MEASUREMENTS OF LOW-ENERGY PROTONS AND ALPHA PARTICLES IN THE COSMIC RADIATION

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A detailed study and comparison of the differential spectra of low-energy protons and alpha particles near the earth provides a most powerful method for studying the details of motion of charged particles in the interplanetary medium – with regard to both the modulation of galactic cosmic rays and the propagation and possible retention of solar cosmic rays. In addition, these spectra are directly related to the features of the propagation of these particles in interstellar space and to the escape of the particles from a source region. In recent years, widely divergent results have been reported for the low-energy proton spectrum, and no measurements are available for protons and alpha particles in overlapping rigidity intervals. The differences in the proton spectrum observed at rigidities ~0.5 BV during the period 1959-1961 range from a differential spectrum rapidly increasing towards lower rigidities[1] to one that is nearly flat[2,3] and even rapidly decreasing towards lower rigidities.[4] Although important changes are occurring in the spectrum of these low-energy protons during the solar activity cycle, we do not believe the differences noted above are entirely or even mainly due to time variations of either primary or solar cosmic rays.

The suggestion by Meyer and Vogt[1] that the differential spectrum increasing towards lower rigidities measured by them is due to the retention of solar cosmic rays near the earth also must be re-examined in view of the features of the decay of these particles in space after the event of 1 April 1960 reported by Arnoldy, Winckler, and Hoffman[5] and also the decay of particles from the July 1961 events as measured by ion chambers.[6]

We would like to report some measurements made in 1963 at a number of latitudes with a new detector which is capable of obtaining the spectrum of protons in the range 0.5-2.0 BV (100-1200 MeV) and alphas in the range 0.8-4.0 BV (100-1200 MeV/nucleon) at the top of the atmosphere. This detector is a telescope consisting of a scintillation counter (1.2 g/cm^2 thick) and a combination Cherenkov-scintillation counter (2.4 g/cm^2 thick). The solid-angle area of 30 sr-cm^2 gives a counting rate sufficient to examine the spectra of both protons and alpha particles in detail as the balloon is rising to altitude.

Details of the response of this detector to various particles and the detailed analysis of the data will be presented elsewhere. It is important to note, however, that the ability to obtain the spectrum of protons as a function of altitude as well as the measurements at three closely separated latitudes greatly aids in the separation of the true primary protons from the formidable background of secondary, re-entrant, and splash albedo protons. This is shown clearly in Fig. 1 in which the differential intensity of protons measured at 7.5 g/cm^2 atmospheric depth is shown for all three locations. The curve labeled $J_{RA}+J_{SA}+J_S$ gives the estimated intensity of secondary protons and splash and re-entrant–albedo protons at 7.5 g/cm^2 at Minneapolis. The curve labeled $J_{RA}+J_{SA}$ gives the intensity of splash and re-entrant–albedo protons at Minneapolis as determined from the extrapolation of the ascent data to the top of the atmosphere.

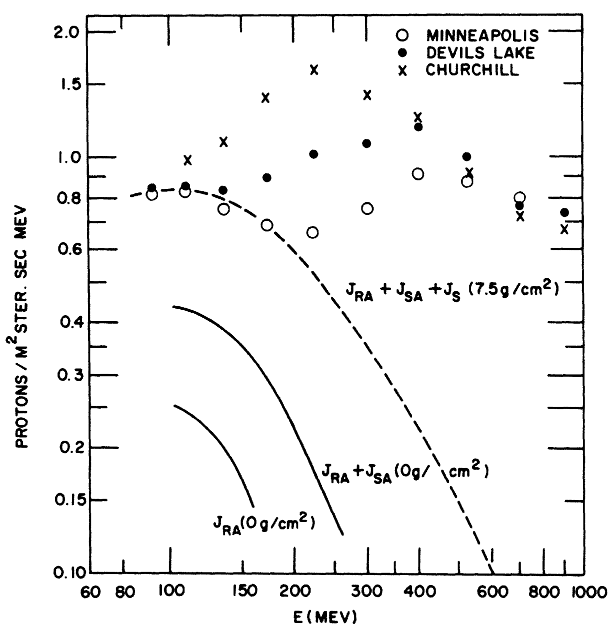

FIG. 1. Proton intensities at a depth 7.5 g/cm^2 at three locations. Intensities of secondary protons and splash and re-entrant albedo are also shown as a function of the particle kinetic energy in MeV.

Table I. Summary of proton and alpha intensities obtained on balloon flights.

Flight	Date	Neutron monitor	Protons >0.5 BV	Protons 0.5-1.0 BV	Protons 1.0-1.5 BV	Protons 1.5-2.0 BV	Protons >2.0 BV	Alphas >0.8 BV	Alphas 1.0-1.5 BV	Alphas >1.5 BV	Alphas 1.5-2.0 BV	Alphas 2.0-3.0 BV	Alphas 3.0-4.0 BV	Alphas >4.0 >
			Intensities (particles/m^2-sr-sec)											
Minneapolis	7 April 1963	2044	1874	86	303	(270)	1215	265.3	41.4	222.8	47.1	53.5	27.8	95.8
Ft. Churchill	8 January 1963	2007	2041	345	282	251	1161	277.9	50.8	218.6	41.6	55.3	28.0	91.5
Devils Lake	11 November 1963	2044	1986	190	316	300	1180	270.8	46.3	221.8	44.0	55.7	28.2	95.0

And finally, the curve J_{RA} gives the intensity of re-entrant albedo that we deduce. This is a factor of 5-10 less than would have been expected at this energy and latitude according to the calculations of Ray.[7]

The excess particles represent the true primary protons, and one can observe the cutoff effects at Devils Lake (~2° north of Minneapolis) and Minneapolis. The Churchill data, from which one can deduce the primary spectrum in the absence of cutoff effects, show clearly that at energies less than 150 MeV, the intensity of primaries is less than 50% of the intensity of all secondary components at 7.5 g/cm^2 and that for the highest altitudes obtainable by balloons (~2 g/cm^2), the secondary components dominate at energies <80 MeV. Improper account of these secondary components can lead to an incorrect primary-proton spectrum at these lower energies.

The data from the three flights for primary protons and alpha particles are summaried in Table I.

The individual primary proton and alpha-particle spectra are shown for the three locations in Figs. 2 and 3. Only the accuracy of the very lowest energy points is limited by statistical errors; the other points are limited by various systematic analysis errors and are believed correct to ±5%.

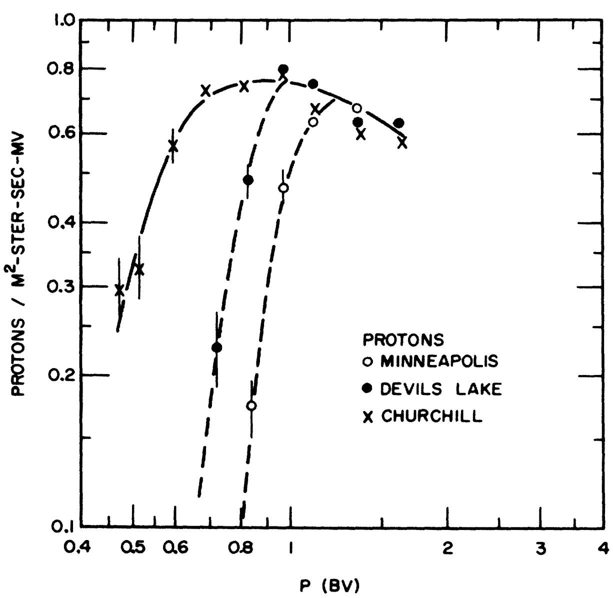

FIG. 2. Differential intensities of primary protons observed at three locations. P is the particle rigidity defined as momentum/unit charge and expressed in units of BV.

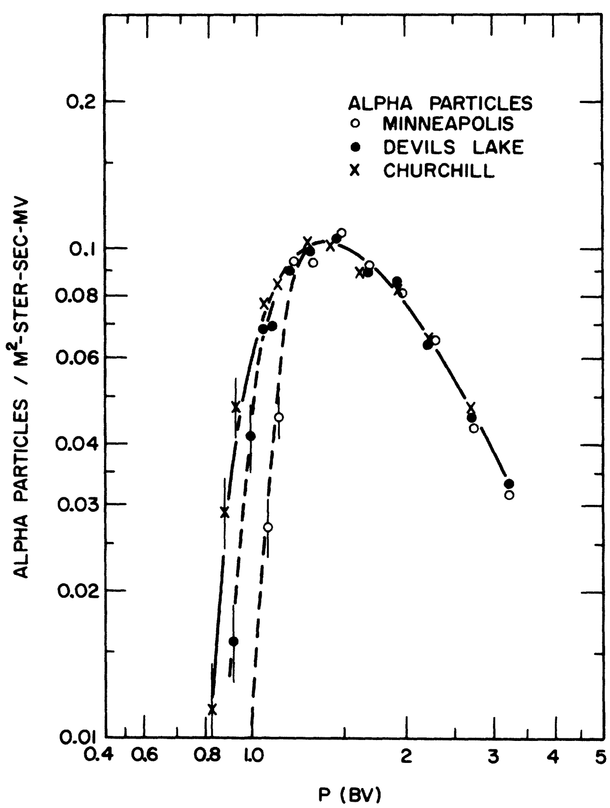

FIG. 3. Differential intensities of primary alpha particles observed at three locations. P is the particle rigidity defined as momentum/unit charge and expressed in units of BV.

The true primary spectra for protons and alpha particles are represented by the Churchill data, and if the alpha-particle data are multiplied by a factor of 6.7 to adequately normalize them to the protons in the rigidity range from 1.5-20 BV, a distinct splitting of the two spectra is noted at low rigidities (Fig. 4). Both spectra are falling sharply at the lowest rigidities we can measure, however.

Our results are in good agreement with those obtained by emulsion techniques used on a companion flight and reported in an accompanying Letter.[8]

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[7]E. C. Ray, J. Geophys. Res. 67, 3289 (1962).
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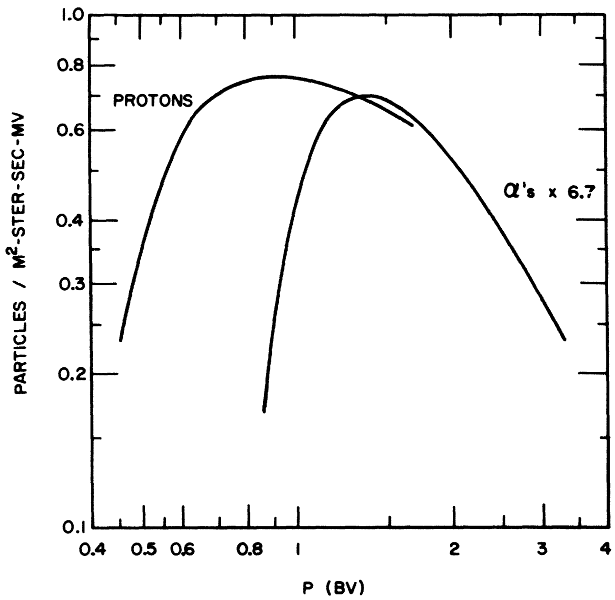

FIG. 4. Comparison of low-energy proton and alpha-particle spectra on a rigidity basis (Churchill data). Differential alpha-particle intensities multiplied by 6.7 to normalize with high-energy proton data in range 2-20 BV. *P* is the particle rigidity defined as momentum/unit charge and expressed in units of BV.

HYDROGEN AND HELIUM NUCLEI IN THE COSMIC RADIATION

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In the past few years, the low-energy proton component of the primary cosmic radiation has been measured in a number of separate experiments.[1-3] The results of these experiments have not been in complete agreement, and although some of the discrepancies have almost certainly been due to temporal variations, it seems highly likely that experimental effects have also been present. Among the most interesting questions that can be sutdied in these experiments is whether the constant value of approximately 7.0 for the ratio of protons to α particles at a given rigidity, known to hold at rigidities above 2.0 BV, still holds at lower rigidities. The observation of a variation in this ratio has important consequences in any theory of the modulation or propagation of cosmic-ray particles in the solar system.[3]

For these reasons a new investigation has been made of the low-energy protons and α particles in the primary radiation, using a nuclear emulsion detector with limited temporal resolution. In this detector a stack of nuclear emulsions was mounted in a device which rearranged the orientation of the emulsions at a preset time. This device will be described elsewhere.[4] This detector was flown on a high-altitude research balloon launched from Fort Churchill on 28 July 1963 at a time when the Deep River neutron monitor bihourly counting rate was 2008. The moving device was activated when ~3 g/cm^2 of residual atmosphere lay above the balloon, which then floated under a mean amount of matter of ~2 g/cm^2 for 11 hours. As a result of the use of the emulsion mover,[4] no correction had to be made for particles entering during the balloon ascent, while due to the great altitude of the flight, ~149 000 feet, the correction for particles produced in the overlying atmosphere was reduced to a minimum. Unlike other detectors, nuclear