In order to place the results of the recent studies of cosmic rays in appropriate perspective, let us recall very briefly their early history. It is well known how at the beginning of the present century C. T. R. Wilson, and Elster and Geitel, showed that normal air is slightly ionized, and how McClennan and Burton at Toronto, and Rutherford and Cooke at Montreal showed by use of absorbing screens that a considerable part of this ionization is due to a penetrating radiation coming from outside the ionization chamber. This radiation was generally supposed to be the gamma-rays from radioactive materials known to occur in the ground and the air. About 1910, however, observations on high towers by Wulf and a series of balloon flights by Gockel showed that the intensity of these ionizing rays decreases less rapidly with altitude than could thus be explained. These striking results led to further balloon observations by Victor Hess and W. Kolhörster, who established the fact that the penetrating radiation actually increases in intensity with increasing altitude, which, of course, it should not do if it emanated from the ground. From these studies Hess drew the bold conclusion in 1912 that a penetrating type of radiation enters our atmosphere from without, and from a source which is almost uniform in all directions. All recent studies have supported this interpretation of the phenomenon.

During the war and for a few years thereafter little attention was paid to these newly found rays. Some, including Hoffmann and Millikan, doubted their existence. Others, especially Kolhörster, proceeded with measurements of their absorption and their time variations. In 1925, Millikan, having become convinced of the reality of the rays by his much improved measurements of their absorption in water, put forward a challenging hypothesis regarding their origin. His idea was that the main part of the rays consists of photons, emitted when protons and electrons combine in interstellar space to form helium nuclei, and this was made a part of a theory of a cyclic and eternal universe. As the evidence has become overwhelming that most of the rays are electrically charged, and of a higher order of energy than was then supposed, it has become necessary to abandon this hypothesis. Nevertheless Millikan's suggestive connection of the origin of the cosmic rays with the origin of the universe has been most effective in stimulating a vast amount of research, and the hope remains widespread that if we can learn how cosmic rays are produced we may read in them the ancient history of our world.

During the past ten years intensive studies by many different investigators have clarified our knowledge of the properties of these extraordinary rays. Absorption measurements reveal two prominent bands having absorption coefficients of about 0.6 and 0.08 per meter of water, respectively. The latter component is about one
hundred times as penetrating as the hardest gamma-rays. We find that the rays come from far outside the earth's atmosphere, and at high altitudes are many times as intense near the magnetic poles as near the equator. This implies that they consist chiefly of electrically charged particles. The total heat that they bring into the earth is of the same order as that brought by starlight. The individual primary cosmic rays, however, have enormous energies, of from $10^8$ to perhaps almost $10^{10}$ electron volts. This means an erg of energy for a single atomic projectile.

**Objectives of the Present Studies**

Present day cosmic-ray research is chiefly concerned with two objectives, investigation of the properties of the rays, and their use as a tool in other investigations. Among the important properties, that of most immediate interest is their composition, that is, the nature of the particles of which the rays are composed, and the energies which these particles possess. What effects do the rays produce as they traverse matter? Where do they originate, and how are they produced? Among the uses of the cosmic rays, we may note their application to nuclear physics, where in the hands of Anderson they led to the discovery of the positron. From studies of their geographic distribution we are extending our knowledge of the earth's magnetic field high above the atmosphere. Electrodynamics is tested in an energy region hitherto inaccessible. In astronomy it would appear that cosmic rays may give us more powerful means of studying the rotation of the galaxy and of learning the ancient history of the universe. In biology it is not impossible that they play an important part in the spontaneous variations upon which evolutionary changes depend.

**Composition of Cosmic Rays**

By analogy with gamma-rays, the extreme penetrating power of cosmic rays was at first taken to mean that they are photons. In 1929, however, some experiments by Bothe and Kolhörster,15 using coincidence counting tubes, gave a strong indication that the primary cosmic rays are electrically charged particles. They called attention to the fact that such particles should on approaching the earth be deflected by the earth's magnetic field so as to reach the poles more easily than the equator. This suggestion led to a series of extensive investigations which have now given us what seems to be adequate evidence that the primary cosmic rays are in fact electrical particles. I want to review this evidence briefly, and then explain how further experiments have enabled us to obtain a tentative analysis of these electrical rays into components that are identifiable with familiar atomic particles.

J. Clay16 had just published his first measurements indicating a greater cosmic-ray intensity in Holland than in Java. This difference Bothe and Kolhörster ascribed to the anticipated action of the earth's magnetic field. At first, expeditions by Bothe and Kolhörster,17 Millikan and Cameron,18 Kerr Grant,19 and others failed to confirm Clay's repeated findings,20 and it was generally supposed21 that no latitude effect exists. Then came, however, several extensive series of observations which have supported Clay's results, and have shown that the geographic variations follow the earth's magnetic field as Bothe and Kolhörster had suggested.

During 1931 to 1934 we sent from Chicago twelve different expeditions including some eighty cooperating physicists, making measurements at more than a hundred stations widely distributed over the earth.22 The data showed that at magnetic latitudes higher than 50 degrees no significant variation with latitude occurs at sea-level. From the equator to 50 degrees, however, there is at sea-level an increase of intensity of about 16 percent. Similar contemporaneous measurements by many different observers have led to essentially the same results.23

In Fig. 1 is shown a summary of the published observations of the various expeditions that have studied the geographic distribution of the cosmic rays at sea-level. The data are shown in the form of curves (isocosms, we may call them) of equal cosmic-ray intensity, with the results of the various investigators all reduced to the same scale. The solid dots represent the sea-level locations occupied by the observers of our Chicago expeditions, and the open circles those reported by other observers, among whom Clay, Hoerlin, Millikan and Neher, Prins, and their collaborators may be especially mentioned. Whereas Millikan and Neher now find a mean latitude effect of about 10 percent instead of the zero effect which Millikan reported three years ago, all other recent observers have found close to 14 percent reduction on going from the pole to the equator. There has thus been some difficulty in fitting the results of Millikan and Neher quantitatively with the other data. Qualitatively, however, the agreement among the various observers is now excellent.

The curvature of these isocosms follows closely the parallels of geomagnetic latitude, identifying the phenomenon as one dependent upon the earth's magnetic field. Still closer is the parallelism between the isocosms and the lines of equal frequency of occurrence of auroral displays, as shown by the dotted lines, according to Fritz's map. This extraordinary similarity must mean that both the aurora and the cosmic rays are affected by the earth's magnetic field in the same manner. Evident also from this chart is the lower intensity of the equatorial cosmic rays in the eastern hemisphere than in the western hemisphere, corresponding to the stronger field of the earth in the east. This longitude effect was found independently by Clay and by Millikan and Neher. Such details leave no doubt but that the latitude effect is due to the action of the earth's magnetic field. The existence of the effect accordingly implies that at least a considerable portion of the primary cosmic rays is electrically charged.

---

A significant aspect of the latitude effect is its rapid increase with altitude. This became evident from our high mountain measurements at different latitudes, as shown in Fig. 2, and has been extended to higher altitudes by the airplane measurements of Bowen, Millikan and Neher and of Clay, and especially by a comparison of the stratosphere balloon observations of Regener, Piccard and Cosyns, Clay, and Compton Stephenson and Millikan. In Fig. 3 are shown some of these data. The striking fact appears that whereas at sea-level the latitude effect is only 15 or 20 percent, near the top of the atmosphere the intensity observed at 52 degrees geomagnetic latitude is 2 times that observed at 42 degrees, apparently 5 or 10 times that to be found in Peru, and about 40 times as great as that observed provisionally by Clay near the equator at Java. This rapid change with latitude has been observed directly by Cosyns as he drifted southward in his Piccard balloon. At the surface of the atmosphere the ratio of intensities between the poles and the equator is certainly greater than over the range covered by these experiments, very possibly as much as 100 to 1.

Since electrically neutral rays should be unaffected by the earth's field, this result means at once that probably not more than a few percent of the ionization at the top of the atmosphere near the poles is due to electrically neutral rays. It is within the remaining few percent of rays which reach the earth at the equator that any electrically neutral primary rays must be sought.

It should be noted that the rays reaching the earth at the equator are absorbed in essentially the same manner as those which are deflected
by the earth’s magnetic field, and are hence known to be electrical. Thus in Fig. 4, curve A represents the absorption in the atmosphere of the rays received at high magnetic latitudes, and B that of the equatorial rays. Curve C is the difference between A and B and thus shows the absorption of the electrically charged rays which are so affected by the earth’s magnetic field that they cannot reach the earth at the equator. The close similarity in shape of curve B, which represents the rays transmitted by the earth’s magnetic field, to curve C, which includes only electrically charged rays, suggests strongly that the two types of rays are of the same kind.

Yet more definitely, Johnson, Alvarez and others observe that near the equator the rays show a marked east-west asymmetry, which is an effect of the earth’s magnetic field. This means that at least a considerable part of even the rays reaching the equator through the earth’s magnetic barrier are electrically charged but with very high energies.

Light on the nature of the rays received at sea-level is given by an extension of the coincidence experiments of Bothe and Kohlhörster. Modifications of their original experiment by Rossi and others seem to make the conclusion inescapable that the more penetrating rays at sea-level consist of high speed electrical particles. A beautiful demonstration of this fact has recently been made independently by Auger and Ehrenfest and by Street, Woodward and Stevenson. Fig. 5 shows the counter controlled expansion chamber as used by the latter investigators, in which 45 cm of lead may be placed between the upper counters, and the expansion chamber is placed between the lower ones. In 90 percent of the photographs the cloud chamber shows the track of a single high energy particle, as illustrated in Fig. 6. The evidence is thus clear that

---

22 T. H. Johnson and J. C. Street, Phys. Rev. 43, 381; T. H. Johnson, ibid. 43, 834; 44, 856 (1933); L. Alvarez and A. H. Compton, ibid. 43, 835 (1933); B. Rossi and S. de Benedetti, ibid. 45, 214 (1934), et al.
23 B. Rossi, Zeits. f. Physik 68, 64 (1931); 82, 151 (1933).
25 P. Auger and Ehrenfest, Comptes rendus 199, 1609 (1934).
such coincidences are due primarily to ionizing and hence to electrically charged particles of great penetrating power. If it were not for the latitude effect, one might assume that these penetrating particles are secondaries formed in the upper atmosphere by easily absorbable high energy photons. Since, however, the theory of the latitude effect requires that electrons shall have energies of the order of those observed in these experiments in order to traverse the earth's magnetic barrier, it seems evident that the particles here observed are in truth primary cosmic rays.

Other lines of evidence such as detailed studies of the east-west and north-south asymmetry\(^\text{37}\) of the cosmic rays, the approximate independence of the transition effect of latitude,\(^\text{31}\) etc.,\(^\text{38}\) give additional strong evidence that all the various components of cosmic rays which are now recognized are due to electrically charged primaries. It seems unnecessary, however, to elaborate the argument further. If any electrically neutral particles such as photons or neutrons are present in the primary rays, they can constitute at most a few percent of the rays entering the surface of the atmosphere, and at sea-level are of too low intensity to show themselves in comparison with the more copious rays due to electrically charged primaries.

**ANALYSIS OF THE PRIMARY COSMIC RAYS**

Our problem is thus reduced to that of identifying the various electrically charged components which may be present in the cosmic rays incident upon the earth. For particles of lower energy, such an analysis is usually performed with a mass spectrograph in which electric and magnetic fields are employed. Attempts to deflect cosmic rays with laboratory electric and magnetic fields have recently met with some success. The energies of the primary particles are however so high that they are deflected only with the greatest difficulty, and even when this is done, it is hard to distinguish between the primary cosmic-ray particles and the secondaries excited within the atmosphere. Fortunately, however, Nature has supplied us with a ready-made magnetic spectrograph suitable for analyzing the primary cosmic rays. The earth itself acts as the magnet, and in place of the electric field we have the stopping power of the earth's atmosphere. This natural instrument has the advantage of such great dimensions that the rays are analyzed far above the atmosphere, where they cannot become confused with secondaries. It leaves something to be desired regarding the uniformity of its magnetic field, and we have not as yet been able to learn accurately the calibration curve with which to determine the energies of the particles in terms of their penetrating power in the atmosphere. In spite of these limitations and even with the incomplete information now available, an attempt to analyze the components of cosmic rays with our earth magnet leads to valuable results, and indicates the kind of data that must be obtained if such an analysis is to be made more rigorous.\(^\text{39}\)

Theoretical studies by Størmer,\(^\text{40}\) Lemaitre and Vallarta,\(^\text{41}\) and others show that if electrical particles approach the earth from remote space, there is at a given magnetic latitude roughly speaking a critical energy for rays of a given type such that rays of lower energy are bent away from the earth, whereas those of greater energy strike the earth freely. Corresponding to this critical energy, there should be a minimum range in air which the particles may have at the latitude where the observations are made.

Our method of magnetic analysis consists in comparing the minimum range thus calculated for various types of particles with the observed minimum ranges found from measurements of the intensity of the cosmic rays at different altitudes. It is found that the calculated minimum ranges for alpha-particles, electrons and protons correspond to the observed minimum ranges of three distinguishable groups of cosmic rays. Though the uncertainty in the comparison is at present unfortunately large, results indicate that the method should eventually give us a

---

\(^{37}\) Cf. e.g., T. H. Johnson, Phys. Rev. 47, 318 (1935).


\(^{40}\) C. Størmer, Zeits. f. Astrophys. 1, 237 (1930); Oslo Obs. Publ., No. 10 (1934).

\(^{41}\) G. Lemaitre and M. S. Vallarta, Phys. Rev. 43, 87 (1933).
complete and reliable analysis of the primary cosmic rays.

In Fig. 7 are shown data collected from the results of various balloon flights, which reveal the existence of the range minima for the rays traversing the atmosphere. The quantity ψ here plotted is not the directly measured intensity of the rays coming from all directions, but rather the intensity of the component which passes vertically down through the atmosphere. This is calculated from the observed total intensity by using a formula developed by Gross. Recently Regener has confirmed Gross's analysis by measuring the vertical component directly, using coincidence counters. It will be noted that for the same effective magnetic latitude μ, the curves obtained by different observers are in close agreement.

It is the flat parts of these curves that represent the range minima; for if no particles of shorter range than such a limit are present, the ionization should not increase further with increasing altitude. On this figure are indicated also the calculated range minima for electrons and alpha-particles capable of penetrating the earth's magnetic field at these latitudes. The calculated range minima for protons are too great to be included on this scale. These calculations can only be carried out to a rough approximation, chiefly because we do not know accurately the rate of energy loss of the various particles on traversing matter. It will be seen, however, that a comparison of the observed with the predicted minima indicates that the less penetrating group consists of alpha-particles and the more penetrating one of electrons. Latitude effect observations at sea-level give similar evidence of a still more penetrating group provisionally identifiable as protons. I have given elsewhere a detailed discussion of this powerful method of analysis, but time does not permit us to follow it further here. Using the information now at hand from our own and other experiments, however, we are thus led to the following tentative analysis:

The most prominent part of the primary cosmic rays observed above sea-level consists of nearly equal parts of positive and negative electrons. At sea-level and below is a very penetrating component for which the identification as protons seems to be required, though there are some difficulties with this conclusion. At very high altitudes there appears a relatively absorbable component which seems to consist of alpha-particles.

That three distinct components of cosmic rays exist is evident from measurements of the intensity of the rays at various depths below the surface of the atmosphere. Fig. 7 shows the presence of two components, which we call A and B, of which A is prominent only at very high altitudes. Component B is the one which we have identified as electrons. The data at depths below sea-level are perhaps best summarized by Fig. 8,
which is Eckart's analysis of the absorption coefficients of the rays at 7000 ft. elevation, based upon the measurements of Regener, Millikan and Benade at great depths in water. Our component \( A \) does not appear at this low altitude, but our component \( B \) may be identified with Eckart's softer component whose mean absorption coefficient is 0.6 per meter of water. His more penetrating component, \( \mu = \text{ca.} \, 0.08 \), may be called \( C \), and according to our tentative analysis consists of protons.

Auxiliary information supporting this analysis comes from the observations by Anderson and others\(^43\) that the high energy cosmic-ray particles observed in cloud chambers at sea-level and on Pikes Peak consist of almost equal numbers of positive and negative rays, with an apparent excess of high energy positives at sea-level. These measurements are chiefly concerned with the component that we call \( B \), and thus confirm its identification as positrons and negatrons. The directional experiments of Johnson, Alvarez, Rossi and others, which show that the coincidence producing particles near the equator come chiefly from the west,\(^44\) reveal an excess of positively charged rays, which presumably are protons; at the same time the primary shower producing particles, though subject to the latitude effect, appear according to Johnson\(^37\) to be symmetrically distributed, and may presumably be identified as equal numbers of positrons and negatrons. Rossi's\(^38\) and Johnson's\(^37\) finding that the showers increase in relative prominence with altitude supports the identification of the protons with the more penetrating component. The failure to identify high energy protons in expansion chamber studies, however, leaves some doubt regarding the composition of this most penetrating portion of the rays.

It can hardly be doubted that a continuation of the lines of investigation now under way will result in a complete and definite analysis of the composition of the cosmic rays.

**Energy Distribution of the Cosmic Rays**

Of the several methods of determining the energy of the cosmic-ray particles, the most

\(^44\) Cf. especially reference 38.

---

**Fig. 9. Energy distribution of total cosmic-ray particles observed near sea-level (Anderson).**

...
energy of about $20 \times 10^9$ electron volts. Directional observations show that many of the particles reaching the equator have energies greater than this amount. It may be stated with confidence from such observations that primary cosmic-ray particles occur with energies of from 2 BV to greater than 60 BV.

Estimates of the energy of the particles based upon penetration to great depths and upon the energy which appears in cosmic-ray bursts are less reliable, but agree as to order of magnitude with those based upon the latitude effect. They indicate occasional cosmic particles with energies as great as 600 BV.\(^{46}\)

**Effects Produced by Cosmic Rays**

Two distinct types of effects are known to be produced by the direct action of the primary cosmic-ray particles. These are (1) direct ionization of the atoms traversed by collision with electrons, as occurs in the case of $\beta$-rays of ordinary energies, and (2) nuclear collisions which result in photon emission, i.e., production of x-rays. In Fig. 6 we have seen an example of the first type of ionization. The evidence for excitation of photons by primary cosmic rays is somewhat less direct. Fig. 10 shows an Anderson photograph of a shower of high energy positrons and negatrons excited in lead by a non-ionizing ray. From such observations it is inferred that the showers are produced directly by the absorption of photons. It becomes evident, however, in such experiments that the photons themselves usually originate in the immediate vicinity of the apparatus, and are hence themselves secondary rays. Coincidence experiments by T. H. Johnson\(^{37}\) have shown, moreover, that the number of showers is subject to the latitude effect. This must mean that they are due to electrically charged primary cosmic rays.

Following such evidence, Geiger and Fünfer\(^{47}\) identify as many as 5 degrees of degradation of the cosmic rays, $A$, the primary electron or positron, coming from outer space; $B$, the x-ray photons excited by the primary electron; $C$, the electrons and positrons produced by the absorption of these photons; $D$, the photons excited in turn by these electrons; and $E$, the electron pairs resulting finally from such photons. This complex scheme of secondary rays seems to be amply confirmed by counter experiments by Clay\(^{48}\) and others as well as by cloud track photographs. Thus finally an electron with energy of the order of $10^{11}$ electron volts spends itself upon many electrons having energies of the order of $10^7$ electron volts. For energies less than $10^7$ v, radiation becomes a less probable mechanism for energy dissipation than is electron collision, so that secondary rays of lower energy are relatively scarce. It now seems probable that the cosmic-ray bursts are the result of this dissipation of energy occurring mostly within the gas of an ionization chamber.

In striking contrast with rays of lower energy, it would appear that for these high energy secondary cosmic rays a photon is more absorbable than is an electron of the same energy.

According to recent theories by Bethe and Heitler\(^{49}\) and by Oppenheimer,\(^{50}\) we should expect by far the greater part of the energy dissipation by very high energy electrons to be a result of the excitation of radiation. For protons, on the other hand, the energy loss by collision with electrons should be predominant. In accord with this theory, coincidence experiments at different altitudes, by Rossi\(^{38}\) and Johnson,\(^{37}\) give strong evidence for two types of primary particles, one of which produces showers


\(^{44}\) J. Clay, Physica 2, 551 (1935).


\(^{50}\) J. R. Oppenheimer, Phys. Rev. 47, 44 (1935).
much more efficiently than the other. Johnson's
directional effect counter experiments also
support the view that the shower producing
primaries are indeed equal numbers of positrons
and negatrons, while the non-shower-producing
particles are positively charged, and hence
presumably protons.

There is in the test of this theory of radiation
by high energy particles, however, a most signif-
cant departure of experiment from the predic-
tions of quantum electrodynamics. Up to
energies of about 70 million electron volts, An-
derson's studies of the energy losses of electrons
traversing matter are in good accord with Bethe
and Heitler's theory (Fig. 11). At higher energies,
however, where the quantum theory's wave-
length of the electron becomes shorter than the
classical theory's radius of the electron, the
energy loss is much less rapid than the theory
predicts. In this region of very high energies a
new modification of electrodynamics is thus
required, similar perhaps to the Lorentz-Einstein
modification which extended electrodynamics
into the regions of high speed. If and when such
an improved theory of electricity is developed,
cosmic-ray studies offer us a tool, and apparently
almost the only available tool, for giving the
time a test.

WHERE DO THE COSMIC RAYS ORIGINATE?

One of the most significant aspects of the
latitude effect is its implication that the cosmic
rays originate far beyond the earth's atmosphere.
The earth's magnetic field is not strong enough
to bend appreciably any radiation produced
within the atmosphere before it is stopped by
collisions with the molecules. Furthermore, as
Blackett has pointed out, if the origin of the
cosmic rays were the earth's atmosphere, the
effect of the earth's magnetic field in returning
to the earth those particles which start outward
should result in a greater observed intensity
near the equator. This is just opposite to the
observed latitude effect.

Except for deflection by the earth's magnetic
field, however, the cosmic rays are found to
approach the earth nearly uniformly from all
directions. Outside the earth's atmosphere, we
fail to find any isotropic distribution of matter
within our galaxy where such rays might origi-
nate. The extragalactic nebulae or space itself
would, on the other hand, satisfy the condition of
spherical symmetry. Calculations by both Ed-
dington and Lemaitre have shown that the
probable absorption of a cosmic-ray traversing
the matter in interstellar space with about the
speed of light for 10^10 years would be wholly
negligible. If, however, these rays are subject
to the same red shift as that which occurs in the
light from the distant nebulae, the rays origi-
nating at distances as great as 10^10 light years
would arrive at the earth with only a small
fraction of their initial energy. If the rays are
being continuously produced, therefore, their
isotropic distribution suggests that most of them
originate in the remote galaxies or in remote
space, at an effective distance of between 10^8
and 10^10 light years. An alternative would be to
suppose with Lemaitre that they were formed at
the beginning of the expansion of the universe,
and have ever since been coursing through space.

Some positive support for this view of the
remote origin of cosmic rays is given by the fact

\[ \text{Fig. 11. Energy loss per cm by high energy electrons traversing lead. Experiments, Anderson; theory, Bethe and Heitler.} \]
that there appears to be an effect on their intensity due to the rotation of the galaxy. According to Oort and other astronomers, this rotation carries us toward about 47 degrees north and right ascension 20 hr. 55 min., at a speed of about 300 km per second—one-thousandth of the speed of light. If the source of the cosmic rays is outside our galaxy, and at rest relative to its center of gravity, calculation shows that at our latitude this motion should cause a diurnal variation, following sidereal time, through a range of the order of 0.1 percent. The best available records of cosmic-ray intensity show, as in Fig. 12, which is Hess and Steinmaurer's summary for 1932, a variation with sidereal time of about the predicted magnitude and with its maximum at very closely the predicted time. Though further experiments are necessary before other possible interpretations of this sidereal time variation are ruled out, the complete agreement with the predictions may justify the presumption that the effect is really due to the rotation of the galaxy. This would necessarily imply that an important part of the rays originates beyond the Milky Way, a long wanted justification of their rather heuristic appellation of "cosmic."

**How Are the Rays Produced?**

Of the many hypotheses regarding the origin of cosmic rays, none has received sufficient experimental support to gain general acceptance. Those which assume the primary cosmic rays to be photons appear to be in definite conflict with the observed latitude effect. Also those which would ascribe their origin to transformations of atomic nuclei with resulting loss of mass are unable to account for the huge energies of from \(10^{10}\) to almost \(10^{12}\) electron volts which the more recent studies require for the individual rays. Local or interstellar fields have been suggested. Swann imagines that electrons are accelerated by electromagnetic induction from the changing magnetic fields of "sun spots" on giant stars. Milne supposes that the particles owe their energy to the gravitational attraction of the universe. Lemaitre's hypothesis is that "super-radioactive particles" are emitted at the initial explosion of his expanding universe. At present we are unable to give these suggestions a definitive experimental test.

Time does not permit discussion of the application of the cosmic rays as an instrument for studying other phenomena. Suffice it to say that the immense individual energies of these rays give them a unique place in the physicist's atomic artillery.

Our analysis of the composition of cosmic rays is thus well under way. Their cosmic origin, though perhaps not established, appears now more probable than ever. How they originate is still obscure; but increased knowledge of their characteristics has helped to limit the types of hypotheses that are admissible. Used as a tool, they have resulted in the discovery of the positron, they seem about to become an adjunct of the telescope for collecting astronomical data, and they now afford a means of extending our knowledge of the laws of electricity and of the properties of matter to energies a thousand times greater than are available from any other known source.

---

**Fig. 12.** Sidereal time variations of cosmic rays in 1932. Data, Hess-Steinmaurer; theory, assuming galactic rotation, Compton-Getting.

---