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III-1-19. Electrons and γ-Rays in the Primary Cosmic Radiation

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In this paper I wish to present a brief summary of the recent experimental work that is concerned with the gamma and electron components of the primary cosmic radiation. Experiments in the past two decades have made it clear that the primary cosmic radiation essentially consists of protons and heavier atomic nuclei. The subsequent discovery of the neutral π-meson satisfactorily accounted for the electromagnetic component in the atmosphere and primary Gamma rays or electrons were no longer needed to describe the observations. In addition, the classical experiment of Critchfield, Ney and Oleska[1], using a balloon borne cloud chamber, established the fact that the flux of primary electrons and gamma rays with energies exceeding about 1 Bev could indeed at most amount to a few percent of the flux of protons.

The search for a small but finite flux of primary electrons or gamma rays has been intensified, however, in recent years for two main reasons: (1) It must be assumed that gamma radiation and electrons are produced in the galaxy as a consequence of interactions of high energy cosmic ray particles with intergalactic matter with the resulting creation and decay of π-mesons, and (2) the radio-astronomical studies of galactic radio noise are interpreted as being due to the synchrotron radiation of high-energy electrons moving in galactic magnetic fields. The presence of a substantial flux of high energy electrons within our galaxy, therefore, is today considered an experimental fact by astrophysicists. A direct measurement of the flux, the energy spectrum and the directionality of these components must therefore be considered a most important task in advancing the understanding of the physical phenomena which occur in our galaxy.

I shall first concentrate on the gamma ray experiments. The fact that the gamma radiation is not influenced by galactic and interplanetary magnetic fields offers the possibility to directly observe the density of cosmic radiation throughout the galaxy. Several attempts were made in the past years to open this field of gamma ray astronomy with the help of balloon borne instrumentation and to observe the relatively low energy gamma rays which would result from π°-meson decay. However, the large flux of gamma radiation created in the atmosphere has made these experiments exceedingly difficult and prevented the identification of galactic γ-rays.

A large step forward has now been taken with the experiment of Kraushaar and Clark on the satellite Explorer XI which was launched in April 1961. The instrument has been described and preliminary results have been reported by the authors during this Conference. Their results indicate the presence of a finite flux of gamma radiation arriving from space. The preliminary value for the flux is in rough agreement with expectation under the assumption that the cosmic ray flux throughout the galaxy is the same as near the earth and the density of galactic matter is one proton/cm^3. Definite evidence for the galactic gamma radiation must come from a measurement of the anisotropy of the incident photons and it is to be hoped that a sufficient amount of data can be accumulated to definitely establish this angular distribution.

Into the field of gamma ray astronomy belong the experiments which are concerned with the identification of discrete sources of gamma radiation. Various possible sources within our galaxy and other galaxies have been discussed in the literature and estimates have been made as to the possible flux of gamma radiation. No discrete gamma ray source could be identified experimentally until now. Again the satellite experiments will, hopefully, provide evidence for the existence of gamma ray sources. In recent years extensive air shower studies have been initiated with the aim of identifying showers which are produced by very high energy photons. During this Conference the results of work by Chudakov, Zatsepin, Nesterova and Ladykin have been reported. This work is based on a measurement of Čerenkov light produced in the atmosphere. An initial report of a small intensity maximum from the radio galaxy Cygnus A could not be confirmed in continuing experiments by these authors. Other experiments in this direction, notably the joint efforts by the Japanese, the MIT, and the Bolivian research groups are now getting under way and one can hope for new results in this field which has important astrophysical implications.

Let me now turn my attention to the primary electron component of cosmic radiation. In the beginning of this year two observations of a finite flux of primary electrons have been reported which were obtained by entirely different experimental methods. One is due to J. Earl of the University of Minnesota[2] and the other was made by R. Vogt and myself at the University of Chicago[3].

Earl uses the method of Critchfield, Ney and Oleska, identifying an electron or gamma ray through the development of a soft shower in a multiplate cloud chamber. The improvement over the earlier work came through the modern developments of balloon techniques which permitted him to work under much smaller layers of residual atmosphere and consequently required smaller corrections for secondary particles. An electron flux of 45 particles/m^2 sec ster with energies greater than 500 Mev has been obtained by Earl.

Earl also reported at the Midwest Cosmic Ray meeting in St. Louis about an observation which was made during the flare of September 3, 1960. While the proton flux was increased as a consequence of the solar particle outburst, no additional electrons were observed.

While the Minnesota experiment only deals with 11 primary electron events, it unambiguously identifies those particles with the cloud chamber technique. The Chicago experiment does not lack in number of electron events. The problem here is the determination of their energy. We identify the electrons in a counter telescope through their relativistic energy loss in a thin sodium iodide crystal and the subsequent finite range of the resulting soft shower in a lead absorber. A balloon measurement made from Ft. Churchill, Manitoba on September 8, 1960 led us to a lower limit for the electron flux between 100 and 1300 Mev of 35 particles/m^2 sec ster. The evaluation of two additional measurements provide us with further evidence which bears on the question of the origin of the electrons, and has been described in detail during this Conference. The main results are the following:

A. While low energy solar protons which were produced in the September 3 flare and stored in interplanetary space are observed on September 8, the electron flux did not increase. Therefore, electrons were not stored and almost certainly not produced in the flare process. This agrees with the result of Earl.

B. On September 8 the electron intensity actually decreased by about 40% below the value of August 22 and it partially recovered by September 15. Hence, the electrons are affected by a Forbush decrease which began on September 4 and showed an amplitude of about 4% at high latitude neutron monitor stations on September 8. We conclude that the electrons are affected by the Forbush decrease mechanism and that their history shows a similarity to galactic protons.

C. The measurement of the electron flux on August 22, 1960 permits us to increase our lower limit for that day to about 60 electrons/m^2 sec ster in the energy interval from 100 to 1300 Mev.

In conclusion, I would like to discuss some consequences of these experimental results and prospects for future experiments. It is at the present time by no means established that the electrons which we now observe as primary particles are of galactic origin. Even if it should turn out that they originate in the galaxy, we must expect that their flux and energy spectrum is greatly modified by the solar modulation mechanisms which are known to influence primary protons of similar rigidity. With this in mind, it is completely premature to draw conclusions regarding the strength of galactic magnetic fields using the values for the electron flux which is now observed near the earth in combination with radio noise data. This situation may soon change. In the coming years of solar minimum we may be able to measure the energy spectrum and flux of galactic electrons without much distortion through interplanetary magnetic fields. Combined with the data on the galactic radio noise we may then obtain a much improved measurement of the galactic magnetic fields, where only estimates are available now.

Should the electrons and gamma rays both originate in collision processes in our galaxy, the observations of the two components will eventually be linked together. The gamma ray spectra and fluxes provide the source distribution for electrons from collision processes and with a knowledge of the galactic magnetic field, they will predict the flux of electrons in the vicinity of the solar system which may in turn be checked experimentally.

Experiments in the coming years will have to establish whether the electrons which are now observed near the earth are of galactic or solar origin. They should provide an energy spectrum and extend it to higher energies than has been possible so far. An additional important measurement is to establish the ratio of the flux of positrons and electrons in the primary radiation. This ratio will strongly depend on the process of high energy electron production in the galaxy.

References

1) C. L. Critchfield, E. P. Ney and S. Oleska, P. R. **85** (1952) 461.
2) J. A. Earl, P. R. Letters **6** (1961) 125.
3) P. Meyer and R. Vogt, P. R. Letters **6** (1961) 193.

Discussion

Powell, C. F.: I should like to mention, in connection with the energy spectra of primary electrons and γ-rays, that in a paper submitted to this Conference. Fowler and Perkins and their colleagues report on intensity of high protons and electrons. They can measure the energy of individual photons, from the cascades they produce in a stack composed of tungsten and emulsion, with a precision of 10% and count them. By going to great altitudes, they can greatly reduce the number of γ-rays produced in the overlying air. They conclude that among the particles with energy$>$400 Bev, the γ-rays are less than one in a thousand of the protons. It seems clear that such observations have a bearing on the origin of the γ-rays and electrons; and taken in conjunction with the low-energy observations show that the spectra of electrons and γ-rays are widely different from those of protons.

Shapiro, M. M.: Dr. Meyer has alluded to a possible link between the electron and gamma ray components, *i.e.*, their secondary origin in collisions of the cosmic-ray nuclei. There is thus far no evidence against these origin for the gamma rays. However, Dr. Baldwin yesterday presented cogent evidence against secondary origin of the electrons. Observations of non-thermal radio emission yield an electron spectrum less steep than the spectrum of the nuclear component. If the electrons were secondaries, exactly the opposite would be expected. Their spectrum would be steeper owing to a deficit of the higher-energy electrons due to greater loss by synchrotron radiation.

Meyer, P.: This is certainly correct and the origin of the electrons has still to be established. Only further experiments will lead to an answer.

Hayakawa, S.: The radio spectrum expected from the secondary electrons is not inconsistent with Baldwin's observation. The flattening of the spectrum towards low energy is due to that of pions produced by nuclear collisions, as shown by Fig. 2 (see III-3-10 Fig. 2) calculated by Okuda. I would also like to show the energy spectrum of the secondary electrons˙ This again seems to be consistent with the experimental one reported by Meyer. For the reference of future experiments, the spectra of electrons and positrons are shown separately in Fig. 1 (see III-3-10 Fig. 1).

Yamaguchi, Y.: Why do you obtain more positrons than electrons in lower energy side?

Hayakawa: Merely due to the proton—proton collisions.