ISOTOPIC COMPOSITION OF LOW-ENERGY HELIUM NUCLEI IN THE PRIMARY COSMIC RADIATION AT SOLAR MINIMUM*

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Since the discovery of a rather large abundance of He^3 nuclei in the primary cosmic radiation by Appa Rao,[1] a number of groups have been pursuing the problem of determining the ratio of He^3 nuclei to total helium nuclei (Appa Rao et al.,[2] Aizu,[3] Foster and Mulvey,[4] Dahanayake, Kaplon, and Lovakare,[5] and Hildebrand et al.[6]). The detectors used in these experiments were nuclear emulsions, and the reported results were in a higher energy interval than that in this experiment. In the measurement reported here, a dE/dx-E scintillation counter device was employed on a 26-hour balloon flight between 3.5 and 4.5 g/cm^2 atmospheric depth from Barrow, Alaska (69.5°N geomagnetic latitude) on 12 May 1965 as a part of the IQSY polar circling balloon (POCIBO) project. On this date, the Deep River neutron monitor and the OGO-A ionization chamber in free space (Kane, Winckler, and Arnoldy[7]) indicated the highest counting rate during the current solar cycle. Thus the flight was made at absolute solar minimum in terms of particle influx. The inherent mass resolution of the detector and the increased amoung of data gathered, compared with previous balloon measurements, permit the energy spectra from about 80 to 150 MeV/nucleon of the two resolved isotopes He^3 and He^4 to be evaluated separately and thus to examine for the first time the dependence of the ratio $He^3/(He^3+He^4)$ on energy and rigidity.

Figure 1 is a cross section of the detector used in this experiment. The principal elements are the thin dE/dx crystal, the thick E crystal, and the guard crystal surrounding the E crystal. The purpose of the guard or anticoincidence crystal is to eliminate upward-moving particles and particles which do not come to rest in the E crystal. A coincident event in dE/dx and E but not in the guard scintillator is then analyzed by two 64-channel analyzers with two gain modes to cover the range of both hydrogen nuclei and helium nuclei.

Figure 2 is a two-dimensional pulse-height distribution from the dE/dx-E scintillation counters showing all events in the low-gain helium mode during the flight. The smooth curves are the theoretical positions of the He^3 and He^4 lines. Background due to nuclear interactions in the crystals is a serious problem only below 25-MeV/nucleon kinetic energy, and these data have been excluded from the analysis. Data in the region >25 MeV/nucleon are shown as a mass histogram in Fig. 3. Also shown are Gaussian distributions with 10% half-widths, the estimated resolution of the dE/dx scintillator for particles of this energy. In Fig. 4, the differential energy/nucleon and rigidity spectrums of the He^3 and He^4 components taken separately and grouped together and treated as He^4 are given. The latter is the spectrum one would obtain if the two components could not be resolved. The data has been extrapolated to 0 g/cm^2 using appropri-

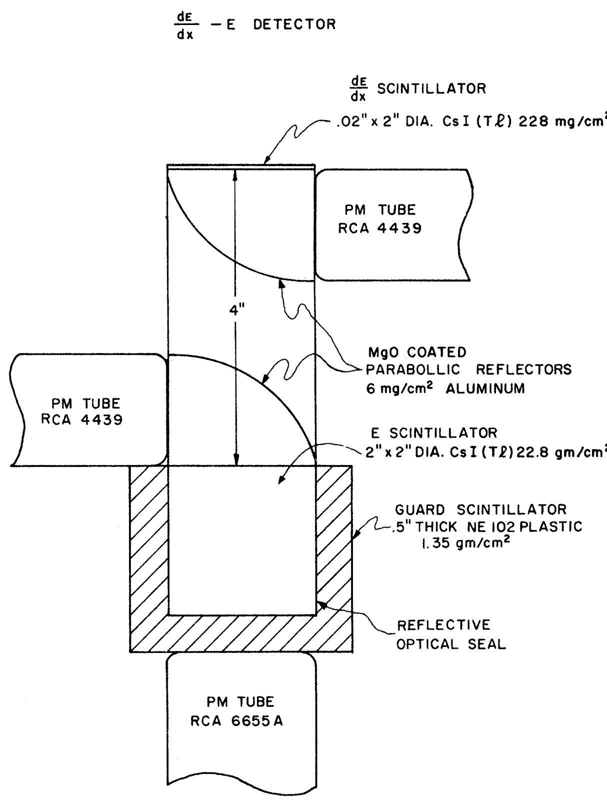

FIG. 1. A cross section of the dE/dx-E detector showing the essential components.

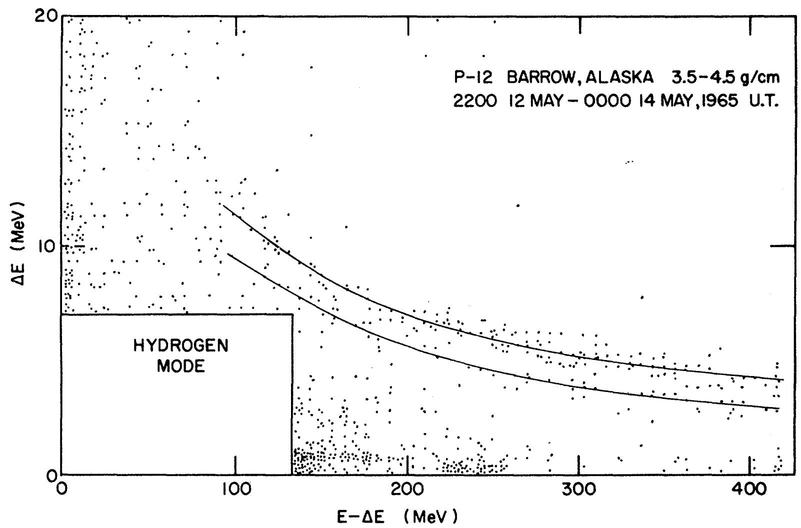

FIG. 2. Pulse height distribution of the energy lost in the dE/dx crystal (ΔE) plotted versus the energy lost in the E crystal ($E-\Delta E$) in the low-gain helium mode. Smooth curves are the theoretical He^3 and He^4 lines. Scattering of points below 100 MeV is due to nuclear interaction background.

ate range-energy data for the two species, and includes small flux corrections for secondaries produced in the atmosphere above the detector and particles removed by nuclear interaction. The errors indicated in the figure are purely statistical. The ratio $He^3/(He^3+He^4)$ in terms of energy/nucleon was found to be constant over the range 80-150 MeV/nucleon with a value of 0.19 with a statistical deviation

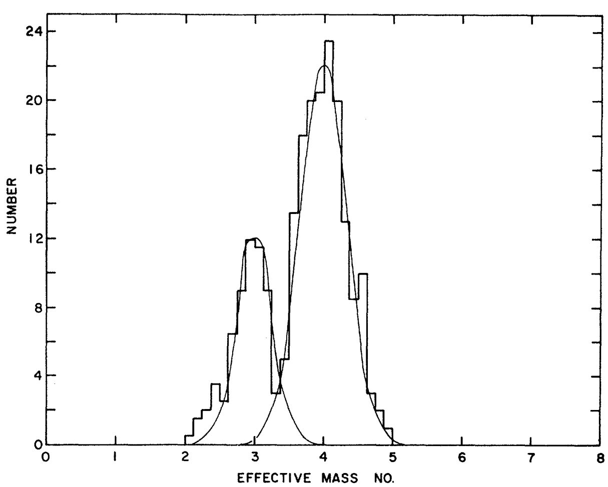

FIG. 3. Mass histogram taken perpendicular to the helium lines between 1.5 and 5.5 mass units and $E > 25$ MeV/nucleon. Gaussian distributions superimposed were calculated for 10% half-widths as estimated for the resolution of the dE/dx scintillator.

of ± 0.035 if all particles in the interval are grouped together. The rigidity spectra of the two components may be compared at 0.8 BV and give a ratio of 0.39 ± 0.09.

The ratio $He^3/(He^3+He^4)$ measured at the earth is dependent on the cosmic-ray source spectrum, interstellar fragmentation of He^4 and heavier nuclei, propagational effects such as energy loss by ionization in interstellar hydrogen and acceleration of deceleration in interstellar magnetic fields, and local modulation by solar influences. The scarcity of He^3 in most stellar atmospheres implies that the major source of He^3 is spallation of He^4 and heavier nuclei in passing through interstellar hydrogen. From the measured flux of He^3, one can estimate the amount of matter encountered by cosmic rays in interstellar space or in sources themselves if one knows the probabilities of heavier particles producing He^3 nuclei. These fragmentation parameters are, however, not well known and may in fact vary with energy. In addition, the effects of solar modulation must be taken into account since the two nuclei have different charge-to-mass ratios and may be modulated differently. Since this measurement was made at solar minimum, the observed spectrum is as close to the true interstellar spectrum as one can possibly observe near earth. The form of the solar modulation is presently under study, and prelimi-

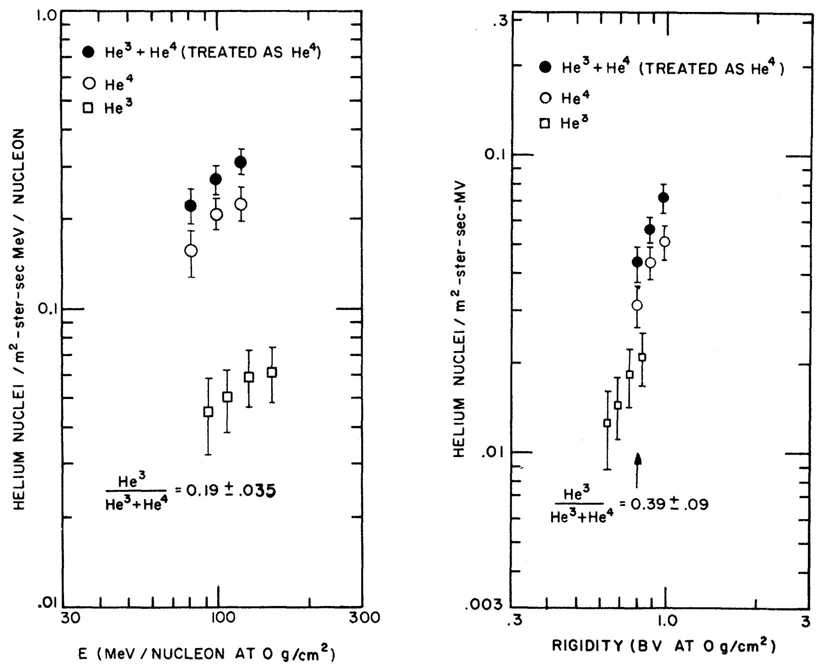

FIG. 4. Differential energy/nucleon and rigidity spectra extrapolated to the top of the atmosphere for He^3, He^4, and the two taken together and treated as He^4.

nary results indicate that the value 0.19 for the ratio in terms of energy/nucleon is very nearly the interstellar ratio in this energy interval, i.e., the correction to the ratio appears to be small. Emulsion measurements at higher energies (O'Dell et al.[8]) indicate a lower ratio while recent satellite results (McDonald[9]) at lower energies also indicate a slightly lower value for the ratio. The statistics of the experiments are at present not adequate to determine a precise energy dependency in the ratio which would indicate an energy dependency in the path length or in the fragmentation parameters. Thus, until the statistics of the measurements over a wide range of energies can be improved, the question of the amount of matter encountered by cosmic rays cannot be precisely determined. The advent of counter type devices for making these measurements should provide the necessary statistics in the near future.

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