Meyer, P.: The *F*-decrease started on Sept. 4 and reached a maximum amplitude of 4% at the Deep River Neutron monitor station. During our mesurement of Sept. 8 recovery had first begun. It was at that time that we measured the ~40% decrease in electron flux.

Peters, B.: Can you give me absolute flux value corrected for the proton effect?

Meyer: I can not. We are going to calculate the proton contribution but I can not guess an answer yet. I have only a lower limit available.

Kraushaar, W.L.: Have you estimated the electron intensity you would expect from collisions of cosmic rays in the galactic gas?

Meyer: No, we have not. In order to do that, we would have to use the rather uncertain figures for the galactic magnetic fields. Also we are in no position to estimate the attenuation of the electron flux by solar modulation in the energy range that we observe.

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INTERNATIONAL CONFERENCE ON COSMIC RAYS AND THE EARTH STORM Part III

III-1-3. The Flux of Primary Protons and Helium Nuclei Near the Geomagnetic Equator

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Introduction:

Balloon flights have been made from Hyderabad (India)-geomagnetic latitude 9°N, longitude 78.5°E-to determine the flux of primary protons and helium nuclei at the top of the atmosphere, near the geomagnetic equator. Measurements were made using both Cerenkov-scintillation counter telescopes and nuclear research emulsions.

A. *Measurements with Cerenkov-scintillation counter telescopes*:

Three counter telescopes of identical geometry, using lucite Cerenkov counters and plastic scintillation counters in combination, were flown successfully from Hyderabad during February-March 1961, to level altitudes of ~10 gm/cm² for several hours each time.

The geometry of the telescopes is shown in Fig. 1. The geometry is similar to that employed by McDonald[1] except for two specific points of difference: (a), in our case the Cerenkov radiator was blackened at the top and at the sides; this blackening resulted in very good directional discrimination-for example, the back to front ratio in detection efficiency was <1%; we thus eliminated upward moving "splash albedo"; also, the

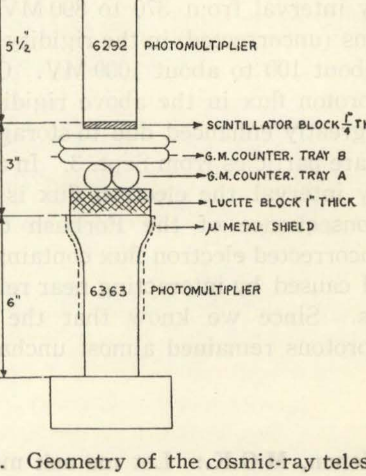

Fig. 1. Geometry of the cosmic-ray telescope

blackening of the sides cut out side showers which were "out of geometry"; (b), in our telescopes the crossed G-M counter trays were placed between the Cerenkov counter and scintillator, unlike in McDonald's geometry where they placed below the two detectors; the G-M counter tray was used to restrict the acceptance geometry so that particles which only traversed the edges of the scintillator or Cerenkov counter were excluded since if admitted they would have caused too large a dispersion in the pulse height distributions.

The geometrical factor of these telescopes for isotropic angular distribution was 8 cm^2 sterad.

The amount of matter in each telescope was 5.5 gm/cm^2, distributed as follows: glass–1.5 g/cm^2, perspex–2.5 g/cm^2, polystyrene–0.5 g/cm^2, copper–10 g/cm^2.

The telescopes were calibrated using single relativistic μ-mesons at sea level. Pulse height distributions were obtained for both the Cerenkov counter and the scintillator; from these distributions we obtained the most probable pulse, hereafter denoted as "mpp" in the Cerenkov counter and in the scintillator due to the passage of a singly charged relativistic particle. In Fig. 2 is shown a cross-

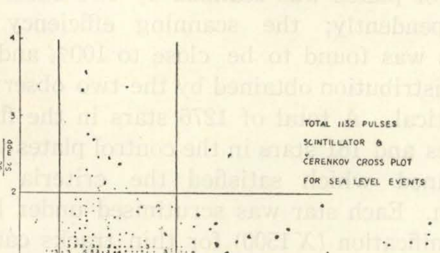

Fig. 2.

plot of the pulse in the scintillator versus the pulse in the Cerenkov counter, expressed in terms of mpp, for each μ-meson. The numerical figures shown on this diagram show the actual numbers of events located at the corresponding points. It may be that out of 1132 events (selected as being due to the passage of singly charged relativistic particles) only 3, (*i.e.* less of 0.3% of the cases), lie in a region corresponding to pulses ≥ 3 mpp in each of the detectors, a region where helium nuclei are expected to give points on such a cross-plot.

The data obtained on the three flights was combined appropriately and analysed to obtain the intensity of the singly charged and doubly charged components as a function of depth in the atmosphere.

Fig. 3 shows, in the case of typical data obtained at ceiling altitude on one of the flights, the pulse height distribution in the Cerenkov counter for all events in which the

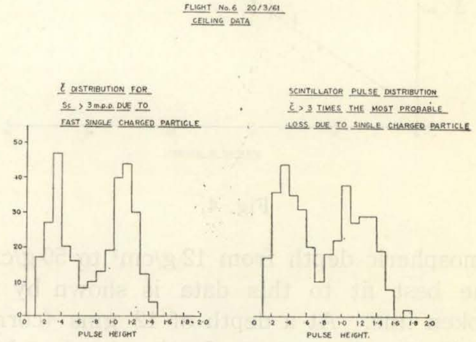

Fig. 3.

pulse height in the scintillator had a value ≥ 3 mpp; also shown in the same figure is the corresponding plot of pulse height distribution in the scintillator for all events in which the pulse height in the Cerenkov detector was ≥ 3 mpp. The distribution in each case shows two maxima—the first maximum occurring at the "mpp" for fast singly charged particles and the other at four times this value; the first maximum corresponds to protons, which have a small probability of giving a pulse ≥ 3 mpp in one detector but then give a pulse $\sim$ mpp in the other detector; the second maximum is due to helium nuclei. We have already seen that the probability is extremely small, $\leq 0.3\%$, that a singly charged particle which gives a pulse ≥ 3 mpp in one detector will contribute to the second maximum, (which is ≥ 3 mpp, and around 4 mpp), in the other detector. One can therefore resolve adequately from the cross-plot (of scintillator pulse vs Cerenkov pulse) the singly and doubly charged components.

In the case flight data, all events in which the pulse heights in the scintillator as well as in the Cerenkov counter were between 0 and 3 mpp were taken to be to the passage of singly charged particles, and when the pulse heights were between 3 and 6 mpp in each detector as due to the passage of doubly charged particles.

In Fig. 4, is shown the intensity of the singly charged component as a function of

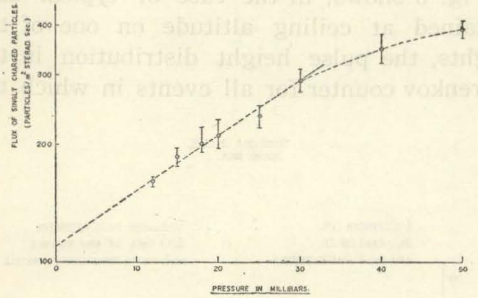

Fig. 4.

atmospheric depth from 12 g/cm² to 50 g/cm². The best fit to this data is shown by the broken line. At a depth of 12 gms (corresponding to the average floating level, taking into account the angular aperture of the telescope) the intensity was 160 ± 3 particles/m²/sterad/sec. The flux at the top of the atmosphere obtained by extrapolation is 110 ± 3 particles/m²/sterad/sec. This represents the true primary proton flux along with any return albedoflux. It may be emphasised that the splash albedo has been eliminated but the contribution due to returning albedo still exists.

In the case of helium nuclei the observed intensity at 12 g/cm² was 16.1 ± 0.9 particles/m²/sterad/sec. The flux at the top of the atmosphere obtained by extrapolation is 19.1 ± 1.2 particles/m²/sterad/sec: for this extrapolation we have used the fragmentation parameters of Rajopadhye and Waddington[2].

B. *Measurements with Nuclear Research Emulsions*:

Nuclear research emulsions have been used to determine the primary proton flux in the manner described by Waddington[3].

The method essentially consists in observing nuclear interactions produced by singly charged particles and estimating the flux $J(X)$ of singly charged, strongly interacting particles, (at a depth X gm/cm²), from the relation:

$$J(X) = \frac{\lambda dN}{V \Omega t} \text{ particles/m}^2\text{/sterad/sec.},$$

where λ = interaction mean free path of these particles in emulsion, dN=total number of stars (with $N_h \geq 0$) observed in a volume V in cubic metres, Ω=solid angle of acceptance of the primary protons and t=time of exposure in seconds. Complications due to the presence of pions and other strongly interacting particles amongst the singly charged primaries can be reduced by working with thin stacks exposed at very high altitudes. A pair of Ilford G 5, 600 μ thick emulsions, each of size 6″×6″, was flown from Hyderabad (geomagnetic latitude 9°N, longitude 78.5°E) on 12th March, 1960, at a level altitude of 106,000 ft. (7 gm/cm²) for 6 hours.

The plates were scanned for stars which satisfied the following criteria:

(i) The star should have at least three heavy prongs ($N_h \geq 3$);

(ii) At least one of the prongs should have a range$\geq 60\ \mu$ (to eliminate background arising from radioactive contamination);

(iii) The star should lie within the central 80% of the emulsion thickness.

An area of 202.5 cm² of the flight plates and an area of 48.7 cm² of the control plates kept at ground level were scanned in this manner. Approximately half the area in both sets of plates was scanned by two observers independently; the scanning efficiency for stars was found to be close to 100% and the N_h distribution obtained by the two observers identical. A total of 1276 stars in the flight plates and 161 stars in the control plates were obtained which satisfied the criteria laid down. Each star was scrutinised under high magnification (X1500) for thin tracks caused by minimum ionizing particles. The primary of each star was determined and the angle of the primary with respect to the vertical direction measured. 50% of the stars were looked at independently by two observers and the efficiency was found to be 100%. The zenith angle distribution of the primaries strongly was found to be 100%. The zenith angle distribution of the primaries strongly indicated that the efficiency for detection of the primaries was indenpendent of the zenith angle. The number of stars with $N_h \geq 3$ and with charged primaries within a zenith angle of 60° from the vertical was found to be 174 ± 13 in the flight plates and 26 ± 5 in the control plates. Thus the numbers of stars, (with $N_h \geq 3$), with charged primaries at zenith angles $\leq 60°$, during flight, was determined to be 148 ± 14.

To obtain the number of stars with $N_h \geq 0$, it is necessary to know the ratio $N_h \geq 0/N_h \geq 3$ at cosmic ray energies. Observations show that this ratio exhibits little variation in the energy region from ~3 BeV to 25 BeV where experiments have been carried out using artificially accelerated particles. This ratio in the case of stars produced by 6.2 BeV protons was found to be 1.50 ± 0.11 by Daniel *et al.*[4]. Using this value, the total number of stars with $N_h \geq 0$ during flight was deduced to be 222 ± 27. It may be remarked that the N_h distribution obtained in the flight plates (for $N_h \geq 3$) is in good agreement with that obtained by careful along-the-track scanning by Daniel *et al.* in their work on the 6.2 BeV proton induced interactions.

The flux, $J(X)$, at $X=7$ gms/cm^2, then turns out to be 125 ± 15 particles/m^2/sterad/sec; $\lambda = 37.1 \pm 1.0$ cms, as given by Bogachev *et al.*[5], for the interaction mean free path of 9 BeV protons has been used for the computation of $J(X)$. The flux $J(X)$ obtained above has to be extrapolated to the top of the atmosphere, in order to obtain the primary proton flux. The growth curve of protons as a function of atmospheric depth has been calculated by Waddington[3]. Using the growth curve computed by Waddington the flux of primary protons is found to be 86 ± 11 particles/m^2/sterad/sec. Using the experimental growth curve of singly charged particles as obtained by us with the Cerenkov scintillator technique the primary proton flux is found to be 87 ± 12 particles/m^2/sterad/sec. The errors shown here include uncertainties in our knowledge of the interaction mean free path λ. It may be remarked that background problems are greatly reduced in the case of flights conducted at low geomagnetic latitude particularly with freshly poured emulsions (using liquid G 5 gel supplied by Ilford Ltd.).

Discussion and Conclusions:

The intensities of protons and helium nuclei at the top of the atmosphere over Hyderabad (geomagnetic latitude 9°N) deduced from our experiments are as follows:

Particle	Technique	Extrapolation based on	Flux part./m^2/sterad/sec
Protons	Cerenkov-scintillator telescope	experimental growth curve	110 ± 3
Protons	Nuclear Emulsion	experimental growth curve	87 ± 12
Protons	Nuclear Emulsions	Waddington's computed growth curve	86 ± 11
Helium Nuclei	Cerenkov scintillator telescope	Fragmentation parameters of Rajopadhye and Waddington	19.7 ± 1.2

The days on which our flights were carried out were normal (undisturbed) days in that neutron counting rates for those days of sea level neutron monitors showed no appreciable departure from their average values for the period.

The flux of primary helium nuclei obtained by us (at 9°N g.m) is in excellent agreement with that obtained by McDonald (at 3°N g.m) with an identical technique. The flux of primary protons obtained by us (at 9°N g.m) with the Cerenkov-scintillator technique is in excellent agreement with the value obtained by McDonald (at 3°N g.m) with an identical technique. Our experiment provides new data of great statistical weight, which confirms the generally accepted value for the flux of primary protons near the geomagnetic equator given by McDonald. This value (of McDonald and of ours) for the primary proton flux is down by a factor of two compared to various other earlier determinations. The lower value is quantitatively correct for understanding the cosmic ray energy balance in the atmosphere. Both in our experiment and in McDonald's the value quoted for primary proton flux includes the re-entrant albedo to the extent present.

There appear to be a definite difference between the primary proton flux determined by the Cerenkov-scintillator technique and by the nuclear emulsion technique. This difference appears to us to be real and needs to be further investigated. One possibility is that the difference is due to re-entrant albedo. Two points appear to be relevant in this connection: (a) the primary proton flux of 110 particles (in the usual units) obtained by the Cerenkov-scintillator technique includes the contribution due to re-entrant albedo; with maximum correction for re-entrant albedo, the flux become 85 particles which is in the right direction and right magnitude for agreement with the emulsion data; (b) whereas Cerenkov-scintillator telescopes will count μ-mesons and electrons, the nuclear emulsion method of looking for stars will exclude these and these particles are expected to contribute significantly to the re-entrant albedo.

References

1) McDonald: Phys. Rev., **109** (1958) 1367.
2) Rajopadhye and Waddington: Phil. Mag., **3** (1958) 25.
3) Waddington: Phil. Mag., **5** (1960) 1105.
4) Daniel, Kameswara Rao, Malhotra and Tsuzuki: Nuovo Cimento **16** (1960) 1.
5) Bogachev, Bunyatov, Merekov, Sidorov and Yarba: Proc. IX Inter. Conf. on High Energy Physics (Kiev) 1959—as reported by Veksler.

Discussion

Kaplon, M. F.: How is the correction made for background, particularly during ascent in the emulsion determinations?

Menon, M.G.K.: (a) The results presented here from the emulsion experiments do not take account of ascent corrections.

(b) It may be pointed out that in our flights, with dark balloons, the ascent to 10 g/cm^2 takes about 80 minutes in contrast to the normal 2 hours or more.

(c) Corrections will be made soon using data from emulsions which are being scanned—then controls include an identical emulsion dropped by parachute at the time the balloon levels at ceiling.

Neher, H.V.: In the future, measurements on primary flux of protons and α-particles near the equator, should be made to find the variations during the 11-year cycle. (to III-1-3 and III-1-6)