PRIMARY COSMIC-RAY ELECTRONS BETWEEN 17 Mev and 1 Gev in 1967

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ABSTRACT

We report results of primary cosmic-ray electron observations made
with a balloon-borne detector launched from Fort Churchill, Manitoba.
In three flights, on 17 June, 2 July, and 21 July, the detector floated
near 2 g/cm^2 atmospheric depth for a total of 35 hours. The detector
consists of a scintillation-counter telescope, a gas Čerenkov counter,
and a spark chamber with lead plates. The primary electron results de-
pend critically upon the correction which is made for atmospheric second-
ary electrons. Data gathered during balloon ascents enable us to verify
a previously published calculation of atmospheric secondaries. At energies
below 350 Mev we find that the observed electron flux can be entirely ac-
counted for by atmospheric secondaries. We give 2σ upper limits on the
primary electron flux of 20, 9, and 13 electrons/m^2 sec ster in the energy
intervals 17-57, 57-112, and 112-374 Mev respectively. Between 374 and
1060 Mev we find 16 ± 14 electrons/m^2 sec ster. Comparison between the
observed upper limits to the primary flux and a calculation of the flux
of galactic secondary electrons indicates an absolute solar modulation of
electrons below 100 Mev by at least a factor of three.

INTRODUCTION

Since the first direct observations of primary cosmic ray electrons
in 1960 [Earl, 1961; Meyer and Vogt, 1961], the electron spectrum has been
extensively studied at energies above 200 Mev. (Recent measurements in
the energy range of 200 Mev to 1 Gev include those of L'Heureux and Meyer
[1968], Webber [1968a], Fanselow [1968], and Simnet [1968].) Also, electrons from
3 to 12 Mev have been observed for several years [Cline et al, 1964; Cline
and McDonald, 1968].

In this paper, we present measurements of the electron spectrum between 17 Mev and 1 Gev. The low end of this energy interval, below 200 Mev, is of particular interest because the observed spectrum of electrons below 12 Mev is not a simple extension of the spectrum above 200 Mev. Delineation of the spectrum in this intermediate interval can provide information about the origin of the cosmic-ray electrons and about solar modulation of cosmic rays. The most recent reports on the energy spectrum in this region are those of Fan et al [1968], Israel and Vogt [1968], and Webber [1968a].

Electron measurements between 12 and 200 Mev have been carried out almost exclusively on high altitude balloon flights. (One observation of electrons between 10 and 40 Mev from an IMP satellite, outside the magnetosphere, will be discussed below.) Two serious problems affect these balloon-borne observations. First, the geomagnetic cutoff rigidity at the location of the flights (near Fort Churchill, Manitoba) exhibits a strong diurnal variation. The effect of this variation on electron observations was first pointed out by Jokipii et al [1967]. All electron fluxes at energies ≲ 100 Mev published prior to this paper were contaminated by a large contribution of return albedo electrons and so must be disregarded when treating primary electrons. (See accompanying paper, hereinafter referred to as paper 2, [Israel and Vogt, 1969].)

The second problem in the interpretation of low-energy electron observations is the flux of atmospheric secondary electrons. The electrons incident on a balloon-borne detector include those impinging on the top of the atmosphere and also electrons created in the residual atmosphere above the detector as secondary products from interactions of primary

cosmic ray nuclei with the air. At energies above 500 Mev, the secondary

electron flux is a small fraction of the total electron flux observed at

balloon altitudes. Thus the details of the correction for secondaries are not

critical. (See e.g. L'Heureux [1967].) Below 100 Mev, the secondary elec-

tron flux is about 20 percent of the electron flux observed during daytime,

so as long as the high daytime flux of electrons was believed to be pri-

maries, the details of the secondary correction remained uncritical. How-

ever, with the realization that the lower, nighttime flux represents the

primary electrons, the details of the secondary correction become extremely

important. Atmospheric secondaries represent at least half, and perhaps

all, of the 12 to 100 Mev electrons observed at nighttime at balloon float

altitudes.

One approach to the problem of secondary corrections is to calculate

the expected secondary flux from the known flux of primary nuclei and the

accelerator-determined cross-sections for pion production. Two such cal-

culations have been published [Perola and Scarsi, 1966; and Verma, 1967].

They agree rather well at energies between 200 Mev and 1 Gev, but disagree

by a factor of three between 10 and 100 Mev. Because of this marked dis-

agreement, we determine the secondary contribution from the flux of low

energy electrons which we observed during the ascent of our detector. Our

ascent data were all gathered at night, when only the low primary electron

flux and the atmospheric secondaries were present. The lack of contamina-

tion by the large flux of return albedo electrons enables us to make a

more accurate determination of the primary and secondary contributions than

would be possible with data gathered during a daytime ascent.

EXPERIMENTAL PROCEDURE

The detector system includes a scintillation counter telescope, a gas Čerenkov counter, and a spark chamber with lead plates. The instrument and the data analysis procedures have been described in an accompanying paper (paper 1) [Israel, 1969b]. We identify electrons as particles with velocity above the Čerenkov threshold (0.9984 c) which either stop or produce a shower in the lead. Contamination of the measurement by other particles is negligible at all energies with the possible exception of the 350 to 1000 Mev interval where interacting protons with energy above 16 Gev may give a 15 percent contribution to the electron observation [Israel, 1969a].

The data reported in this paper were gathered during three balloon flights launched from Fort Churchill, Manitoba in June and July, 1967. In each flight, the detector floated near 2 g/cm^2 atmospheric depth for approximately 10 hours. The flights, designated C1, C2, and C4, have been described more fully in paper 2.

ATMOSPHERIC SECONDARIES

In the upper 10 g/cm^2 of the atmosphere, the principal source of secondary electrons at energies $\gtrsim 20$ Mev is the decay of charged pions. These pions originate in interactions of primary cosmic ray nuclei with air nuclei. The resulting secondary electron spectrum has been calculated from the known primary cosmic ray spectrum and the pion production cross-sections by Perola and Scarsi [1966] and by Verma [1967]. The calculated electron spectra at 2 g/cm^2 atmospheric depth are shown in Figure 1. Also shown is the spectrum of knock-on electrons [K. Beuermann, to be published] and the combined spectra formed by adding the knock-on electrons to those originating in interactions. At energies $\lesssim 100$ Mev the two in-

dependently calculated spectra differ by a factor of two to three, although both authors claim an uncertainty of less than 25 percent. Between 200 and 1000 Mev, the two are in good agreement.

The importance of the secondary electron contribution at these energies is clear when we consider the variation of electron flux with atmospheric depth (Fig. 2). The observed rate of type 1 events (electrons of approximately 12 to 50 Mev, see paper 1) decreases almost linearly with atmospheric depth. This indicates that even at 2 g/cm^2 a large fraction of the observed electrons are atmospheric secondaries. Also plotted in Fig. 2 (curves 1 and 2) are the expected event rates derived by folding the type 1 detection probability with the secondary electron spectra calculated by Perola and Scarsi and by Verma. We include the knock-on electron contribution in these curves. We also make an approximate correction for the difference between the primary proton flux assumed in the calculations and the proton flux at the time of our flights. This correction gives a 15 percent decrease for the spectrum based on the calculation of Perola and Scarsi, and a 5 percent decrease for that of Verma.

Because the two calculated secondary electron fluxes are in disagreement, we make an independent estimate, based upon our data of Figure 2. We derive the secondary flux from our data in the following manner. We take the altitude dependence of the total flux of type 1 electrons, J(d), to be of the form

$$J(d) = a \ s(d) + b \ p(d) \tag{1}$$

where $\underline{d}$ is atmospheric depth; the function $\underline{s(d)}$ describes the depth dependence of the flux of secondary electrons; the function $\underline{p(d)}$ describes the depth dependence of the flux due to primary electrons; and the coefficients $\underline{a}$ and $\underline{b}$ are parameters which we determine by a least-squares fit to the nine data points from 2 to 25 g/cm^2.

The solid curve in Figure 2 is the least-squares fit for $J(d)$ based upon the following assumptions:

1) $\underline{s(d)}$ varies linearly with depth. This is the depth dependence of the calculated curve 2.

2) $\underline{p(d)}$ is calculated by assuming a primary electron spectrum of the form E^{-n} with n = 0.5. The flux of primary electrons in the energy interval corresponding to type 1 events varies with depth as the incident electrons lose energy in penetrating the atmosphere.

Curves A and B indicate the secondary and primary contributions respectively to the least-squares fit. The solid curve, which is the sum of A and B, fits the data with a χ^2 of 3.9. The primary electron contribution at 2.1 g/cm^2 resulting from this fit is 2.4 ± 1.5 events/hour, approximately one fourth of the observed events. This result is not sensitive to the choice of n, the exponent of the primary energy spectrum. It differs from this value by less than 10 percent for any value of n between 0 and 2.

On the other hand, the results of the fit are very sensitive to the assumed depth dependence of the secondary flux. If we take $s(d) = d^{0.9}$ (in agreement with the depth dependence of curve 1), then the least squares fit gives a primary electron contribution of 0.4 ± 1.6 event/hour, consistent with zero. In this case, the secondary electron contribution to the least squares fit agrees with curve 1 within 5 percent. This is well within the

20 percent stated accuracy of the calculation from which curve 1 is derived.

If we take the secondary depth dependence as $s(d) = d^m$ and allow m to vary as a third parameter, we find the minimum χ^2, 3.5, for m = 0.85; in this case the primary electrons give -0.8 ± 1.7 event/hour, still consistent with zero.

This analysis leads us to two conclusions regarding electrons in the interval 12 to 50 Mev. First, our observations are in good agreement with the calculations of Perola and Scarsi and in disagreement with those of Verma. The contribution of atmospheric secondaries to our observed data falls within 20 percent of curve 1 whether we assume the secondary electron flux to vary linearly with depth or as slowly as $d^{0.85}$. We cannot reconcile our observations with a secondary contribution near curve 2. Secondly, we conclude that our results are consistent with the entire observed flux being atmospheric secondaries. As an upper limit to the primary contribution to type 1 events, we take the result of the least squares fit assuming linear growth of secondaries, 2.4 ± 1.5 events/hour.

For higher energy electrons, our count rate is so low that measurements of the rate during the balloon ascent have very large statistical uncertainty, precluding useful least-squares fitting. We note, however, that at energies above 200 Mev the two calculations agree with one another as well as agreeing with the measured data of L'Heureux (1967). Therefore, we shall calculate the spectrum of the total flux at the detector and then subtract the spectrum of atmospheric secondaries based upon the calculations of Perola and Scarsi, to derive the primary flux. These spectra are presented below.

RESULTS

In this discussion of our primary electron observations, we accept the explanation of the diurnal flux variation described in paper 2. For those types of electron events which display a diurnal variation, types 1 and 2, we shall use only the nighttime data. For the events of type 3 and 4 (higher electron energies) which display no significant diurnal variation, we shall use data gathered over the entire float period of each flight. The observed event rates are listed in Table 2 of paper 2. We apply the analysis described in paper 1 to derive the flux of electrons observed at the detector, including primaries and atmospheric secondaries. The results are listed in lines 2, 3, and 4 of Table 1. The float altitudes of flights C2 and C4 agreed within 0.1 g/cm^2, and the calculated electron fluxes in the two flights are in close agreement. Therefore, the results of these two flights have been combined, yielding the fluxes tabulated in line 5. In Figure 3, we plot the differential energy spectra derived from these data. Also plotted in this figure is the calculated spectrum of atmospheric secondaries at the float altitude of flights C2 and C4.

In line 6 of Table 1 we list the atmospheric secondary fluxes for flights C2 and C4. We note that below 350 Mev our total observed flux is consistent with the flux expected from atmospheric secondaries only; i.e., our results below 350 Mev are consistent with the complete absence of primary electrons. In line 8 we list upper limits to the primary electron fluxes. These limits represent two standard deviations of statistical uncertainty, plus the systematic uncertainty. Similar subtraction

of atmospheric secondaries for flight C1, which had a lower average float altitude, are indicated in lines 9 and 10. The last line of Table 1 gives the energy interval at the top of the atmosphere to which the calculated primary fluxes correspond. This adjustment of energy intervals takes into account the energy loss of primary electrons in penetraing 2.1 g/cm^2 of air.

The observed flux of electrons between 50 and 350 Mev appears to be higher on flight C1 than on flights C2 and C4, even after accounting for the difference in atmospheric secondaries. The deviation lies, however, at the edge of the experimental uncertainty. More precise results would be required to confirm a short term flux variation.

In Figure 4 we plot, as solid symbols, the differential fluxes derived from our data. Also plotted are the results of other recent electron measurements. In plotting results of other observers, we omit any data point which includes electrons with energy below 110 Mev unless it is derived from nighttime observations only.

DISCUSSION

Above 100 Mev, the flux of primary electrons which we observed in 1967 is significantly lower than the 1966 flux reported by Webber [1968a] and by L'Heureux and Meyer [1968] . Between 112 and 374 Mev, the upper limit to the primary flux of our flights C2 and C4 is a factor of three below the flux reported by Webber. Between 374 Mev and 1060 Mev, our best estimate of the flux is nearly a factor of two below that of Webber and L'Heureux and Meyer. On the other hand, our results are in agreement with the 1965 observations of Fanselow [1968] , while the 1967 observations of Simnet [1968] are significantly higher than those of any other observer.

It is possible to attribute the difference between our 1967 measurements and other 1966 measurements to solar modulation of the electron flux. However, the differences between the various observers cited above indicates the possibility of systematic errors. It would be preferable to study the modulation with a single detector system over several years.

Figure 4 shows that below 112 Mev our upper limits for the primary flux are consistent with the values reported by Webber. Our results disagree with those of Jokippi et al, but this difference lies primarily in the correction for atmospheric secondaries. They used the atmospheric secondary corrections calculated by Verma $\left[1967\right]$ rather than those of Perola and Scarsi $\left[1968\right]$. As we have discussed above, Verma's calculations yield too low a flux of secondary electrons below 100 Mev.

There is, however, a large discrepancy between the flux we observe in the 17 to 57 Mev interval and the flux reported by Fan et al $\left[1968\right]$. Their results are derived from data gathered with a satellite borne energy-loss-total-energy detector. Their best flux estimate between 20 and 40 Mev lies above our upper limit by a factor of four. It is not likely that this difference can be accounted for entirely by solar modulation even though their data were taken a year and a half before ours. Webber's data, taken a few months after theirs, is a factor of ten below their result. The data reported by Fan et al were taken on an IMP satellite, outside the magnetosphere, so their results are free of atmospheric secondaries and effects of the geomagnetic field. Both Webber's data and ours are derived from nighttime observations with a balloon-borne detector near Fort Churchill.

We are unable to find any possible systematic error in our results which could account for the large difference between our data and that of Fan et al. The difference between the satellite data and the balloon data could be explained if the present understanding of the diurnal variation were incorrect, and the nighttime flux at the balloon were somehow lower than the interplanetary flux. We believe this to be quite unlikely. As pointed out in paper 2 , the nighttime flux is significantly lower than the splash albedo flux, indicating a lack of return albedo at night. We know of no mechanism by which both return albedo and primaries can be excluded from the observations. The lack of return albedo implies that primary electrons must be able to reach the detector from interplanetary space.

CONCLUSIONS

We next consider the implications of our observations below 100 Mev on the question of the origin of the electrons and of the absolute solar modulation. One source of cosmic-ray electrons is the collision of cosmic-ray protons and alpha particles with nuclei of the interstellar gas. Such collisions can produce charged pi mesons which in turn produce electrons by $\pi \to \mu \to e$ decay. In addition, cosmic-ray electrons may be produced by acceleration of electrons from ambient matter, perhaps in the same sources where cosmic-ray nuclei are accelerated.

The electron flux observed at higher energies, above 400 Mev, is significantly larger than the flux expected from the collision source alone [Ginzburg and Syrovatski, 1964; Ramaty and Lingenfelter, 1966; Perola et al, 1968] ; and the small positron/electron ratio observed between 500 Mev and 5 Gev gives further evidence for the dominance of primary electron acceleration at these higher energies [Hartmann, 1967] .

We may attempt to compare our low-energy electron measurements with the calculated flux of collision-source electrons. This comparison, however, requires an estimate of the absolute solar modulation of electrons. Although the modulation of electrons is not established, solar modulation of cosmic-ray protons and alpha particles has been extensively studied. (See review by Webber [1967a].) There is reasonable agreement between observations and the diffusion-convenction model, originally proposed by Parker [1958]. In this model the differential rigidity spectrum $j(R;t)$ observed at the earth at some time, t, is related to the spectrum $j_o(R;t)$ outside the region of solar modulation by

$$\frac{j(R;t)}{j_o(R;t)} = \exp\left[-\frac{\eta(t)}{\beta\, f(R)}\right] \qquad (2)$$

where R is the particle rigidity, β is the particle velocity in units of the speed of light, $\eta(t)$ is a parameter depending upon the solar wind velocity and interplanetary magnetic field irregularities but independent of the properties of the modulated particles, and $f(R)$ is a function of rigidity whose functional form depends upon properties of the magnetic field irregularities; see e.g. [Jokipii, 1968]. The quantity which has been most extensively measured is the change in $j(R;t)$ with time, during the solar cycle. This change is related to $\Delta\eta$, the change in $\eta(t)$, between two times of observation.

$$\frac{j(R;t_1)}{j(R;t_2)} = \exp\left[-\frac{\Delta\eta}{\beta\, f(R)}\right] \qquad (3)$$

In a simple form of the theory,

$$f(R) = \begin{cases} R & \text{for } R > R_o \\ R_o & \text{for } R < R_o, \end{cases} \qquad (4)$$

where R_o is some fixed rigidity. This model gives agreement with much of the proton and helium data for $R_o \approx 0.5$ GV. (Near solar minimum, a somewhat better fit obtains with $f(R) = R^{0.5}$ [Ormes and Webber, 1968; Jokipii, 1968].)

The applicability of this modulation model to electrons is open to question. There is no feature of the theory which distinguishes particles except by their velocity and rigidity; so one would expect that if it fits protons and alpha particles, the theory would also fit electrons. However, the experimental evidence for electrons is, at present, contradictory. For electrons between 0.25 and 1.05 GV, L'Heureux et al [1968] found no modulation from 1960 to 1966; they set an upper limit of 60 percent on the fractional change of electron intensity during this period. The proton and helium data between 1960 and 1965 [Webber, 1967a] fit the diffusion-convection model with $\Delta \eta \approx 0.8$ GV and $R_o \approx 1$ GV; but modulation with these parameters would produce an increase by near 120 percent in the electron flux below 1 GV, in disagreement with the results of L'Heureux, et al. This disagreement implies that the modulation of electrons is significantly weaker than that of protons and alpha particles. On the other hand, between 1965 and 1966 [Webber 1967b] reports significant electron modulation in the interval from 100 to 2000 Mev, with both electrons and protons satisfying $\Delta \eta = 0.17$ GV, $R_o = 0.5$ GV.

The comparison between the observed electron flux and that calculated from the collision source involves an estimate of the total electron modulation which is related to η, not merely $\Delta\eta$. Ramaty and Lingenfelter [1968] estimate $\eta = 0.4 \pm 0.1$ at solar minimum, 1965. They derive this value by comparing observed fluxes of deuterium and helium-3 with calculated fluxes, assuming that these nuclei originate in the interactions between cosmic ray nuclei and the interstellar gas. Independent estimates of η are derived by comparing the observed electron spectrum at energies $\gtrsim 200$ Mev with the observed non-thermal galactic radio noise. Depending upon what radio data are selected for comparison, values of η near solar minimum of 0 to 0.5 GV [Verma, 1968], 0.65 GV [Anand et al, 1968], and 0.6 to 0.75 GV [Webber, 1968b] have been calculated. Between solar minimum (in 1965) and the time of our observations, we estimate $\Delta\eta = 0.3$ GV. (This value is derived from proton data over a similar period before solar minimum [Webber 1967a].) Thus we estimate that η at the time of our observations was probably between 0.6 and 1.0 GV. This uncertainty in η gives a corresponding uncertainty in the total modulation. Furthermore, the form of the modulation below several hundred MV is not certain; i.e., R_o in the expression for the total modulation is uncertain.

These uncertainties in the total modulation of electrons, expecially at energies below a few hundred Mev, make it difficult to draw quantitative conclusions regarding the electron source at these energies. Our data, however, do provide constraint upon the absolute modulation and the sources.

The solid curve in Figure 4 displays the interstellar spectrum of galactic secondary electrons calculated by Ramaty and Lingenfelter [1968a]. The

calculation requires assumptions about the amount of interstellar material traversed by the cosmic rays and the volume in which the electrons are stored. A similar calculation by Perola, Scarsi, and Sironi [1968] indicates that the flux of galactic secondary electrons between 10 and 100 Mev can vary by an order of magnitude as the galactic parameters are varied over the range of possible values. In the following discussion we shall accept the Ramaty and Lingenfelter calculations as the best available estimate of the galactic secondaries.

The solid curve must be treated as a lower limit to the interstellar electron spectrum because there may be additional electrons from other sources. Since the upper limit to our electron flux lies a factor of three below this curve, we conclude that there must be significant modulation of these low-energy electrons - a reduction in flux by at least a factor of three. If the absolute modulation were proven smaller than this, then our data would imply that some of the galactic parameters used in Ramaty and Lingenfelter's calculation were seriously in error.

The dashed curves in Figure 4 indicate the spectrum of galactic secondaries near the earth under the assumption of various forms of modulation. These forms are consistent with our present knowledge of the proton and alpha particle modulation. If the actual modulation is approximately as indicated by curve 1 or 2 in Figure 4, then the low energy electron flux observed near the earth can be accounted for entirely by galactic secondary electrons. This would contrast with the result at energies $\gtrsim 500$ Mev, where primary acceleration of electrons clearly dominates. At present, however, we cannot eliminate the possibility that the absolute modulation of electrons is significantly stronger than that of curve 2, and the contribution of primary accelerated electrons is significant, even at low energies.

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TABLE 1

Electron Flux (electrons/m^2 sec sr)				
1. Energy interval at detector (Mev)	12 - 50	50 - 100	100 - 350	350 - 1000
2. Total flux at detector. Flight C1	39 ± 12	31 ± 11	38 ± 15	23 ± 11
3. Flight C2	27 ± 10	17 ± 9	25 ± 12	26 ± 15
4. Flight C4	31 ± 10	15 ± 7	20 ± 8	22 ± 13
5. Flights C2 and C4	29 ± 8	16 ± 7	23 ± 10	24 ± 12
6. Atmospheric secondaries at 2 g/cm^2 (C2 & C4)	28 ± 6	23 ± 5	31 ± 6	8 ± 2
7. Primary electrons Flights C2 and C4				16 ± 14
8. Upper limit to primary electrons (2σ) Flights C2 and C4	20	9	13	(35)
9. Atmospheric secondaries (mean during C1)[a]	41 ± 9	33 ± 7	37 ± 7	10 ± 2
10. Upper limit to primary electrons Flight C1	21	23	20	(31)
11. Energy interval at top of atmosphere (Mev)	17 - 57	57 - 112	112 - 374	374 - 1060

(a) During flight C1, atmospheric depth varied between 2.1 and 3.4 g/cm^2.

REFERENCES

Anand, K. E., R. R. Daniel, S. A. Stephens, Radio emitting electrons in the galaxy and the solar modulation of cosmic rays, Nature, 217, 25, 1968.

Cline, T. L., G. H. Ludwig, and F. B. McDonald, Detection of interplanetary 3-12 Mev electrons, Phys. Rev. Letters, 13, 786, 1964.

Cline, T. L., and F. B. McDonald, Interplanetary and solar electrons of energy 3-12 Mev, Can. J. Phys., 46, S 761, 1968.

Earl, J. A., Cloud chamber observations of primary cosmic ray electrons, Phys. Rev. Letters, 6, 125, 1961.

Fan, C. Y., G. Gloeckler, J. A. Simpson, S. D. Verma, The primary cosmic-ray electron energy spectrum from 10 Mev to 40 Mev, Astrophys. J., 151, 737, 1968.

Fanselow, J. L., The primary cosmic-ray electron spectrum between 0.09 and 8.4 Bev in 1965, Astrophys. J., 152, 783, 1968.

Ginzburg, V. L., and S. I. Syrovatskii, The Origin of Cosmic Rays, MacMillan Co., New York, 1964.

Hartman, R. E., The energy dependence of the positron-electron ratio in the primary cosmic radiation in 1965, Astrophys. J., 150, 371, 1967.

Israel, M. H., Primary cosmic-ray electrons and albedo electrons in 1967 at energies between 12 and 1000 Mev, Ph.D. thesis, California Institute of Technology, Pasadena, 1969a.

Israel, M. H., Albedo electrons between 12 and 1000 Mev, J. Geophys. Res., 74, 1969b (accompanying paper).

Israel, M. H., and R. E. Vogt, Flux of cosmic-ray electrons between 17 and 63 Mev, Phys. Rev. Letters, 20, 1053, 1968.

Israel, M. H., and R. E. Vogt, Characteristics of the diurnally varying electron flux near the polar cap, J. Geophys. Res., 74, 1969 (accompanying paper).

Jokipii, J. R., Modulation of low-rigidity cosmic rays and the power spectrum of the interplanetary magnetic field in 1962 and 1965, Can. J. Phys., 46, S 950, 1968.

Jokipii, J. R., J. L'Heureux, and P. Meyer, Diurnal intensity variation of low-energy electrons observed near the polar cap, J. Geophys. Res., 72, 4375, 1967.

L'Heureux, J., The primary cosmic-ray electron spectrum near solar minimum, Astrophys. J., 148, 399, 1967.

L'Heureux, J., and P. Meyer, The primary cosmic-ray electron spectrum in the energy range from 300 Mev to 4 Bev from 1964 to 1966, Can. J. Phys., 46, S 887, 1968.

L'Heureux, J., P. Meyer, S. D. Verma, and R. Vogt, Long-term variations of the primary cosmic-ray electron component, Can. J. Phys., 46, S 896, 1968.

Meyer, P., and R. E. Vogt, Electrons in the primary cosmic radiation, Phys. Rev. Letters, 6, 193, 1961.

Ormes, J. F., and W. R. Webber, Proton and helium nuclei cosmic-ray spectra and modulations between 100 and 2000 Mev/nucleon, J. Geophys. Res., 73, 4231, 1968.

Parker, E. N., Cosmic ray modulation by solar wind, Phys. Rev., 110, 1445, 1958.

Perola, G. C., and L. Scarsi, Flux and energy spectrum of secondary electrons in the upper atmosphere, Nuovo Cimento, 46, 718, 1966.

Perola, G. C., L. Scarsi, and G. Sironi, Secondary cosmic-ray electrons produced in interstellar medium, Nuovo Cimento, 53B, 459, 1968.

Ramaty, R., and R. E. Lingenfelter, Galactic cosmic-ray electrons, J. Geophys. Res., 71, 3687, 1966.

Ramaty, R., and R. E. Lingenfelter, Solar modulation and the galactic intensity of cosmic-ray positrons and negatrons, Phys. Rev. Letters, 20, 120, 1968a.

Ramaty, R., and R. E. Lingenfelter, Cosmic-ray deuterium and helium-3 nuclei, Can. J. Phys., 46, 627, 1968b.

Simnett, G. M., The intensity and time variation of primary cosmic-ray electrons, Goddard Space Flight Center Preprint X-611-68-108, 1968.

Verma, S. D., A calculation of the flux and energy spectrum of secondary electrons at high altitudes in the atmosphere, Proc. Indian Acad. Sci., 66, 125, 1967.

Verma, S. D., High energy electrons and emission of the omnidirectional synchrotron radiation in radio frequency and X-ray regions, Astrophys. J., 152, 537, 1968.

Webber, W. R., The modulation of galactic cosmic rays by interplanetary magnetic fields, Proc. Tenth International Conf. on Cosmic Rays, Part A, University of Calgary, Calgary, 146, 1967a.

Webber, W. R., Measurements on the solar modulation of galactic electrons and protons in the energy range 70 Mev to 2 Bev, J. Geophys. Res., 72, 5949, 1967b.

Webber, W. R., Diurnal variation of the intensity and energy spectrum of low-energy electrons incident at Fort Churchill, Canada, J. Geophys. Res., 73, 4905, 1968a.

Webber, W. R., On the relationship between recent measurements of cosmic-ray electrons, non-thermal radio emission from the galaxy, and the solar modulation of cosmic rays, University of Adelaide, preprint ADP 43, 1968b.

FIGURE CAPTIONS

Fig. 1   Kinetic energy spectrum of atmospheric secondary electrons at

$2 \ g/cm^2$ atmospheric depth.

Curve 1		Electrons from nuclear interactions, Perola and Scarsi $\left[1966\right]$.
Curve 2		Electrons from nuclear interactions, Verma $\left[1967\right]$.
Curve 3		Knock-on electrons.
Curve 4		Sum of curves 1 and 3.
Curve 5		Sum of curves 2 and 3.

Fig. 2   Rate of type 1 events vs. atmospheric depth. Data points are com-

bined results of data gathered during ascent of flights C1, C2,

and C4 and data gathered during "night" portion of float on flights

C2 and C4. (See paper 2 for distinction between "day" and "night"

data.) (Ascent of all flights occurred at "night".)

Curve 1	Count rate derived from Perola and Scarsi $\left[1966\right]$ with addition of knock-on electrons.
Curve 2	Count rate derived from Verma $\left[1967\right]$ with addition of knock-on electrons.
Solid line	Least squares fit to data, assuming $s(d) = d$.
Curve A	Secondary contribution to solid line.
Curve B	Primary contribution to solid line.

Fig. 3   Differential kinetic energy spectrum of downward moving electrons.

Data points indicate total observed electron flux at detector during

float. For those types of events displaying a diurnal variation only

nighttime data are used. (Vertical error bars indicate combined

statistical and systematic uncertainty.)

Circles   flight C1, 2.1 to 3.4 g/cm^2.

Squares   flights C2 and C4, 2.1 g/cm^2.

Solid curve indicates atmospheric secondaries at depth of flights

C2 and C4 based upon calculations of Perola and Scarsi. Adjust-

ments are included for knock-on electrons and for the difference

between the proton flux at the time of our flights and that for

which the calculations were made.

Dashed curves indicate ± 20 percent uncertainty band about the

calculated secondary spectrum.

Fig. 4   Differential kinetic energy spectrum of primary electrons.

Solid data points   this experiment, June and July, 1967

Squares   flights C2 and C4

Circles   flight C1, where different from C2 and C4.

Diamonds   Webber, July, 1966 [1968a]

Crosses   L'Heureux and Meyer, June 1966 [1968]

Large rectangle   Jokipii, L'Heureux, and Meyer, June 1966
                     [1967]

Open squares   Fan, Gloeckler, Simpson, and Verma, June
                     1965 - March 1966 [1968]

Open circles   Cline, Ludwig, and McDonald, Jan. 1964 [1964]

Open triangles (point up) - Fanselow, 1965 [1968]

Open triangles (point down) - Simnet, 1967 [1968]

Solid curve - calculated interstellar spectrum of galactic second-

ary electrons [Ramaty and Lingenfelter, 1968a]

Dashed curves - solid curve, modulated according to diffusion-convection model, equations 2 and 4.

Curve 1 - $\eta = 0.6$ GV $\qquad R_o = 0.5$ GV

Curve 2 - $\eta = 1.0$ GV $\qquad R_o = 0.5$ GV

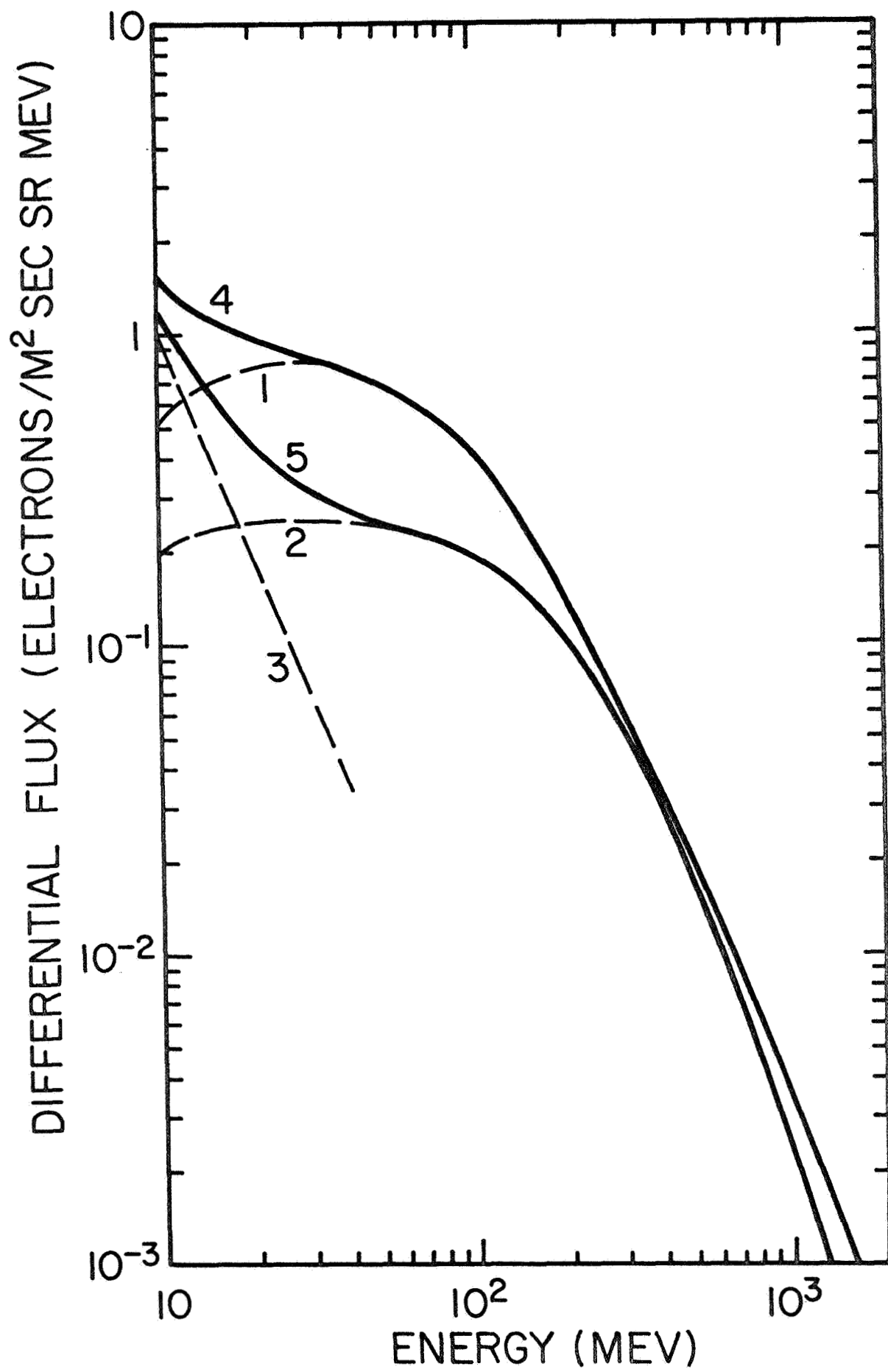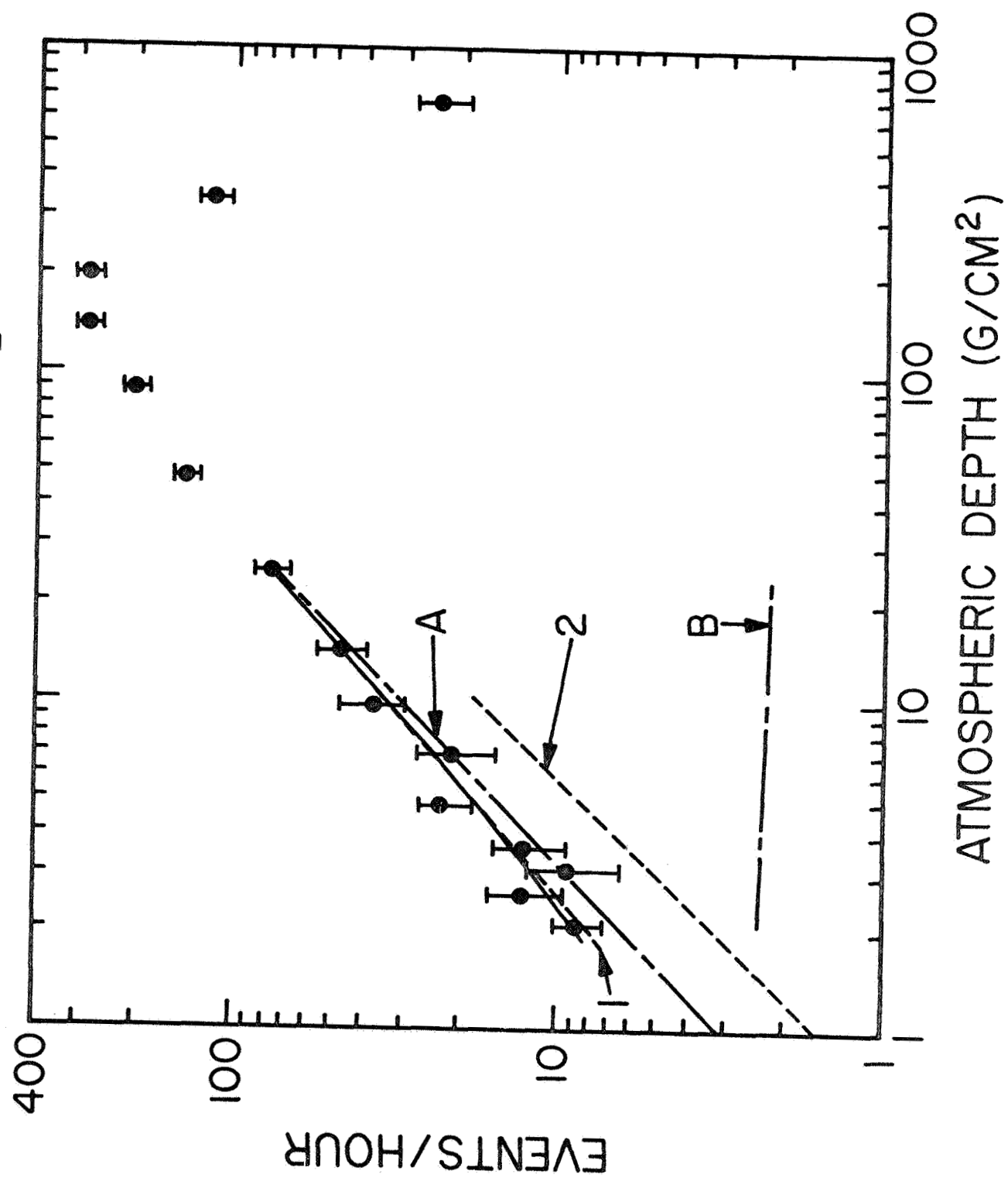Curve 3 - $\eta = 0.6$ GV $\qquad R_o = 0$

Curve 4 - $\eta = 1.0$ GV $\qquad R_o = 0$

Figure 1

Figure 2

Figure 3

Figure 4