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Scope of Study: Studying cosmic rays may lead to the discovery of energies that could dwarf the energies now obtained from nuclear reactions. The physics of high-energy particles is still, to a great extent, cosmic ray physics. The nuclear forces that are being unleashed in atomic bombs, hydrogen bombs, particle accelerators, and nuclear reactors have been developed as a result of knowledge obtained from man's quest of knowledge in the "cosmic ray chase". This report involves a brief study of the history, nature, and the possible future of cosmic rays. Materials used are chiefly science journals and the film "The Strange Case of the Cosmic Rays" which was made available by the Bell Telephone Company.

Findings and Conclusions: The "cosmic ray chase" is a continuing one. Much effort was expended during the recent International Geophysical Year to learn more of the nature of cosmic rays. A study of cosmic rays could lead to many things that are of paramount interest. These could include new sources of energy, the origin of cosmic rays, more of the nature of the universe, and how the human race is affected by the mutations resulting from cosmic radiation. It is felt by many outstanding scientists that aging may be partially due to cosmic rays. We are all affected, whether we know it or not, by cosmic rays.

ADVISER'S APPROVAL James H. Zant

A STUDY OF COSMIC RAYS

BY

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A STUDY OF COSMIC RAYS

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CHAPTER I

INTRODUCTION

The study of elementary particles is probably the greatest problem of physics in this power-conscious world. We know that an electron reacts with the anti-electron (the positron), with the mass of both disappearing in favor of radiant energy. Is it too much, then, to expect that other and much larger particles, such as anti-protons, can be generated and annhilated in a similar manner? The larger building blocks, the proton and neutron, cannot be created from energy until energies on the order of ten billion electron volts are available. This may seem like an unattainable amount of energy, but the three billion electron volt cosmotron at the Brookhaven National Laboratory and the six billion electron volt bevatron at the University of California are both now in operation. Possibly the first generation of protons and neutrons will be observed by studying the reactions induced by cosmic rays.

Although we now have the high energy electro-nuclear machines, cosmic rays were, for a number of years, the only source of high-energy particles available to physicists. Most of our present knowledge of high-energy particles was obtained through the study of cosmic ray phenomena. The physics of high-energy particles is still, to a great extent, cosmic ray physics.

The purpose of this article is to trace the development of events that accompanied the "cosmic-ray chase" and to present material concerning cosmic rays which is easily understood.

CHAPTER II

HISTORICAL AND RELATED DEVELOPMENTS

The first clue of the nature of cosmic rays came about with the studies of Father Theodore Wolfe. It was known that radiation from the radioactive elements would cause a collapse of the leaves of an electroscope. In 1912 Wolfe was studying the rate of collapse of leaves in a charged electroscope due to what he thought was radioactivity from the earth. In order to prove that these radiations came from the earth he took his electroscope to the top of the Eiffel Tower, some 1,000 feet high, in order to prove that the discharge of the electroscope was due to some radioactive element in the earth. After comparing the times of collapse on the ground and on the top of the tower, he was amazed to find that if anything, the leaves collapsed faster on top of the tower.

What caused the leaves to collapse? Could it be ultraviolet or gamma rays? Was it uranium or its disintegration products? It was known that all of these could cause the discharge, but it was also known that none of these would penetrate considerable thicknesses of lead. Even when the electroscope is placed behind nine feet of lead there is still a discharge!

In order to find out more of the nature of these rays, Victor Francis Hess, in 1912, took an electroscope to an altitude of fifteen thousand feet, and amazingly, the leaves collapsed three times as fast. The answer that they came from the earth was definitely proved wrong. The next logical answer was that they might originate in our own atmosphere.

To find this answer Robert A. Millikan designed an electroscope that could be automatically charged. He sent this electroscope to an altitude of fifty thousand feet as well as to great depths in California lakes. His work proved that these particles did not originate in our own atmosphere. It was at this point that Millikan named these mysterious objects "cosmic rays". This name was apt since he showed that these particles come from outer space and not necessarily the sun because the radiation is as great in the night as in the day.

The next step was to prove that the cosmic rays are particles. This was accomplished by showing that they are affected by the earth's magnetic field.

The next question would be to find out if they are electrons, protons or neutrons. As we shall later see electrons and neutrons are only secondary effects of the cosmic rays caused by their crashing into air particles of the earth's atmosphere. Actually, each cosmic particle causes dozens of secondary particles.

To digress, let us pause to learn how these secondary effects are detected. A cloud chamber designed by C. T. R. Wilson will track electrons and protons in much the same way we could look at the vapor trail of a jet airplane and determine its speed and direction. After finding a method of tracking them, how can we tell if they are electrons, protons or neutrons? T. M. S. Black studied their tracks by placing the cloud chamber between the poles of an electromagnet. If the particles were neutral they would be unaffected. If they were positive they would veer to the right, if negative, to the left. It turned out that they did all three.

Now that the secondary effects were shown to be the fundamental particles, the electron, the proton and the neutron, what is the nature of the primary particle, the cosmic ray itself? Was it neutral, positive, or negative? The answer was to be found by studying the effect of the magnetic field of the earth. If they were neutral they would rain in on the earth with equal intensity throughout the world. If charged they would bend more at the equator. Charged particles coming into the atmosphere at the equator would strike the field at right angles and would be deflected more than the rays at the poles. Sure enough, after considerable investigation it was shown that for every hundred particles that came in at the poles, there were only eighty seven at the equator. Evidently they were charged.

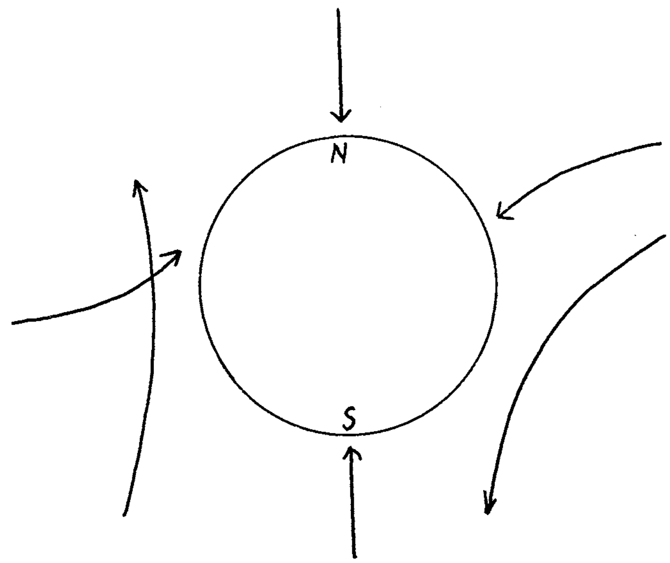

Figure 1. Diagram showing how charged particles would be deflected by the earth's magnetic field.

The next question naturally is, "What is the charge?" We again turn to the earth for an answer. On first examination we would declare them to be electrons or protons since neutrons have been eliminated as a possibility.

Now that the particles were shown to be charged, the scientists next wanted to know if they were positive or negative. Bruno Rossi, the noted Italian physicist now at the Massachussetts Institute of Technology, proposed that if we look down on the earth at the south pole the positive charges would be more abundant from the west. If they were negative we would get more from the east.

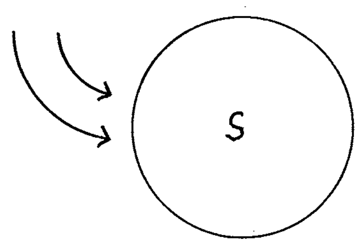

Figure 2. Direction of positively charged cosmic rays.

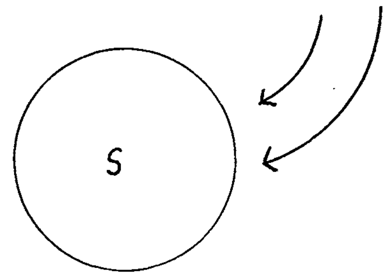

Figure 3. Direction of negatively charged particles.

Compton, Johnson, and Alvarez (in Mexico) showed that more came in from the west, consequently, the cosmic rays are positive. The next step was to identify the particle.

At the present time there are thirty fundamental particles. Most of these particles were discovered in the cosmic ray chase. One of the first of these was the positron, a particle that behaved much like the electron except that it had a positive charge. An up-to-date list of these particles is given at the end of chapter three. We have Anderson's own description of this particle:[1]

> "A determination of the specific ionization of cosmic ray particles, first, by a count of the number of drops per cm. along cosmic ray tracks on cloud chamber photographs and, second, by measurements of the energy loss in lead has shown that the great bulk of the cosmic ray particles of positive charge are positive electrons. The primary ionization was found to be about thirty-one ion-pairs per cm. in air at S. T. P., but the total energy loss represents about 120 ion-pairs per cm. in air. Approximately the same values of specific ionization were found for the positives as for the negatives. Positive and negative electrons were found to occur in nearly equal numbers and to have similar distributions in energy. . . .

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[1]Carl D. Anderson, "Cosmic Ray Positive and Negative Electrons," Physical Review, Vol. 44 (Sept. 1, 1933), No. 5, p. 406

This charged particle was subsequently named the positive electron or positron. This positron was a newly found secondary effect of the cosmic ray.

In general force manifests itself in three ways. The gravitational force may be associated with the graviton and the nuclear force may be associated with the pi meson in much the same manner as the electromagnetic force is associated with the photon. What was this nuclear force? H. Yukawa predicted that this small unit would appear as a small particle, would live 10^{-6} seconds and would be 200 times as heavy as the electron. This particle, the pi meson, was predicted by Yukawa at Usaki University in Japan in the year 1935. Neddermeyer, Anderson, Street, and Stevenson, in 1937, discovered a particle very similar to the one predicted by Yukawa, but still it didn't quite live up to the expectations of its predictions. This new particle was called the mu meson.[2]

In 1947 Lattes, Occhialini and Powell, of the University of Bristol, in England did discover the pi meson which had been predicted by Yukawa. In the words of Lattes, Muirhead, Occhialini and Powell[3] we read:

> "In recent investigations with the photographic method, it has been shown that slow

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[2]Seth H. Neddermeyer and Carl D. Anderson, "Note on the Nature of Cosmic-Ray Particles", Physical Review, Vol. 51 (May 15, 1937), No. 10, p. 884.

[3]C. M. G. Lattes et al., "Processes Involving Charged Mesons", Nature (London), Vol. 159 (May 24, 1947), No. 4047, pp. 694-697.

> charged particles of small mass, present as a component of the cosmic radiation at high altitudes, can enter nuclei and produce disintegrations with the emission of heavy particles. It is convenient to apply the term 'meson' to any particle with a mass intermediate between that of a proton and an electron. In continuing our experiments we have found evidence of mesons, which, at the end of their range, produce secondary mesons. We have also observed transmutations in which slow mesons are ejected from the disintegrating nuclei."

These men went on in their article to describe their experiments which bore on the important problem of developing a satisfactory meson theory of nuclear forces. Yukawa's efforts earned him a Nobel prize. It is the pi meson which is the nuclear force that holds the nucleus together.

In 1932 there were considered to be only three basic particles of the universe. In 1957 there were at least twenty with more being discovered all the time. One real "odd ball" is the neutrino which goes through lead like a rifle bullet through a cracker. How many more? The cosmic ray chase has lead to these. Will it lead us to the key to the universe?

What about cosmic rays? A new detection device, the cosmic ray detector, helped in the chase to pinpoint the true nature of the cosmic ray. This detector is a photographic plate with a thick coating of silver bromide. This new plate has been taken to altitudes of 140,000 feet and stayed there for days in a new type of balloon called the sky hook. Rockets can really take pictures in the cosmic rays' home territory. They are going in excess of 150 miles in altitude.

This is considerably above the main portion of the earth's atmosphere.

By studying the emulsion plates it was easily proved that most of the cosmic rays were merely very high speed protons. In 1948 some University of Minnesota physicists found some paths on the plates that were too heavy and too highly charged to be protons. These were attributed to the naked helium atoms. Also, there have been found naked oxygen atoms. These all travel at speeds approaching that of the speed of light with an almost unbelievable energy of a million billion electron volts.

We can no more than speculate as to the origin of the cosmic rays. They may arise as a result of explosions on the surface of the stars. Fermi suggested that the intense heat of these solar explosions repels these particles and then they are continually accelerated by the magnetic fields of the swirling galactic clouds of the universe. A minute portion of them reach us as we race our way through the great universe. More of this subject will be described in more detail in a later chapter.

CHAPTER III

THE NATURE OF COSMIC RAYS

The distinguishing feature of cosmic rays is their unique concentration of energy in single elementary particles. Rays that cause the aurora borealis are similar to cosmic rays in that they are probably made up mainly of protons or hydrogen nuclei but are a million or so times less energetic and consequently, are absorbed high in the stratosphere.[1] The total energy of all cosmic rays in the atmosphere is only roughly ten microwatts per square meter and one hundred million times less than the radiant energy from the sun. Therefore cosmic rays apparently do not affect life on earth directly in any physical way. The average quantum of energy of starlight photons is about two electron volts, while the energy of a single cosmic particle is about 20 Bev.

Particles of such energies can penetrate any nucleus and may cause it to disintegrate. Cosmic rays do not obey Newton's laws as do slower moving bodies. Cosmic rays supplied a critical test of the relativistic electromagnetic theory and illustrated the interchange of energy between matter and radiation. They also made possible the discovery of most of

[1]"Cosmic Rays," Encyclopaedia Britannica (Chicago, 1958) Vol 6, pp. 496B-496C.

the known elementary particles of matter.

Though we have no graphic picture of a nucleus, the wave lengths of cosmic rays are so small that when they interact with nuclei, they interact separately with the smallest sub-units of which the nuclei are composed; thus giving us tools by which we can study nuclei. At the other end of the scale, cosmic rays bring information about the far reaches of the universe. The properties of cosmic rays provide a means of testing hypotheses about the stars of interstellar regions where they apparently were created.

Another interesting use of cosmic rays is in radiocarbon dating. Radiocarbon dating depends on the intensity of cosmic rays having been the same ten to twenty thousand years ago as it is now. In some instances it has been possible to check the radiocarbon dating by comparing dates established by other means. There is such good agreement between the dates arrived at by different means that we can be quite sure that the rate of arrival of cosmic rays has been quite constant.

The first information about the nature of primary cosmic rays was derived from the effect of the earth's magnetism on cosmic ray intensity. Although the intensity is weak, it accounts for a considerable effect on most of the cosmic rays.

The rate of deflection of a particle is proportional to the component of field strength perpendicular to the motion, and proportional to the charge Z of the particle and inversely proportional to the momentum, p. For any specific place and direction of arrival, there is a limiting value of the ratio p/z, such that particles with lower values of p/z are turned back and cannot reach the earth at all; while particles with higher values of p/z are admitted almost as freely as if the earth had no magnetic field. For the admitted particles the only effect of the field is to change the region of space from which they appear to have started. The number of lines of force which are crossed varies with the geometric latitude at which the particles arrive, with their direction of motion, and with the sign of their charge, as well as their velocity. Thus, particles of positive charge must cross more lines to arrive from the east than to arrive at a similar inclination from the west; consequently, more of the positive primaries are prevented from arriving from the east than from the west. This gives rise to the east-west effect. Measurements show that more particles arrive from the west than from the east, and therefore most if not all primary cosmic rays are positively charged.

The geomagnetic latitude effect is even more prominent. Even the low-energy auroral particles can spiral in along the lines of force near the geomagnetic poles. Measurements near the top of the atmosphere show little variation with latitude, beyond latitude 59°. This means that almost all of the primaries have energies above 0.4-0.5 Bev, and speeds more than half that of light, since with decreasing latitude the rays must cross more and more lines of force. At latitude 41° the rate of arrival is one per square centimeter every four seconds, about three times the rate at the equator.

Direct experiments have been performed to determine whether the primaries include electrons and positrons, and if photons comprise a portion of the primary radiation. In one of these experiments, a cloud chamber was carried by a balloon near the top of the atmosphere, with lead plates in the chamber so that electrons, positrons, and photons could be recognized by the cascade shower production. It was found that these components, if present at all, are less than one half percent of the primaries of more than 1 Bev.

With neutral particles, photons, positrons, and electrons ruled out, and the primaries known to be both stable and positively charged, the most likely conclusion would be that they are protons and possibly nuclei of heavier atoms. This probably is the case. The most conclusive evidence comes from the tracks seen in nuclear emulsions exposed near the top of the atmosphere; but experiments with balloon-borne lead chambers, scintillation detectors, proportional counters and low-pressure Geiger-Mueller counters have agreed with the emulsion evidence. Most of the tracks show by their grain density that the particles are singly charged and therefore protons; Mass measurements have confirmed this identification. About one-eighth of the primaries produce tracks that identify them as alpha particles and one per cent are nuclei of heavier atoms, including carbon, oxygen, neon, magnesium, silicon, and the iron-cobalt-nickel group, plus small amounts of intermediate elements.

Studies of meteorites, stellar spectra, and the constituents of the earth lead to estimates of the relative abundances of the various elements in the universe. These results are strikingly similar to the composition of cosmic rays.

There are three things that the study of cosmic rays shows us:[2] (1) The rays are not intense, (2) Many of the cosmic ray particles are very energetic, and (3) The sea-level radiation is very complex, being a nucleonic, mesonic, electronic, and photonic debris caused by the interaction of an energetic primary radiation with the nuclei of the upper atmosphere. An up to date summary of subatomic particles is given in the following table.[3] These particles were discovered mostly in the cosmic ray chase.

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[2]David Halliday, Introductory Nuclear Physics (2d ed., New York, 1955), p. 415.

[3]S. B. Treiman, "The Weak Interactions," Scientific American, Vol. 200 (March, 1959) No. 3, pp. 74-75.

TABLE I

SUMMARY OF SUB ATOMIC PARTICLES

PARTICLE	SYMBOL	MASS	PRINCIPAL MODES OF DECAY	LIFETIME (SECONDS)
Photon	γ	0	Stable	
Neutrino	$\nu(\bar{\nu})$	0	Stable	
Electron	$e^-(e^+)$	1	Stable	
Mu mesons	$\mu^-(\mu^+)$	206	$\mu^- \to e^- + \nu + \bar{\nu}$	2.22×10^{-6}
Pi mesons	$\pi^-(\pi^+)$	273	$\pi^- \to \mu^- + \bar{\nu}$	2.56×10^{-8}
	π^0		$\pi^0 \to \gamma + \gamma$	less than 10^{-15}
K mesons	$K^-(K^+)$	967	$K^- \to \mu^- + \bar{\nu}$	1.2×10^{-8}
			$\to \pi^- + \pi^0$	
			$\pi^- + \pi^+ + \pi^-$	
			$\pi^- + \pi^0 + \pi^0$	
			$e^- + \bar{\nu} + \pi^0$	
			$\mu^- + \bar{\nu} + \pi^0$	
	K_1^0	~ 973	$K_1^0 \to \pi^+ + \pi^-$	10^{-10}
			$\to \pi^0 + \pi^0$	
	K_2^0		$K_2^0 \to \pi^+ + \pi^- + \pi^0$	8×10^{-8}
			$\to \pi^0 + \pi^0 + \pi^0$	
			$e^- + \bar{\nu} + \pi^+$	
			$e^+ + \bar{\nu} + \pi^-$	
			$\mu^- + \bar{\nu} + \pi^+$	
			$\mu^+ + \nu + \pi^-$	

TABLE I

SUMMARY OF SUB ATOMIC PARTICLES

(CONTINUED)

PARTICLE	SYMBOL	MASS	PRINCIPAL MODES OF DECAY	LIFETIME (SECONDS)
Proton	$p(\bar{p})$	1836	Stable	
Neutron	$n(\bar{n})$	1839	$n \to e^- + p + \nu$	1010
Lambda Particle	$\Lambda^0 (\bar{\Lambda}^0)$	2182	$\Lambda^0 \to p + \pi^-$ $\to n + \pi^0$	
Sigma Particles	$\Sigma^0(\bar{\Sigma}^0)$	2326	$\Sigma^0 \to \Lambda^0 + \gamma$	10^{-11}
	$\Sigma^+(\bar{\Sigma}^+)$	2328	$\Sigma^+ \to p + \pi^0$ $\to n + \pi^+$	$8x10^{-11}$
	$\Sigma^-(\bar{\Sigma}^-)$	2342	$\Sigma^- \to n + \pi^-$	$1.7x10^{-10}$
XI Particles	$\Xi^-(\bar{\Xi}^-)$	2585	$\Xi^- \to \Lambda^0 + \pi^-$	10^{-10}
	$\Xi^0(\bar{\Xi}^0)$		$\Xi \to \Lambda^0 + \pi^0$	?

CHAPTER IV

WHAT IS THE ORIGIN OF COSMIC RAYS?

In answer to the question asked by the title of this chapter there naturally follow two questions: (1) Where do they come from initially? and (2) How do they receive their energies? Most theories agree that there is a continuous production of primaries by an equal rate of loss of primary particles by collision with interstellar matter or by escape from the region in which the cosmic rays are present. "The fact that the distribution of ions in the primaries is very much like that deduced from spectroscopic studies of starlight may suggest stellar atmospheres as an ultimate source."[1]

According to Richtmeyer and Teller[2] cosmic rays are assumed to be confined largely to the solar system:

> ". . ., we suggest that the energy of cosmic rays is derived from the most plentiful source in our neighborhood, the sun. We introduce a magnetic field of about 10^{-5} gauss which extends throughout and beyond the planetary system. This field serves to convert the cosmic rays into isotropic radiation. The long circulation periods in this field (10^5 - 10^8 years) also explain why the cosmic intensity does not show long-period

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[1] D. Halliday, Introductory Nuclear Physics (New York, 1955) John Wiley and Sons. p 443.

[2] R. D. Richtmeyer and Edward Teller, "On the Origin of Cosmic Rays," Physical Review, Vol 75, (June 1, 1949), No. 11, p 1731.

> fluctuations connected for instance, with the sun-spot cycle. Finally, the magnetic field helps to keep the cosmic ray intensity at a high level. . . . H. Alfven presents a plausible explanation of this magnetic field. He also describes a possible mechanism for the acceleration of charged particles near the sun.
>
> "If our ideas are correct, the expression "cosmic rays" is a misnomer. We wonder to what extent this name has hindered discussion of the solar origin of this radiation."

According to Fermi[3] the cosmic rays originate in our galaxy:

> "In recent discussions on the origin of cosmic radiation E. Teller has advocated the view that cosmic rays are of solar origin and are kept relatively near the sun by the action of magnetic fields. These views are amplified by Alfven, Richtmeyer and Teller. The argument against the conventional view that cosmic radiation may extend at least to all the galactic space is the very large amount of energy that should be present in form of cosmic radiation if it were extended to such a huge space. Indeed, if this were the case, the mechanism of acceleration of the cosmic radiation should be extremely efficient.
>
> "I propose in the present note to discuss a hypothesis on the origin of cosmic rays which attempts to meet in part this objection, and according to which cosmic rays originate and are accelerated primarily in the interstellar space, although they are assumed to be prevented by magnetic fields from leaving the boundaries of the galaxy. The main process of acceleration is due to the interaction of cosmic particles with wandering magnetic fields which, according to Alfven, occupy the interstellar spaces."

These arguments present a strong discussion in favor of cosmic rays having their origin in our own solar or

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[3]Enrico Fermi, "On the Origin of the Cosmic Radiation," Physical Review, Vol. 75, (April 15, 1949), No. 8, p. 1169.

galactic system. There are equally impressive arguments which reason that cosmic rays have their origin in the wide open spaces of the entire universe. This is the presently accepted view held by most cosmic ray physicists. The next discussion of this chapter is by Arthur H. Compton and Ivan A. Getting[4] who present the idea that cosmic rays have their origin in the heavens of the entire universe.

> "Doppler effect studies of the globular cluster and the extra galactic nebulae have shown a motion of the earth of about 300 km/sec. toward about declination 47° N and right ascension 20 hr. 40 min., which is due chiefly to the rotation of the galaxy. Calculation shows that because of this motion the intensity of cosmic rays at sea level on an unmagnetized earth should be about 1.2 percent greater on the front side than on the back. Taking into account the earth's magnetic field, it is estimated (assuming the cosmic rays reaching the earth to consist of protons and electrons) that the diurnal variation at latitude due to this motion should be within a factor of 2, equal to 0.1 percent, with its maximum at 20 hr. 40 min. sidereal time. Data published by Hess and Steinmaurer show a sidereal time variation having just this amplitude and phase. While this agreement gives a strong presumption that the cause of this sidereal time variation is the earth's motion through space, another possible explanation is also considered. The implication would be that cosmic rays originate beyond our galaxy.

The absence of the Compton-Getting effect speaks against the idea that the cosmic rays are universal in origin. There is reason to believe that the sun is one source of cosmic rays due to the fact that the rays are more intense during periods of intense activity on the sun.

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[4]Arthur H. Compton and Ivan A. Getting, "An Apparent Effect of Galactic Rotation on the Intensity of Cosmic Rays," Physical Review, Vol. 47, (June 1, 1935), No. 10, p. 817.

Fermi, in his article, proposes that the galaxy has two spiral arms which possess a weak intragalactic magnetic field. These arms are assumed to be, roughly, tubes of magnetic force due to the motion of charged particles in the intragalactic space. The lines of force fluctuate randomly in direction and intensity. A 10-bev proton rotating in this field (which is about 10^{-6} gauss) will spiral in an orbit less than that of the earth's orbit. Occassionaly this proton will reach a magnetic field which is strong enough to cause the proton to tighten its spiral and hurl back in the opposite direction. The energy added to the energy of the proton is only a few ev, but over millions of years this can build up tremendous energies.

There are suggestions that acceleration might be due to betatron action of stars during magnetic disturbances. This idea is not clearly understood at the present time.

There is still controversy as to the origin of cosmic rays. In 1956 it was reported[5] that cosmic rays bombard the earth more intensely when the sun is at a low point in its eleven year sunspot cycle than when solar activity is high. This new evidence as reported to the American Physical Society by H. V. Neher of the California Institute of Technology also gave records of atomic disintegrations occurring miles above the earth's surface, gathered over

[5] Science Digest (Chicago, 1956), Vol. 45, (May 1959), No. 5, p. 80.

many years by high flying balloons seem to confirm the theory that cosmic ray intensity varies inversely with the sunspot cycle. The theory was suggested by Dr. Scott E. Forbush of Carnegie Institution of Washington D. C.

CHAPTER V

LATEST DEVELOPMENTS

During the International Geophysical Year there were 195 stations representing 31 nations which studied cosmic rays using neutron monitors and meson telescopes, cloud and ionization chambers, special emulsions and window Geiger counters. Tools for observation included rockets, balloons and earth satellites.

Scientists from the University of Chicago[1] have shown the location of a line where the cosmic ray intensity is at a minimum ("cosmic ray equator") and deviates systematically from the geomagnetic equator. Experiments leading to this result began in 1954-55. These studies showed approximately a forty-five degree westward shift of the inclined cosmic ray equator with respect to the magnetic equator. It has been suggested that this warping may indicate the presence of important magnetic fields, probably of extraterrestrial origin, which alter the trajectories of the incoming primary cosmic ray particles.

Concerning latitude effect, balloons carrying ionization chambers have shown that, at constant latitude, there is a

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[1]Hugh Odishaw, "International Geophysical Year. A Report on the United States Program," Science, Vol. 127, (1958), p. 118.

strong latitude effect. This effect was shown to be so strong that changes in latitude of as little as seven miles can be measured. Other balloon experiments show that lower energy cosmic rays (less than about 2 Bev) have practically disappeared during the present period of high solar activity, with ionization at high altitudes down to half the value it had in 1954.

One of the most interesting observations made during I. G. Y. cosmic ray experiments was that of relatively soft radiation in the high atmosphere, associated with primary auroral radiations. High altitude flights of rockets and balloons have led to the positive identification of soft x-radiation in the 10^4 and 10^5 electron volt range. There seems to be good correlation between the presence of such radiation and solar magnetic and auroral activity. This effect is probably secondary. It is thought that incoming auroral particles create the x-rays by bombardment of the atmospheric particles.

Sputnik II carried two instruments that detected cosmic radiation.[2] An analysis of the material obtained shows the intensity of cosmic radiation increases by about forty percent from the minimal height (225 kilometers) to an altitude of 700 kilometers. This increase is due mostly to the fact that the screening effect of the earth decreases with altitude and that cosmic rays could reach the instrument from many directions.

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[2] Science, Vol. 127 (June 13, 1958), Research Based on Sputniks I and II Reported by Soviets, p. 1378.

It was shown that the earth's magnetic field creates an obstacle to particles reaching the earth. Consequently, only particles of certain energies ever reach the earth. Naturally, the farther we are from the earth the weaker its magnetic field becomes and the smaller is its effect upon the cosmic rays.

Instruments in the sputnik may also reveal the dependency of the intensity of cosmic rays on latitude and longitude. From this study we can gain new information about the earth's magnetic field. Measurements of the earth's magnetic field should give an idea about the character of terrestial magnetism at great distances from the earth. Proceeding from this we should be able to calculate the intensity of cosmic rays over the earth's surface. That is, it is possible to indicate the lines of constant intensity of cosmic rays (called isocism). Measurements made from sputnik have shown that the lines of constant intensity that are calculated theoretically differ substantially from those obtained experimentally. This is in good agreement with what Simpson, an American physicist, had predicted. They showed that the equator determined by means of cosmic rays does not coincide with the geomagnetic equator.

Consequently, we see that there are considerable divergences between the earth's magnetic field measured by cosmic rays and those measured by magnetic means. These are due to the fact that the trajectories of cosmic rays are determined by the magnetic effect at very high altitudes, while direct measurements characterize the magnetic field near the earth's surface. From this information we now have a new approach to the study of the earth's magnetic field and the system of electric currents in the upper atmosphere.

The sputniks also made it possible to register variations in the intensity of cosmic radiation. These variations are connected with the condition of the interplanetary environment near the earth. One instance of a sharp increase of fifty percent was registered. Ground stations did not detect any essential increase at this time. It may be that it was caused by the sun's generation of particles of low-energy cosmic rays (which are absorbed by the earth's atmosphere) or by the sputnik passing through streams of high-energy electrons (connected with the minute particle radiation of the sun).

CHAPTER VI

CONCLUSIONS

What is going to be the result of all the vast amount of research being done on cosmic rays? There are many basic objectives of carrying on a continuing program of cosmic ray research. These objectives as listed by the Technical Panel on the Earth Satellite Program, U. S. National Committee for the International Geophysical Year, National Academy of sciences are listed as follow:[1]

> "The objectives of a cosmic ray experiment would be: (i) to make comprehensive observations on the total intensity of the cosmic radiation as a function of latitude, longitude, altitude, and time; (ii) to determine whether the nuclei of lithium, beryllium, and boron are present in the primary cosmic ray beam and, if they are present, to measure their intensities; and (iii) to study, as in (i), the intensity of the heavy nuclei separately from the total intensity. Interpretation of the results of (i) and (iii) should yield a crucial test of the theory of deflection of charged cosmic ray particles approaching the earth through the geomagnetic field and should yield new information on the nature and importance of interplanetary magnetic fields. The data of (ii) should settle one of the leading questions on the astrophysical origin of cosmic rays and on their propogation to the earth. The data from (i) and (iii) should provide a greatly improved understanding of the systematic and

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[1]R. W. Porter et al., "Research In Outer Space", <u>Science</u>, Vol. 127 (1958), p. 796.

> and sporadic fluctuations of the primary radiation, the astrophysical causes of these fluctuations, and their consequences, as reflected in the rate at which secondary cosmic ray phenomena occur within the atmosphere. A special question is whether the solar sources of cosmic rays yield the same distribution of nuclear species as the usual primary beam."

Cosmic rays have helped prove the oneness of the universe. These particles that come streaming to us are the same as the ones found here on the earth.

What do cosmic rays mean to us? How we work, love, and hate may have been affected by the mutations resulting when a cosmic particle struck just the right gene. Some day we might learn what makes the universe "tick". A great ocean of truth lies before us. The more we know of creation the nearer we get to the Creator.

SELECTED BIBLIOGRAPHY

Anderson, Carl D. "Cosmic Ray Positive and Negative Electrons." Physical Review, Vol. 44 (Sept. 1, 1933), 406.

Compton, A. H., and Ivan A. Getting. "An Apparent Effect of Galactic Rotation on the Intensity of Cosmic Rays." Physical Review, Vol. 47 (June 1, 1935), 817.

Ferni, Enrico. "On the Origin of the Cosmic Radiation." Physical Review, Vol. 75 (April 15, 1949), 1169.

Halliday, David. Introductory Nuclear Physics. New York: John Wiley and Sons, 1955.

Lattes, C. M. G. "Processes Involving Charged Mesons." Nature (London), Vol. 109 (May 24, 1947), 694-97.

Neldermeyer, Seth H., and Carl D. Anderson. "Note on the Nature of Cosmic Ray Particles." Physical Review, Vol. 51 (May 15, 1937), 884.

Odishaw, Hugh. " International Geophysical Year, A Report on the United States Program." Science, Vol. 127 (1958), 1182.

Porter, R. W. "Research In Outer Space." Science, Vol. 127 (1958), 796.

Richtmeyer, R. D., and Edward Teller. "On the Origin of Cosmic Rays." Physical Review, Vol. 75 (June 1, 1949), 1731.

Treiman, S. B. "The Weak Interactions." Scientific American, Vol. 200 (March, 1959), 74-75.

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