PHYSICAL REVIEW LETTERS

VOLUME 12 | 6 JANUARY 1964 | NUMBER 1

RATIO OF ELECTRONS TO POSITRONS IN THE PRIMARY COSMIC RADIATION*

James A. De Shong, Jr.
Argonne National Laboratory, Argonne, Illinois

and

Roger H. Hildebrand
The University of Chicago, Chicago, Illinois and Argonne National Laboratory, Argonne, Illinois

and

Peter Meyer
Enrico Fermi Institute for Nuclear Studies and Department of Physics, The University of Chicago, Chicago, Illinois

(Received 18 November 1963)

The existence of high-energy electrons in the galaxy was first deduced from observations of the nonthermal galactic radio emission.[1] More recently electrons reaching the earth at energies of a few hundred MeV have been directly observed in balloon experiments.[2,3] It is of great interest to study these electrons in detail in order to gain information on the origin of cosmic rays. As has been pointed out in the literature,[4] a measurement of the positron-to-electron ratio will be decisive in the determination of the electron source. The two sources which have been considered are (1) p-p collisions between the cosmic-ray protons and intergalactic hydrogen, and (2) the production of electrons as a consequence of supernova explosions. The first process has been studied in detail by Hayakawa and Okuda[5] and by Jones.[6] This process yields a prediction for the energy spectrum of the electron component as well as the ratio of positrons to electrons. The e^+/e^- ratio has a value of about 2 at 100 MeV and moves towards 1 with increasing energy. On the other hand, the second process, proposed by Ginzburg[7] and others, is expected to yield predominantly negative electrons. Process (1) will certainly occur in the galaxy since high-energy protons as well as hydrogen are known to be present.

In order to gain information on the nature of the electron source we have carried out an experiment in which we measure the positron-electron ratio of the primary cosmic radiation as a function of energy. We wish to present here some preliminary results.

The essential features of our instrument are shown in Fig. 1. The equipment consists of a permanent magnet, delivering approximately 6000 gauss over a 3-cm gap of 12×12-cm^2 area, a spark chamber telescope for the determination of the particle trajectory before and after passing through the magnetic field, and a tantalum plate spark chamber (4.2 radiation lengths) for particle identification. The four trajectory spark chambers have aluminum plates of 3-mil thickness. The spark chambers are triggered by a triple coincidence counter telescope which includes a Cherenkov counter (index of refraction, 1.27). The Cherenkov counter excludes upward-

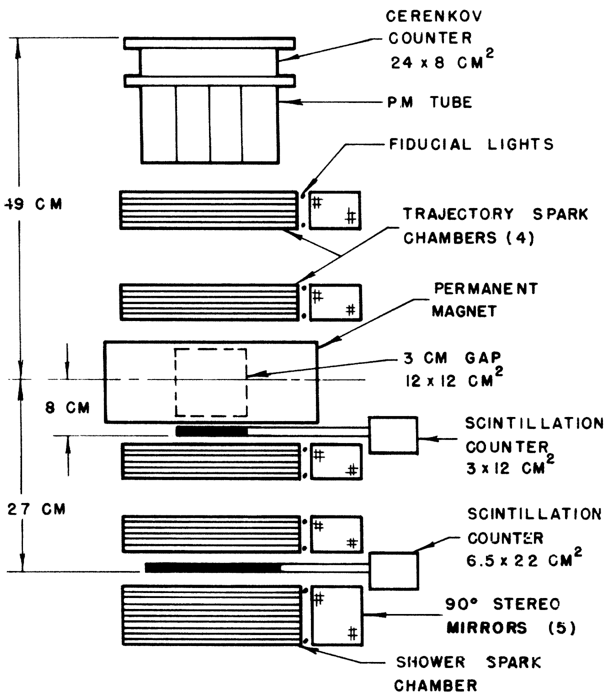

FIG. 1. Schematic view of the magnet, spark chamber, and counter telescope.

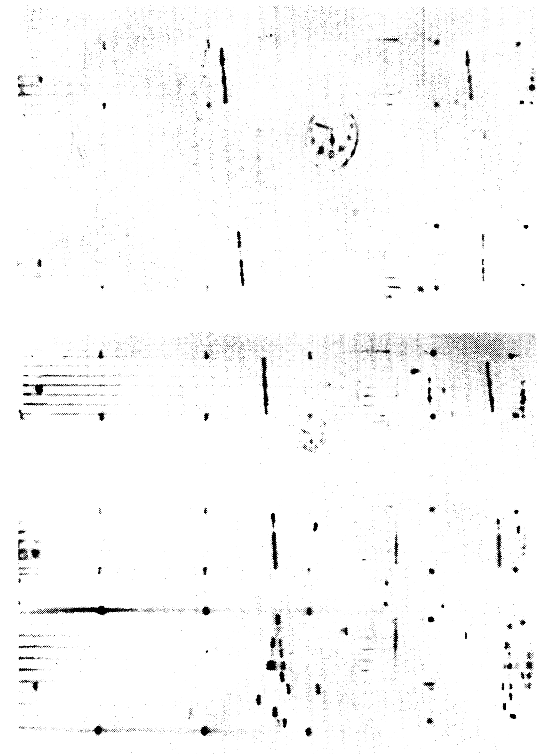

FIG. 2. The track and shower produced by a 700-MeV negative electron. (The evenly spaced "sparks" on the top and bottom of each chamber are mounting screws.)

moving particles and protons with energy below about 600 MeV. The plastic scintillation counter under the magnet gap is sufficiently thin (1/8 in.) to avoid appreciable scattering. The spark chamber array is photographed by two 16-mm cameras.

Two balloon flights were carried out at Fort Churchill, Manitoba. In the first flight on 28 July 1963, the balloon floated for 10 hours under about 3 g/cm^2 of residual atmosphere. The second flight took place on 5 August 1963 with the balloon floating for 12.3 hours under about 5 g/cm^2.

In both flights combined, about 62 000 events were photographed. These events were scanned for the occurrence of electron-photon showers in the tantalum plate spark chamber. The radius of curvature of the particles in the region of the magnetic field was subsequently measured. Figure 2 shows an example of the track and shower produced by a negative electron of approximately 700-MeV energy. In order to exclude pairs or showers which originate in the Cherenkov counter or gondola wall, all events in which more than one track appeared in any trajectory chamber were rejected.

The instrument is capable of discriminating between positive and negative particles up to about 2-BV rigidity. In this preliminary analysis we have included only electrons with $E \leq 1$ BeV, and we have divided this region into three energy intervals. The numbers obtained in the two balloon experiments are shown in Table I. It should be noted that no flux or energy spectrum can be derived from these numbers. The detection efficiency has not yet been determined and is energy dependent. Particularly in the 100-MeV region and below, a fraction of the electrons will not produce a shower of sufficient size for unique identification in the shower chamber. The ratio of electrons to positrons, however, will not depend on the detection efficiency. The division into energy intervals does not yet have the accuracy which we shall eventually achieve. In Table I our results are compared with the fraction of positrons expected on the basis of Hayakawa and Okuda's calculation[5] for the proton-proton collision source.

Within the experimental errors there is no difference in the fraction of positrons between the flights at 3 g/cm^2 and 5 g/cm^2. This agrees with

Table I. Summary of results.

Date of flight	Average atmospheric depth (g/cm^2)	energy interval (MeV)	Number of electrons[a] e^+	e^-	Fraction $e^+/(e^++e^-)$ Observed Individual flights	Combined flights	Calculated[b]
28-7-63	3	50-100	4	13	0.24 ± 0.16	0.31 ± 0.12	≈ 0.70
5-8-63	5		5	7	0.42 ± 0.20		
28-7-63	3	100-300	19	24	0.44 ± 0.11	0.38 ± 0.07	≈ 0.65
5-8-63	5		13	27	0.32 ± 0.10		
28-7-63	3	300-1000	15	52	0.22 ± 0.07	0.16 ± 0.04	≈ 0.60
5-8-63	5		8	65	0.11 ± 0.05		

[a]These numbers must not be used to obtain the total flux or to construct energy spectra for e^+, e^-, or (e^++e^-) since no corrections for the detection efficiency were made. Only the ratios e^+/e^- or $e^+/(e^++e^-)$ are independent of the detection efficiency.

[b]See reference 5. The ratio $e^+/(e^++e^-)$ calculated for secondary production in the atmosphere above the instrument has an average of 0.68 over the energy interval from 50 MeV to 1000 MeV.

earlier results on the altitude dependence of the electron flux,[2] where it was shown that secondary electrons produced in the atmosphere contribute only a few percent of the primary flux in the region of atmospheric depth with which we are concerned. The absence of an appreciable secondary electron contribution is also expected on the basis of calculations using the known cross sections for pion production. Most of the secondary electrons and positrons produced in the Cherenkov counter and gondola wall above the spark chambers were eliminated by the rejection of multiple tracks in the upper spark chambers as discussed above. We have, for the purpose of this preliminary discussion, not attempted to make a correction for secondary electrons. Our values for $e^+/(e^++e^-)$ may be taken as upper limits for the primary cosmic-ray electron component since secondary production processes will yield a positron excess.

From the data presented in Table I we draw the following conclusions: (1) The primary electron component contains an excess of negative electrons which cannot be attributed to the p-p collision source; (2) the fraction $e^+/(e^++e^-)$ appears to decrease with increasing energy between 100 MeV and 1000 MeV.

Although we are in no position to prove that the observed primary electrons are of galactic and not of solar origin, we consider the latter possibility to be unlikely. At the present phase of the solar cycle an enhanced flux of galactic particles of rigidity between 0.4 BV and 1 BV has appeared in the solar system.[8] Also, if the electrons were of solar origin, a positive correlation of their flux with solar activity is to be expected. It would then be difficult to reconcile our observations with the upper limit for the electron flux obtained at solar maximum by Critchfield, Ney, and Oleksa.[9]

Therefore, we tentatively assume the observed electrons to be of galactic origin. Since we are unable, at the present time, to obtain an experimental energy spectrum we try to construct an energy spectrum under the assumption that the energy spectrum as well as the e^+/e^- ratio due to the proton-proton collision source is correctly described by Hayakawa and Okuda.[5] Under the further assumption that all positrons which we observe originate in the proton-proton collision source, we can obtain an energy spectrum for the excess negative electrons as well as for the total electron plus positron flux. The theoretical $(e^+ + e^-)$ spectrum of Hayakawa and Okuda due to p-p collisions and the deduced spectra of the excess negative electrons and of all electrons and positrons are shown in Fig. 3. We conclude from this figure that, in the energy region from 100 MeV to 1000 MeV, the energy spectrum of all electrons is flatter than the spectrum of the p-p collision electrons alone. This would eliminate the difficulty of reconciling the shape of the cosmic-ray energy spectrum with the observed spectral index of the nonthermal galactic radio emission.[10]

It is a pleasure to acknowledge the assistance of R. Hartman in the development of the Cherenkov counter, and in the execution of the balloon flights; of R. Daniels and A. Cook in the design

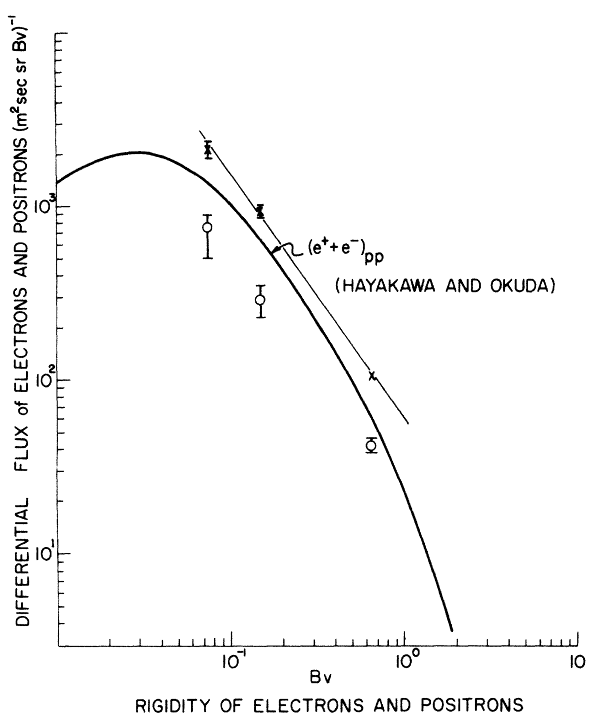

FIG. 3. The calculated energy spectrum of positrons and electrons from galactic p-p collisions (Hayakawa and Okuda, reference 5). Circles: the energy spectrum of negative excess electrons, based on reference 5 and the measured fraction $e^+/(e^+ + e^-)$. Crosses: the energy spectrum of all electrons and positrons based on reference 5 and the measured fraction $e^+/(e^+ + e^-)$.

and maintenance of the electronic system; of J. Upton and S. Lucero in the assembly and testing of the mechanical and optical system; of N. Metropolis and R. Dornberger in presenting the computer program for analysis of the events; of D. Tsui for calculations of the atmospheric corrections; and of J. Dill in scanning and measuring.

Raven Industries, Inc., provided us with the two successful balloon flights. We gratefully acknowledge the excellent support given us by the Skyhook program of the U. S. Office of Naval Research and by the Royal Canadian Air Force at Fort Churchill, Manitoba, Canada.

*This research was supported in part by the National Aeronautics and Space Administration and in part by the U. S. Atomic Energy Commission.

[1]H. Alfvén and N. Herlofson, Phys. Rev. 78, 616 (1950); R. O. Kiepenheuer, Phys. Rev. 79, 738 (1950); V. L. Ginzburg, Dokl. Akad. Nauk. SSSR 76, 377 (1951).

[2]J. A. Earl, Phys. Rev. Letters 6, 125 (1961).

[3]P. Meyer and R. Vogt, Phys. Rev. Letters 6, 193 (1961).

[4]V. L. Ginzburg and S. I. Syrovatsky, Suppl. Progr. Theoret. Phys. (Kyoto) 20, 1 (1961).

[5]S. Hayakawa and H. Okuda, Progr. Theoret. Phys. (Kyoto) 28, 517 (1962).

[6]F. C. Jones, J. Geophys. Res. 68, 4399 (1963).

[7]V. L. Ginzburg, Progress in Elementary Particle and Cosmic-Ray Physics (North-Holland Publishing Company, Amsterdam, 1958), Vol. IV, Chap. V.

[8]P. Meyer and R. Vogt (to be published).

[9]C. L. Critchfield, E. P. Ney, and S. Oleksa, Phys. Rev. 85, 461 (1952).

[10]J. E. Baldwin, Suppl. J. Phys. Soc. Japan 17, 173 (1962).

CRITERION FOR STABILITY AGAINST RESISTIVE INTERCHANGE MODES*

Bruno Coppi†
Plasma Physics Laboratory, Princeton, New Jersey
(Received 19 August 1963)

Considering the stability of hydromagnetic systems in which a small resistivity is introduced, the fastest growth rates of the new modes have been found to be proportional to the cube root of the resistivity.[1,2] In particular, when the analysis is restricted to a plane incompressible sheet-pinch with a finite gravitational field[1] or to very low β systems[3,4] such as the stellarator configuration, with a negative pressure gradient along the radius of magnetic curvature, unstable interchange modes have been shown to exist always. These modes become topologically possible when resistivity is introduced because the mass flow is no longer tied to the magnetic lines of force.

Here we consider a cylindrical pinch configuration and show that if $\beta \equiv 2p/B^2$ is of the same order of magnitude as $p'R/B^2$ and small, but not negligible, a criterion for stability against resistive interchange modes can be given. p is the pressure, p' its gradient, B the total magnetic field, and R the radius of the plasma cylinder. The condition for stability is

$$-\frac{d\ln p}{d\ln r} < \frac{\{(d\ln\iota/d\ln r)^2 + (2kr\iota)^2\}}{(1 + k^2r^2\iota^2) + 0(\beta)}, \tag{1}$$

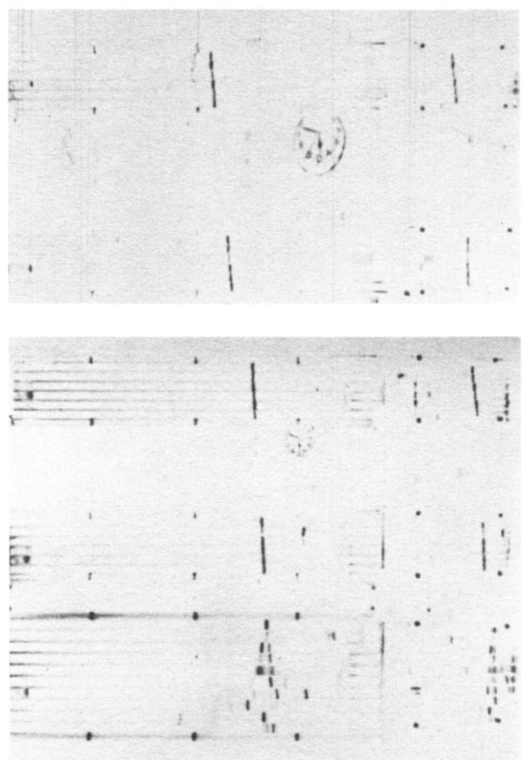

FIG. 2. The track and shower produced by a 700-MeV negative electron. (The evenly spaced "sparks" on the top and bottom of each chamber are mounting screws.)