











MeV at various geomagnetic latitudes have positive slope near the top of the atmosphere and reach a peak between 50 and 100 g/cm<sup>2</sup>. However, this difference may be explained as follows.

The shape of the proton growth curve in the atmosphere depends on the number of secondary protons which are emitted during each interaction of the primary proton (and, to a lesser extent, of  $\alpha$ -particles) with the air nuclei, and registered by the detector. Suppose that during an interaction of a primary proton of energy  $E$ ,  $n$  secondary protons are emitted and, of these, a number  $n' \leq n$  can be

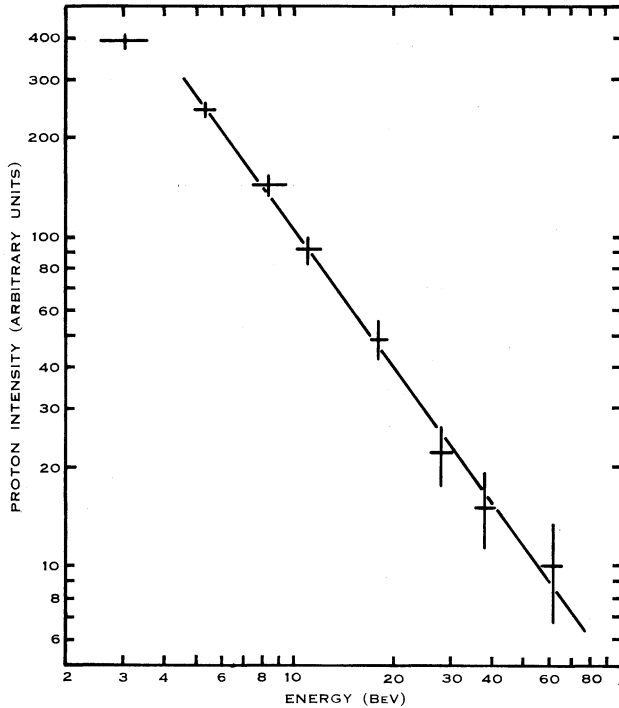


Fig. 4.—Integral energy spectrum of protons fitted by a power law:  
intensity  $\propto (1+E)^{-1.37 \pm 0.10}$ .

detected by the detector which will respond to protons with energy greater than  $E'$ . When  $n'$  is sufficiently large so that during the passage of the protons through the atmosphere more protons are produced than are absorbed, we would expect the proton flux to increase to a peak and then start to decrease when absorption becomes dominant.

If an increase in the energy  $E$  results in an increase in the number  $n$ , or in the proportion of  $n$  with energy greater than  $E'$ , then in either case an increase in  $n'$  will result. Therefore, when  $E$  is increased the position of the peak will be shifted towards greater atmospheric depth. This feature has been derived by Messel (1954) from his nucleon cascade theory and is in agreement with the results of McDonald and Webber (1959, Figs. 7 and 8). On the other hand when  $E$  is decreased, the value of  $n'$  may

also decrease. Consequently we would expect the proton flux to be continually decreasing during its passage through the atmosphere.

For the case when the energy of the primary particles is fixed, the value of  $n'$  will then depend on the properties of the detector, namely, the value of  $E'$  and the overall efficiency in detecting the secondary protons. Therefore, the number  $n'$  will be greater for a detector with a lower value of  $E'$  and higher efficiency. In the present experiment, nuclear emulsions were used as the detector and protons were detected only if they interacted with the emulsion nuclei. This requirement meant that only protons of sufficiently high energy were capable of being detected. This could be the reason why the growth curve determined in this experiment at  $\lambda = 47^\circ$  using nuclear emulsions does not have a peak, in contrast to the curve determined by McDonald and Webber (1959) using Čerenkov scintillator arrays.

TABLE 3  
COMPARISON OF PRESENT RESULTS AND THOSE OF MCDONALD AND WEBBER FOR  
THE PROTON FLUX AT THE TOP OF THE ATMOSPHERE

Flux at the Top of the Atmosphere $J(0)$ (protons $\text{m}^{-2} \text{sr}^{-1} \text{s}^{-1}$ )	Cut-off Kinetic Energy (BeV)	Reference
$1800 \pm 50$	0.38	McDonald and Webber (1959)
$2190 \pm 50$	0.5	McDonald and Webber (1959)
$1770 \pm 50$	0.55	McDonald and Webber (1959)
$1670 \pm 50$	0.67	McDonald and Webber (1959)
$1550 \pm 50$	0.8	McDonald and Webber (1959)
$1120 \pm 50$	2.1	Present Work
$610 \pm 40$	3.5	McDonald and Webber (1959)
$590 \pm 40$	3.8	McDonald and Webber (1959)

According to the results reported by Rajopadhye (1960) on the interactions of 5.7 BeV protons with emulsion nuclei, the average number of energetic protons emitted during each interaction is approximately 24% of the total number of shower particles produced. The stars selected for the present study have a mean shower multiplicity  $\bar{n}_s = 1.8$ . If we assume the same percentage of the shower particles to be energetic protons, it would give the mean energetic proton multiplicity a value of 0.43. The results of Camerini *et al.* (1951) indicated that the percentage of protons among the shower particles emitted from each star was greater for stars with greater  $N_h$ , and the increase was in a ratio of approximately 1.15 for stars with  $N_h = 3-8$  to all stars with  $N_h \geq 3$ . Therefore, if we only consider the interactions with the light nuclei of the emulsions (that is,  $N_h = 3$  to  $N_h = 8$ ) which bear a closer resemblance to the air nuclei, the average number of energetic protons emitted per star for the present study would be approximately 0.5. Thus we expect the growth curve to have a negative slope.

The experimental growth curve has been used to extrapolate the proton flux to the top of the atmosphere. It gives the value  $J(0) = 1120 \pm 50$  protons  $\text{m}^{-2} \text{sr}^{-1} \text{s}^{-1}$ . It can be compared with the values reported by McDonald and Webber (1959) deter-

mined during 1955 and 1956—a period of comparable solar activity to the period when the present measurements were made (Table 3). Corrections for the re-entrant albedo have been made to the values given by McDonald and Webber. The results are in agreement.

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