event

$$e^- + \gamma + \gamma \to e^- + \gamma' + \gamma',$$

which satisfies the second-order Bragg reflection condition $\theta \cong 2\omega/p$. It should thus easily be distinguishable from Compton scattering.

It is a pleasure to acknowledge informative conversations with Professor L. S. Bartell, Dr. H. R. Reiss, and Dr. R. W. Detenbeck.

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FLUX AND ENERGY SPECTRUM OF PRIMARY COSMIC-RAY ELECTRONS*

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Since the discovery of primary electrons in the cosmic radiation,[1,2] attempts have been made to measure the flux of these particles at various energies.[3-6] The low intensity of the electron component causes great difficulties in obtaining enough events for good statistics and energy resolution and has so far prevented the determination of a reliable energy spectrum. Yet the knowledge of the electron spectrum in the vicinity of the earth is important for several reasons. At the present time, it appears likely that the primary electrons observed near the earth are of galactic origin. A determination of their flux and spectrum makes it possible to investigate in detail their relation to the nonthermal galactic radio emission. Furthermore, the modulation of their intensity and spectrum due to solar-controlled mechanisms may be different from the modulation of heavier primary particles. Parker[7] has discussed the possibility of velocity-dependent modulation, which can be tested by investigating the primary cosmic-ray electrons.

The experiment which we shall discuss here gives an approximate energy spectrum of the primary electron component. It was carried out in the summer of 1964 at a period near solar activity minimum. This period is most advantageous for investigations of low-energy galactic particles since the effects of solar modulation are approaching their minimum. Two balloon flights were made at Ft. Churchill on 22 and 29 July 1964, both of them floating under about 4 g/cm^2 of residual atmosphere, in order to measure the flux and energy spectrum of the electron component. A schematic cross section of the instrument which was used is shown in Fig. 1. Vertically incident particles trigger a counter telescope consisting of the scintillation counters T and I and a gas Čerenkov counter C. The geometry factor of the telescope is 1.08 cm^2 sr. The gas counter is filled with 2.4 atm of SF$_6$ and has a threshold of about 8 MeV for electrons and 15 BeV for protons. The energy loss of the particles in Counter I is measured in order to discriminate between singly and multiply charged particles. After passing through counter I, the particles penetrate a layer of 10.8 g/cm^2 of lead, a plastic scintillation counter S, and en-

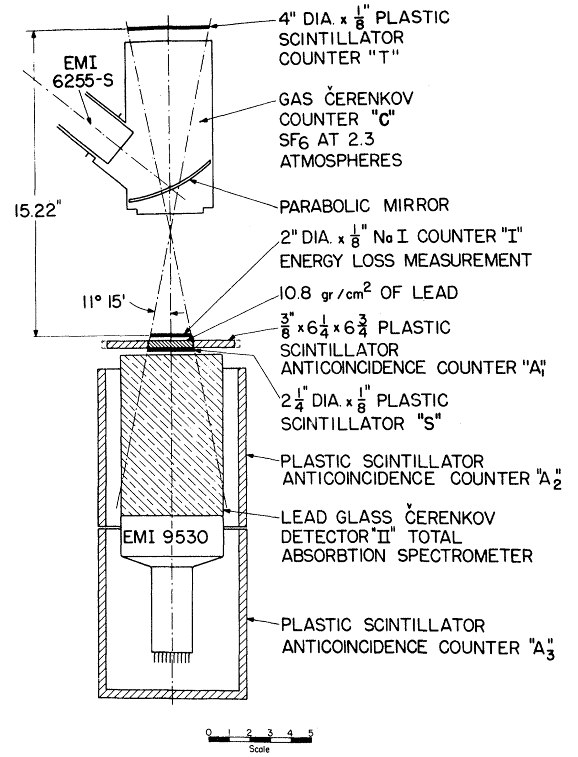

FIG. 1. Schematic cross section of the counter telescope.

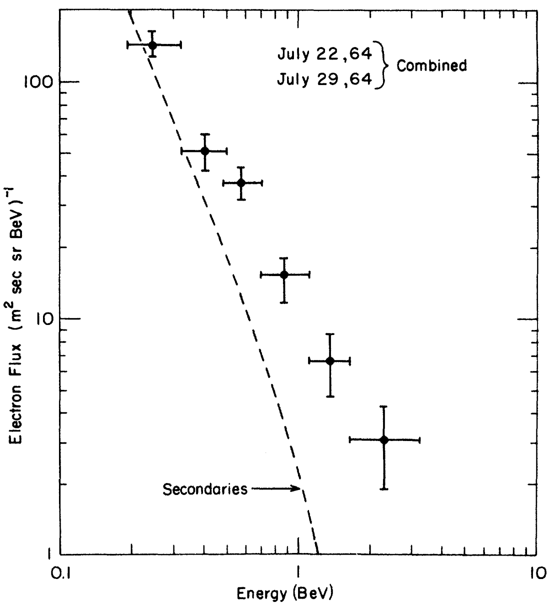

FIG. 2. The energy spectrum of electrons as measured under $4.1\ \mathrm{g/cm^2}$ of residual atmosphere. Dots: experimental points; dashed line: estimated flux and energy spectrum of secondary electrons.

ter a lead-glass Čerenkov counter II (Schott glass no. SF6-FA) with a total depth of 13 radiation lengths. The amount of Čerenkov light produced in this counter is measured by a pulse-height analyzer. Provided the incident particle is an electron and the photon-electron shower produced by this electron is absorbed in the lead glass, then the light output is a measure of the energy of the incident electron. The lead-glass Čerenkov counter is completely surrounded by anticoincidence counters in order to discriminate against events in which one or several particles emerge from the lead glass. All events in which the anticoincidence counter A3 is fired are also recorded and high-energy protons which penetrate the entire telescope are used for in-flight calibration of the counters I and II. In order to further discriminate against high-energy protons and interactions produced by protons in the lead glass, the scintillation counter *S* is connected to two independent triggers which respond to singly charged minimum-ionizing particles and to particles with 1.6 times minimum ionization or more, respectively. The equipment was calibrated in a monoenergetic beam of electrons[8] at energies ranging from 700 MeV to 4 BeV. These calibration runs served to determine (a) the pulse height in counter II as a function of the energy of the incident electrons; (b) the resolution of the lead-glass Čerenkov counter at various energies; (c) the resolution of counter I; (d) the fraction of events in which any of the anticoincidence counters was triggered as a function of the energy of the incident electrons; (e) the probability that an incident electron produces more than one particle in counter *S* as a function of energy; and (f) the efficiency of the gas Čerenkov counter which was measured to be 95%. The resolution of counter I is 37% for relativistic electrons (full width at half-maximum), and the lead-glass Čerenkov counter has a resolution which varies slightly with energy. We obtained 32% at 700 MeV to 21% at 1.3 BeV. Using the calibration data it is possible to show that contributions by protons to the measured electron flux are less than 5% at any energy. In Fig. 2 we present the electron-energy spectrum under $4.1\ \mathrm{g/cm^2}$ of residual atmosphere which we obtained from 20 h of exposure at ceiling (both flights combined) and which is based on 330 electrons with energies exceeding 180 MeV.

In order to arrive at the spectrum of the primary electrons, the contribution of secondary

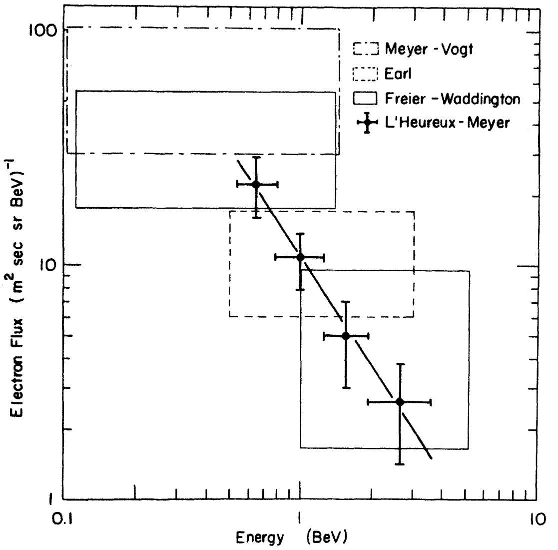

FIG. 3. The flux and energy spectrum of primary electrons between 500 MeV and 3.5 BeV (corrected for secondary electrons and energy loss in the atmosphere).

electrons which are produced in the residual atmosphere above the equipment has to be estimated. We have, at the present time, based this estimate on the following data: (1) the measured altitude dependence of the electron flux; (2) simplified calculations based on the cross section and multiplicity of π-meson production by cosmic-ray protons, and (3) measurements of the μ-meson energy spectrum obtained at aircraft altitude.[9,10] The resulting energy spectrum of secondary electrons under 4.1 g/cm^2 of atmosphere is shown as a dashed line in Fig. 2. It should be noted that the estimate of the secondary electron flux is preliminary. We shall investigate it in greater detail in the future.

At energies exceeding about 500 MeV the secondary correction becomes small compared to the measured flux of electrons. In this region our results will be little modified by a more refined analysis. We therefore restrict this discussion to primary electrons with energies above 500 MeV. In Fig. 3 the energy spectrum of primary electrons in the range from 500 MeV to 3 BeV is shown after applying corrections for secondaries and for energy loss (ionization and bremsstrahlung). We may represent this spectrum as a power law of the form

$$dJ/dE = 11 \times E^{-1.6} (\mathrm{m}^2 \text{ sec sr BeV})^{-1},$$

where E is measured in BeV. The exponent has an error of about ±0.5. This spectrum falls inside the limits set by earlier determinations[1,2,5] and, if extrapolated beyond 4.5 BeV, is compatible with the results of Agrenier et al.[3] An extrapolation to lower energies falls closely on the data which Cline, Ludwig, and McDonald[6] obtained below 10 MeV. Although it is interesting to note this point, it does not lead to any conclusions at this time. In view of the large error limits in the earlier data,[1,2] it is not surprising that solar modulation effects, even if present, cannot be noticed in the comparison with the results of this paper.

In the energy interval which we cover in this experiment, the exponent of the power law is appreciably smaller than would be expected on the basis of a collision origin of the electron components in the galaxy.[11,12] It is lower, although not incompatible, with the exponent deduced from observation of the frequency spectrum of the nonthermal galactic radio emission.[13]

We are indebted to Dr. R. Vogt who participated in the early phases of this experiment; to Mr. R. C. Hartman, who developed the gas Čerenkov counter; and to Mr. T. Burdick, Mr. H. Boersma, Mr. W. Johnson, Mr. A. Hoteko, and Mr. S. Avery for their participation in the development and construction of the equipment. We greatly profited from discussions with Dr. Y. A. Smorodin concerning the secondary electrons. Mr. R. Eckstrom provided the computer program for the analysis of the data.

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MODE-STRUCTURE INDEPENDENCE OF STIMULATED RAMAN-SCATTERING CONVERSION EFFICIENCIES*

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The power density needed to convert a given amount of laser energy to stimulated Raman-scattered radiation has been found to be about an order of magnitude less in nitrobenzene than theoretically expected for the case of a Raman cell external to the laser cavity.[1] It has been suggested[1,2] that the multimode character of the laser pump might be responsible for this disagreement. Bloembergen and Shen[2] have given a semiquantitative estimate of the enhancement of the Raman gain. It indicates that with a typical multimode laser a Raman gain ~4 to 8 times greater than that for a single-mode laser should be produced. It is the purpose of this communication to show that the Raman gain in nitrobenzene for a single-mode laser pump is precisely that for a multimode laser pump, and to suggest other reasons for the above-mentioned disagreement.

In this experiment, the collimated beam from our giant pulse laser was directed onto a 1.45-mm aperture 70 cm from the laser, and the portion of the beam transmitted by the aperture passed through a 10-cm cell of nitrobenzene onto a MgO diffuse reflector placed 50 cm after the cell. The power of the laser and the first Stokes line was monitored by suitably filtered fast photodetectors that sampled the diffuse reflection from the MgO. The cell was tilted at ~3° with respect to the laser beam. This arrangement is like that described in more detail by Weiner, Schwarz, and McClung,[1] except that the aperture and cell are now further from the laser and closer to the MgO. Also, another beam splitter to allow a measurement of the far-field pattern has been added.

Our laser has been mode-selected to give single-transverse and longitudinal mode behavior. The details of the mode-selection techniques will be given elsewhere.[3] The transverse mode structure was determined with the aid of a 1-m focal-length camera. The longitudinal mode structure was determined with the aid of a 2-cm spaced Fabry-Perot etalon with $\lambda/80$ flat plates of ~1% transmission. When completely mode-selected, the laser produced 2 MW of power in a beam whose divergence equaled the diffraction limit corresponding to the laser-beam diameter. When not mode-selected, the laser output was ~10 MW, the beam divergence $\sim 1.5\times10^{-3}$ rad, and the spectral width $\sim\frac{1}{2}$ cm^{-1}. The pulse length was ~30 nsec for both cases. The results of the conversion-efficiency measurements for mode-selected and non–mode-selected lasers are shown in Table I. The experimental arrangement is the same for both cases. The relative error for the power measurements is ~5%. Measurements at other power densities for our mode-selected laser gave a conversion-efficiency curve which agreed very well with our previous curve for a non–mode-selected case.[1] The data of Table I indicate strongly that the anomalously high gain is not caused by the laser mode structure.

The theoretical gain in nitrobenzene at 20 MW/cm is 0.028 cm^{-1}. This gain is computed using a formula of Hellwarth[4] and a recently measured peak Raman-scattering cross section of 1.3 ± 0.4 cm^{-2}. This cross section agrees within the expected error with our earlier[5] and less accurate measurement of 2.3 ± 1.2 cm^{-1}. It also agrees with the recent measurement of Damen, Leite, and Porto[6] in the fol-