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[10] Let $f_\gamma(t)$ and $\tau(t)$ be the frequency and round-trip time delay, respectively, of a signal whose echo is received at t. Successive "crests" of the echo detected at t and $t+f_\gamma^{-1}$ were transmitted, respectively, at $t-\tau$ and approximately $t+f_\gamma^{-1}-\tau(t+f_\gamma^{-1})$, with the difference of the latter being simply f^{-1}. Since the instantaneous frequency is the time derivative of phase, it follows exactly that $f^{-1}=f_\gamma^{-1}-\dot{\tau}f_\gamma^{-1}$ and hence that $\Delta f \equiv f_\gamma-f=-f\dot{\tau}$ with all times and frequencies as measured by the observer. If the transmitter and receiver are physically separated (one-way effect), this derivation is still valid provided that the "same" clock is available at both locations (e. g., provided that a universal coordinate time exists).

[11] Expected improvements in frequency standards may make such terms experimentally accessible by means of phase-coherent radio communications maintained between Earth and an interplanetary spacecraft.

[12] I. I. Shapiro, Lincoln Laboratory Technical Report No. 368, 1964 (unpublished).

[13] I. I. Shapiro, Phys. Rev. 145, 1005 (1966).

[14] I. I. Shapiro, Phys. Rev. Letters 13, 789 (1964).

[15] C. R. Smith and I. I. Shapiro, to be published.

[16] Neglect throughout of the differences between Newtonian and relativistic orbits has not significantly affected our conclusions.

[17] See also J. P. Richard, Bull. Am. Phys. Soc. 11, 708 (1966).

[18] A formula valid for arbitrary orbits is given by M. J. Tausner, Lincoln Laboratory Technical Report No. 425, 1966 (unpublished).

[19] If highly accurate frequency standards were placed in interplanetary orbits, the one-way Doppler shift could be monitored; this feature would, in addition, allow the "red-shift" effect to be studied.

COSMIC ELECTRONS ABOVE 10 GeV AND THE UNIVERSAL BLACK-BODY RADIATION AT 3°K

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(Received 27 September 1966)

The increasing number of observations made during recent years on the cosmic-ray electrons, whose abundance is only about 1 % of that of cosmic-ray protons, has focused importance on the important role they can play in helping to understand some of the astrophysical properties associated with cosmic space traversed by them; of these the most important ones are the magnetic field strength and the radiation energy density. The potentiality of this method arises from the basic fact that the rates of energy loss suffered by electrons, through synchrotron radiation in magnetic fields and inverse Compton scattering in radiation fields, are both essentially proportional to the square of the energy, resulting in a progressively rapid depletion of electrons of high energy. The radiation field due to the universal black-body radiation at 3°K suggested on the basis of recent evidence[1-5] is expected to become so important compared to visible light in cosmic space (such as galactic halo and intergalactic space) that the energy loss suffered by electrons through inverse Compton scattering in this field would seriously affect their energy spectrum at high energies.

Until recently, all measurements on the cosmic-ray electrons have been made at energies <10 GeV; of these seven are between 1 and 10 GeV.[6-12] At these energies the importance of the deductions that can be made of the type described earlier is severely limited because of the following two reasons: (i) At energies below a few GeV, solar modulation considerably modifies the energy spectrum of the electrons reaching the vicinity of the earth. Hence, in order to infer the spectrum in interstellar space, it is necessary to make corrections for the solar modulation which are not known well enough yet. (ii) It is now generally believed that the bulk of the cosmic rays, including electrons, are randomized and stored within the halo of our galaxy by chaotic magnetic fields present there; further, they exist in a state of equilibrium within this space. Within the framework of this "galactic halo model," which successfully explains a variety of cosmic-ray observations, the effect of the energy losses suffered by electrons due to processes mentioned earlier would become important only at energies >10 GeV.

The first observations on electrons of energy ≳12 GeV, based on a total of 12 events, were made from this laboratory recently[13] (hereafter referred to as I). This number of events has now been increased to 28, allowing us to construct a differential energy spectrum between about 12 and 350 GeV with a statistical accuracy sufficient enough to draw some meaningful conclusions about the universal black-body radiation at 3°K; the object of this Letter is to discuss this aspect only, while a detailed paper dealing with other aspects would be published elsewhere.[14]

The present investigation is a continuation of our earlier work described in I (for details of the nuclear emulsions used, the scanning procedures adopted, the method of electron energy estimation, corrections made, the method of electron charge determination, etc., see I). We now have obtained a total of 28 electrons identified to be of primary origin. From these the following results are obtained: (i) The integral flux of primary electrons above an effective threshold energy of 16 GeV is 0.51 ± 0.10 per m^2 sec sr. (ii) The differential energy spectrum between about 12 and 350 GeV can be represented as

$$N(E)dE = 12.7E^{-2.1\pm0.2}dE \text{ m}^{-2}\text{ sec}^{-1}\text{ sr}^{-1}, \quad (1)$$

where E is the electron energy in GeV. (iii) The fraction of positrons among the total number of "electrons" whose charge could be determined by the method described in I is 0.70 ± 0.20; this may be compared with the value of 0.35 ± 0.15 obtained by Hartman, Meyer, and Hildebrand[15] for energies between 100 MeV and 3 GeV and of <0.39 ± 0.11 obtained by Agrinier et al.[9] for energies between about 4 and 10 GeV. Thus it is found that while at lower energies there is a large excess of electrons over positrons, at energies ≳12 GeV there is indication of an excess of positrons over electrons; a similar conclusion, though based on still poorer statistics, was drawn in I also.

In what follows, all discussions will be made within the framework of the galactic halo model. From a careful analysis of the data on the electron flux available up to energies of ~10 GeV, Felten[16] has suggested the following energy spectrum for the halo electrons:

$$N(E)dE = 80E^{-\beta}dE \text{ cm}^{-2}\text{ sec}^{-1}\text{ sr}^{-1}. \quad (2)$$

Here β is a constant which has a value of 2.4. This spectrum together with a magnetic field strength of 2 μG were the best choice Felten could make to account for the observed isotropic radio emission and the observed cosmic-ray electron spectrum. While there could still be small improvements to this spectrum with the availability of improved experimental data, it seems unlikely that it would require any serious modification.

In a more recent paper Felten and Morrison[17] have extrapolated this spectrum up to energies of ~200 GeV by taking into account the inverse Compton scattering with starlight photons of energy density 0.1 eV/cm^3 and mean energy 3 eV/photon as well as the 3°K black-body radiation; for the latter they have taken the appropriate energy density of 0.4 eV/cm^3 and mean energy of 7×10^{-4} eV/photon. Following their procedure we obtain for equilibrium conditions in the halo

$$N(E)dE = 80E^{-\beta}dE \text{ for } E \ll 1/bT(\beta-1) \quad (2)$$

and

$$N(E)dE = \frac{80E^{-(\beta+1)}dE}{bT(\beta-1)} \text{ for } E \gg \frac{1}{bT(\beta-1)}, \quad (3)$$

where b is given by the relation $bE^2 = -[(dE/dt)_{\text{syn}} + (dE/dt)_{\text{C}}]$. (In their calculations, Felten and Morrison[17] had neglected the quantity $\beta-1$.) The value of T, the lifetime of the electrons against leakage from the halo, is taken to be 3×10^{15} sec in this calculation; this is considered to be the most reasonable value and is consistent with the 2.5 g/cm^2 of hydrogen traversed by the cosmic-ray nuclei and with the direct measurement of the lifetime of cosmic rays ($T \gtrsim 1.5\times10^{15}$ sec) by Daniel and Durgaprasad.[18] Since the E^2 dependence of the rate of energy loss due to inverse Compton scattering is valid only up to some value of energy which depends on the mean photon energy in the radiation field, we have used the relation

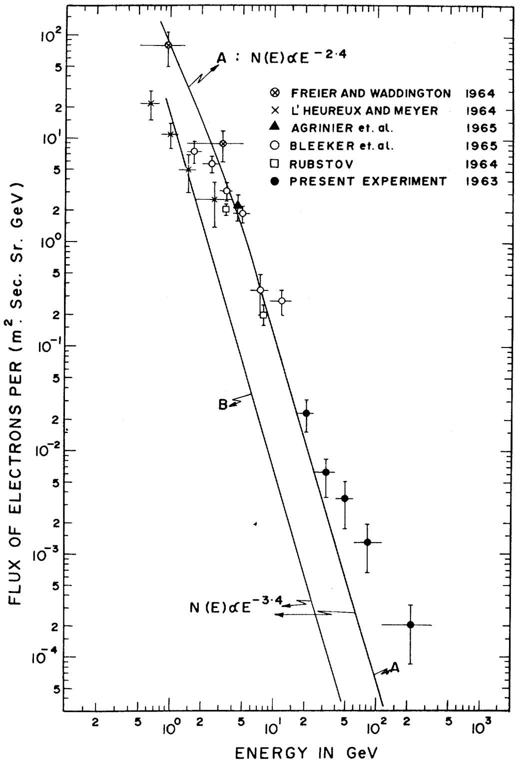

FIG. 1. The observational data on the differential energy spectrum of electrons between 1 and 350 GeV are shown; the points due to Rubtsov are obtained from the integral spectrum given by him. The calculated spectrum of electrons in the galactic halo as given by Eqs. (2) and (3) is shown in curve *A*. Curve *B* is the spectrum of the electrons in the intergalactic space computed from Eqs. (2) and (3) by taking $H \approx 10^{-7}$ G, starlight density $\approx 2\times10^{-3}$ eV/cm^3, $T \approx 10^{17}$ sec, and the same black-body radiation as that in the galaxy.

given by Gould and Burbidge[19] (Eqs. 19I and 19II of this paper) to calculate the electron spectrum accurately. Curve *A* in Fig. 1 represents the calculated energy spectrum of the halo electrons between 1 GeV and a few hundred GeV using Eqs. (2) and (3). In Fig. 1 are also shown the differential flux values obtained from the present experiment, as well as other determinations between 1 and 10 GeV. The apparently poor fit of the experimental data at energies <2 GeV with curve *A* could be understood as due to the suppression of the electron flux by solar modulation. On the other hand, there seems to be a significant disagreement between our experimental results and the calculated curve *A* of Fig. 1. We would now try to bring out the seriousness of this disagreement from the following:

(i) It seems extremely unlikely that the statistical errors in our data could be the source of this disagreement. We have also explored the possibility of systematic errors in energy determination of electrons being responsible for this and find none that could be comparable to the statistical errors.

(ii) The energy loss due to the inverse Compton scattering of the electrons by the microwave photons of the universal 3°K black-body radiation is about twice that due to the combined effect of synchrotron losses in the magnetic fields and inverse Compton scattering by the starlight photons in the halo. The magnetic field strength of 2 μG and starlight energy density of 0.1 eV/cm^3 used in these calculations seem at present unlikely to be in serious error. This would therefore mean that if the 3°K black-body radiation exists, curve *A* of Fig. 1 cannot be far wrong for energies >10 GeV.

(iii) The calculated spectral index for energies >20 GeV in curve *A* of Fig. 1 is 3.4 while the experimental value obtained by us is 2.1 ± 0.2; further, it seems extremely unlikely that the spectral index determined by us could be $\gtrsim 3.0$. On the other hand, the value of $\beta = 2.4$ used in the calculated spectrum is not only the best choice to fit the spectral index of 0.7 for the isotropic radio emission, but also has the attractive feature of being in good agreement with the value for cosmic-ray nuclei at these energies.

From all these considerations, we feel that there is at present strong reason to doubt the existence of the universal black-body radiation at 3°K if the galactic halo model used here is correct. If one works with the extragalactic model for the containment of electrons, the disagreement between calculations and observations would become more severe as shown in curve *B* of Fig. 1.

However, if future experiments, by direct observations in the millimeter wavelength region, happen to prove the existence of the universal black-body radiation, one could straightaway rule out an extragalactic model for electrons; there are, however, two alternatives for understanding our observations at electron energies >12 GeV. (i) The electrons may not be in a state of equilibrium. (ii) The electron spectrum so far observed from the lowest to the highest energies may be due to two different components operating within the framework of the galactic halo model: one component re-

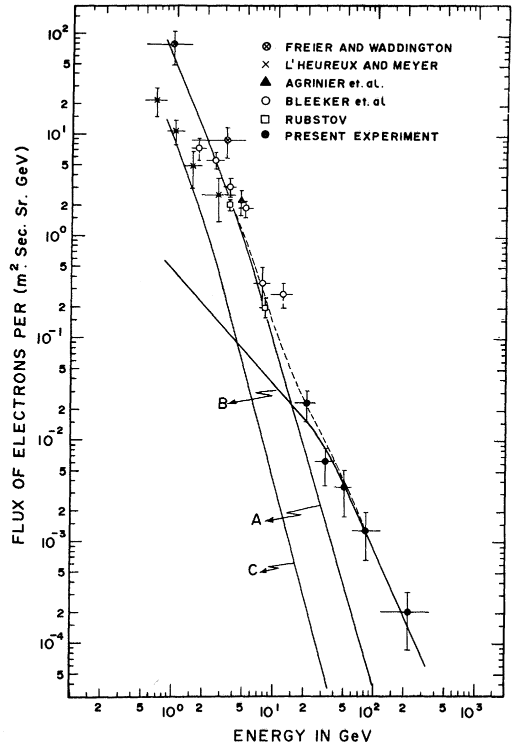

FIG. 2. Curve *A* is the postulated low-energy component of the galactic electrons which includes the secondary electrons produced in the interstellar space by collisions of cosmic rays as shown in curve *C* and the "directly accelerated" electrons. Curve *B* is the postulated second component responsible for the observed electrons between about 15 and 350 GeV. Curves *A*, *B*, and *C* take into account the energy losses due to the black-body radiation at 3°K. The dotted line is the sum of curves *A* and *B*. The observed differential spectrum of electrons between 1 and 350 GeV is also shown.

sponsible for electrons up to energies of ~10 GeV (curve *A* in Fig. 2) having a spectrum of the type $N(E)dE = 50E^{-2.4}dE$; this component would include the secondary electrons resulting from nuclear collision made by cosmic-ray nuclei traversing ≈ 2.5 g/cm^2 of hydrogen (curve *C* of Fig. 2) and the "directly accelerated" electrons. The second component accounts for electrons with energy between about 10 and 350 GeV and has a spectral form $N(E)dE = 0.45 \times E^{-1.1}dE$ (curve *B*, Fig. 2). The first component steepens beyond about 10 GeV due to the existence of the black-body radiation and becomes increasingly ineffective for electrons of energy >20 GeV. The second component, which is considerably flatter, steepens only beyond about 20 GeV and attains a spectral index of ~2.1 for the energy interval covered in the present experiment[20]; this spectrum would make the most dominant contribution to the flux at our energies. The combined electron spectrum due to the two components is shown as a dotted line in Fig. 2. Such a model would also have its place for the observations[9,15] on the large excess of electrons over positrons for energies <10 GeV (component *A* of Fig. 2) and the possible evidence, from the present experiment, for an excess of positrons over electrons at energies >12 GeV (component *B* of Fig. 2). However, the major difficulty in this model would be the postulation of a source within our galaxy with such an efficient acceleration mechanism that the injection spectrum can attain a slope $\beta \sim 1.1$ for electrons; further, the source may have to be an efficient positron emitter too!

We are grateful to the members of the cosmic-ray group of this Institute for very critical and valuable comments.

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$$N(E)dE = \frac{4.5(E^{-0.1} - 0.316)}{bTE^2} dE.$$

INTERFERENCE EFFECTS IN THE REACTION $K^+ + p \to K + N + \pi$ AT 1.2 BeV/c*

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(Received 1 August 1966)

Substantial interference has been observed between N^* and K^* production in 1.2-BeV/c K^+-p interactions.

Many reactions involve production of three-body final states in which two or all three of the possible particle pairs can be decay products of resonant states. Interference effects at the crossings of bands representing these resonances in a Dalitz plot have been considered previously, particularly in connection with the consequences of Bose statistics,[1] as for example in the reaction $K^- + p \to Y^{*\pm} + \pi^\mp \to \Lambda^0 + \pi^+ + \pi^-$. More recently Goldhaber et al. have reported evidence of constructive interference at the crossing of K^* and N^* bands in the reaction $K^+ + n \to K^+ + p + \pi^-$ at 2.3 BeV/c incident momentum[2]; and Friedman et al. have found sizable constructive interference for the same resonances in the reaction $K^- + p \to K^- + \pi^+ + n$ at 1.45 BeV/c.[3] In the present paper, we report evidence for very substantial interference between the $K^*(891)$ and $N^*(1236)$ in the reactions

$$K^+ + p \to K^0 + p + \pi^+ \quad \text{(2908 events)} \tag{1}$$

and

$$K^+ + p \to K^+ + p + \pi^0 \quad \text{(1104 events)} \tag{2}$$

at an incident momentum of 1.2 BeV/c. The Dalitz-plot populations for (1) and (2) can be well accounted for by a model in which the K^* and N^* amplitudes are assumed to have phase variations over the Dalitz plot given by the appropriate Breit-Wigner terms, and in which the over-all phase difference between the K^* and N^* amplitudes is determined by a best fit to the data.

The data were obtained in an exposure of the Lawrence Radiation Laboratory's 25-inch hydrogen bubble chamber to a separated K^+ beam at the Bevatron.[4] The sample for Reaction (1) includes events with and without a visible K_1^0 decay. The film was measured principally with the Berkeley flying-spot-digitizer system.

The Dalitz plots for Reactions (1) and (2) are shown in Fig. 1. It is particularly apparent in the $K^0 p \pi^+$ Dalitz plot that the population in the K^*-N^* overlap region greatly exceeds the sum of the individual N^* and K^* bands. To exhibit this interference effect more clearly, we have plotted in Fig. 2(a) the K-π invariant-mass distributions for events lying in two equally wide bands of $p\pi^+$ mass squared ($1.35 < M_{p\pi}^2 < 1.55$ and $1.59 < M_{p\pi}^2 < 1.79$ BeV^2) chosen to cross the K^* band at conjugate points.[5] The lower of these $p\pi$ mass bands is centered on the actual N^* peak, and the upper one is on the tail of the N^*. Subtraction of one of these distributions from the other leads to the his-