray would be sorted out on the long journey through space, and if detectable would furnish means for determining their origin.

Other Theories.

Professor Milne,[10] of Oxford, states that the vast spaces between the various galaxies are thronged with unattached floating particles of the kinds of matter of which form stars. These particles are affected by the gravitational attraction of the whole universe, which causes them to move with almost the speed of light. Milne thinks that cosmic rays are these free flying particles drawing their energy from the universe.

Dr. T. H. Johnson thinks that negatively charged clouds of dust or vapor over a star's surface might attract positively charged atomic ions and project them into space like the beam of a cathode tube.[11] Nuclei of hydrogen and helium atoms, the principal constituents of the atmosphere of stars would thus become the cosmic rays.

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[9] Ibid., p. 116.

[10] The Americana, 1936 Annual, p. 192.

[11] New Standard Encyclopedia, 1935 Year Book, p. 437.

Hannes Alfuen tries to account for the origin of cosmic radiation by thinking of double stars acting as giant cyclotrons.[12]

Many of the scientists believe that cosmic rays were formed in bygone ages. Lemaître advances the hypothesis that they are super-radioactive particles emitted at the initial explosion of the expanding universe.[13]

Swann suggests that they are electrons accelerated by electromagnetic induction from the changing magnetic field of sun spots on giant stars.[14]

Here are several theories as to the origin of these mysterious cosmic rays, they may or may not be the true answer. They show that there is much yet to be learned in this field before a definite answer can be made to the question, whence come cosmic rays?

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[12] Nature, Oct. 31, 1936, p. 761.

[13] Scientific Monthly, vol. 42, Feb., 1936, p. 189.

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