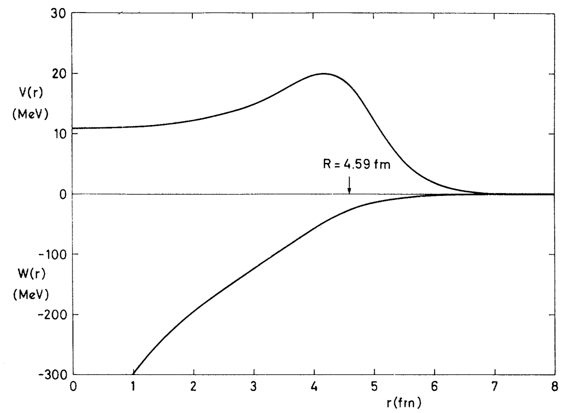


FIG. 3. Real and imaginary parts of the optical potential for $^{63.6}$Cu at 19.3 BeV/$c$, calculated in high-energy approximation with the parameters of Table I.

decreases steadily with increasing proton energy and appears to change sign around 0.6 BeV. Our result is strongly supported by the evidence,[12] from the recent small-angle scattering experiments, for considerable repulsive real parts of the $p$-$p$ and $\pi^{\pm}$-$p$ scattering amplitudes between 10 and 26 BeV.

We wish to thank Dr. A. M. Wetherell and his colleagues at CERN for sending us copies of their data and for valuable information about their experiments.

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# ISOTOPIC ABUNDANCES AND ENERGY SPECTRA OF He$^3$ AND He$^4$ ABOVE 40 MeV PER NUCLEON FROM THE GALAXY*

C. Y. Fan, G. Gloeckler, K. C. Hsieh,† and J. A. Simpson†

Enrico Fermi Institute for Nuclear Studies, University of Chicago, Chicago, Illinois
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The abundances of He$^3$ and He$^4$ in the galactic cosmic rays as a function of energy are important for understanding the origin of cosmic rays. Since He$^3$ is a rare isotope in nature, the appearance of He$^3$ in the cosmic rays provides information on the propagation of He$^4$ both in cosmic-ray sources and in interstellar space. Since the first detection of He$^3$ by Appa Rao,[1] many balloon measurements above 150 MeV/nucleon have been made.[2,3] Hofmann and Winckler[4] have extended the measurements at balloon altitude down to ~80 MeV/nucleon and found a higher value for the ratio He$^3$/(He$^3$ + He$^4$) ($\equiv\Gamma$) than reported by Biswas, Lavakare, and Sreenivasan[2] and O'Dell et al.[3] at higher energies. The energy dependence of this ratio remained, however, uncertain because of large statistical uncertainties in the individual measurements. We report here measurements of the primary energy spectra of He$^3$ in the energy range ~40 to 110 MeV/nucleon, and of He$^4$ in the energy interval of 13 to 90 MeV/nucleon.

A $dE/dx$-vs-$E$ cosmic-ray telescope was carried in the IMP-III satellite which was launched into a highly eccentric orbit of apogee 260 000

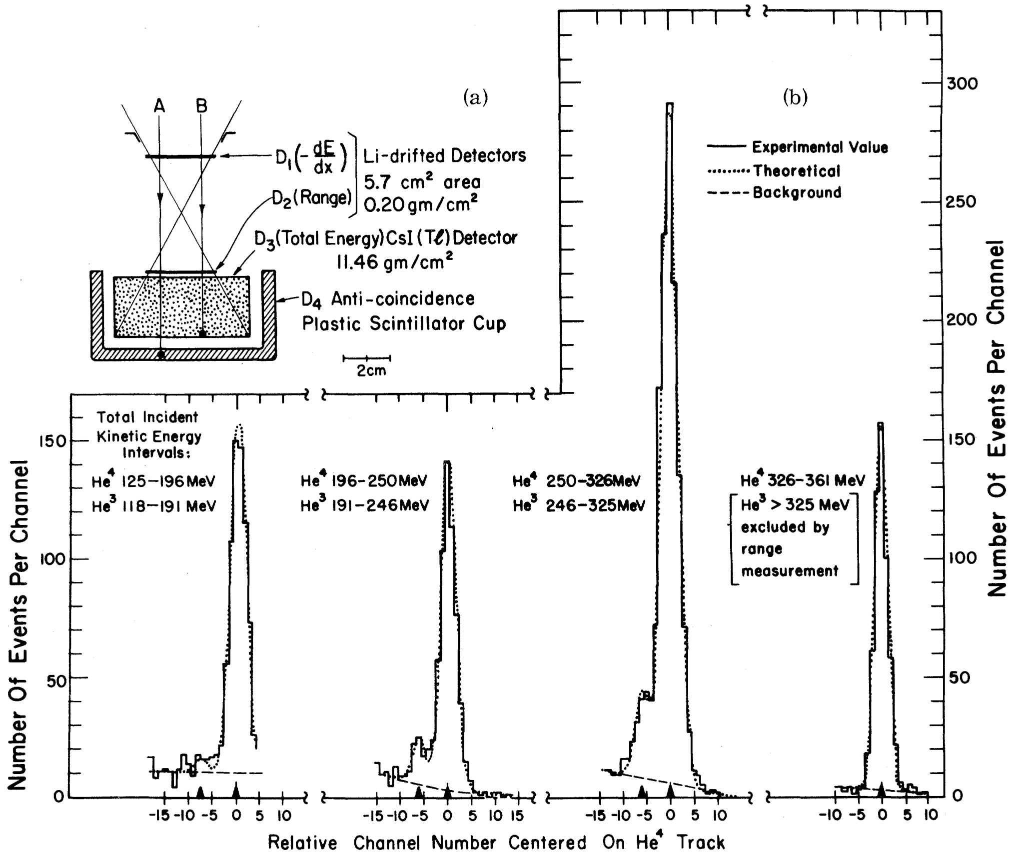


FIG. 1. (a) Cross section of the detector elements. (b) Mass distributions for $He^3$ and $He^4$ for different total kinetic energy intervals. Arrow heads indicate theoretical positions of the $He^3$ (left) and $He^4$ (right) peak for each histogram.

km on 29 May 1965. Continuous data were obtained in the four-month time period 29 May to 20 September 1965, and only data collected inside the magnetosphere (about 10%) were excluded from analysis. The cross section of the detector system is shown in Fig. 1(a). The telescope is similar to the IMP-I instrument which has already been described in detail.[5] The important modification was the replacement of the $D_1$ and $D_2$ surface barrier detectors by Li-drifted detectors each 5.7 cm$^2$ in area and 900 $\mu$ thick, to provide the increased resolution necessary to separate the two isotopes. Particle identification is made by measuring simultaneously the energy loss $(-dE/dx)$ in $D_1$ and the total residual energy $(E)$ in $D_3$ of those particles which are stopped in the thick CsI(Tl) detector $D_3$. $D_1$ pulse-height analysis is also made for coincidence events $D_1$ and $D_2$ but not triggering $D_3$ in order to determine the helium spectrum down to 13 MeV/nucleon. The anticoincidence cup, $D_4$, eliminates much of the background and prevents analysis of backward-moving particles.

Mass distributions covering four total kinetic energy intervals are shown in Fig. 1(b). These histograms are made by summing along the well-defined $He^4$ track in the two-dimensional $dE/dx$-vs-$E$ pulse-height distributions.[5] The smooth curve for each mass distribution has been calculated and represents the best "least-squares" fit to each respective histogram.[6] Since $He^3$ nuclei having total kinetic energies greater than 325 MeV will trigger the anticoincidence cup $D_4$ [Fig. 1(a)], they are not analyzed and, therefore, in the $He^4$ energy interval 328-361 MeV no $He^3$ can be present. This is indeed confirmed by the data in Fig. 1(b). The differential energy spectra are shown in Fig. 2.

There are two reasons for believing that the observed $He^3$ is of galactic origin. First, $He^3$ is a rare isotope in nature, and for instance, $\Gamma$ appears to have an upper limit of less than

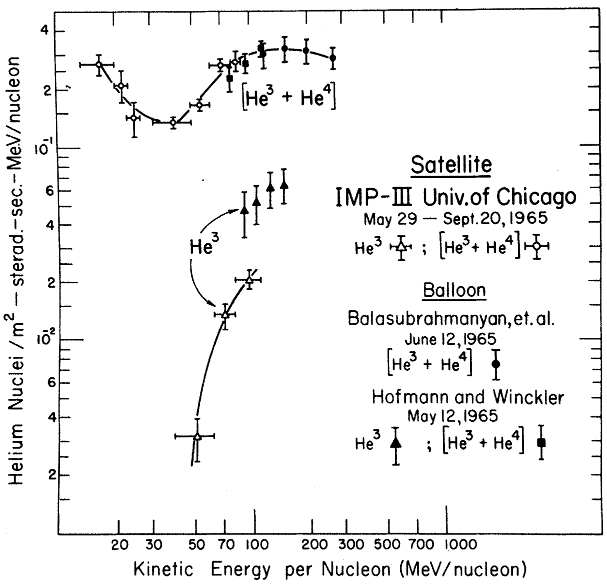


FIG. 2. The observed energy spectra of [$He^3 + He^4$] between 13 and 90 MeV per nucleon, and of $He^3$ between 40 and 110 MeV nucleon. The errors shown for the [$He^3 + He^4$] experimental data are due to both statistics and uncertainties in the energy calibration. The errors shown for the $He^3$ points are purely statistical since the uncertainties in energy calibration are relatively small.

1% on the sun.[7] Second, the $He^3$ spectrum falls off with decreasing energy in the same way as that portion of the $He^4$ spectrum which has been shown to be of galactic origin from studies over the past two years.[8,9]

The upward turn of the $He^4$ spectrum below ~30 MeV/nucleon has been reported recently by Gloeckler[10] and Fan, Gloeckler, and Simpson[11] from measurements during 1964 and 1965, and is believed to be due to the continual presence of nongalactic helium nuclei. Therefore, the composite [$He^3 + He^4$] spectrum may be separated into two components. The experimental data below 25 MeV/nucleon suggest the form $dJ/dE = 86E^{-2}$. We assume that this portion of the spectrum retains this form above 25 MeV/nucleon in order to obtain the galactic portion of the helium spectrum, from which the ratio $\Gamma_{E/n}$ ($\Gamma$ as a function of energy per nucleon) may be computed. The results are given in Fig. 3. Although we realize that some systematic errors may be present, this correction is small, and we cannot avoid the conclusion that $\Gamma_{E/n}$ is energy dependent below ~100 MeV/nucleon, increasing from $0.02 \pm 0.01$ at 50 MeV/nucleon to $0.07 \pm 0.013$ at 100 MeV/nucleon.

With the assumption that $He^3$ is produced by the spallation reaction ($He^4, p$) in interstellar space, three factors enter into the interpretation of the energy dependence of $\Gamma_{E/n}$.

(1) Energy loss by ionization of $He^3$ and $He^4$ nuclei in their passage through interstellar hydrogen: Assuming that $He^3$ has the same velocity as $He^4$ at the time of its production, and that from this time both species traverse equal amounts of interstellar matter, we note that $He^3$ will lose a larger fraction of its total kinetic energy than $He^4$. Since $\Gamma_{E/n}$ is computed from the respective differential fluxes, this ratio will decrease with decreasing energy due to the transformations of the energy intervals which are different for $He^3$ and $He^4$. We illustrate this effect by the following simple example: passage through 2 $g/cm^2$ of hydrogen for both $He^3$ and $He^4$ which are assumed to have energy spectra $\propto E^{-2.5}$ in the galaxy will decrease $\Gamma_{E/n}$ by a factor of 1.3 [i.e., the ratio $\rho \equiv \Gamma_{E/n}(70\text{-}105)/\Gamma_{E/n}(40\text{-}70) = 1.3$].

(2) Energy dependence of the spallation cross section for the production of $He^3$, principally by ($He^4, p$) reactions at $\lesssim 200$ MeV/nucleon: At present the energy dependence of these cross sections is poorly known. If we assume the dependence given by Badhwar and Daniel,[12] we find that $\rho = 0.87$ due to this effect.

(3) Solar modulation: (a) If solar modulation depends only on the velocity of the particle,[10] the energy dependence of $\Gamma_{E/n}$ will remain

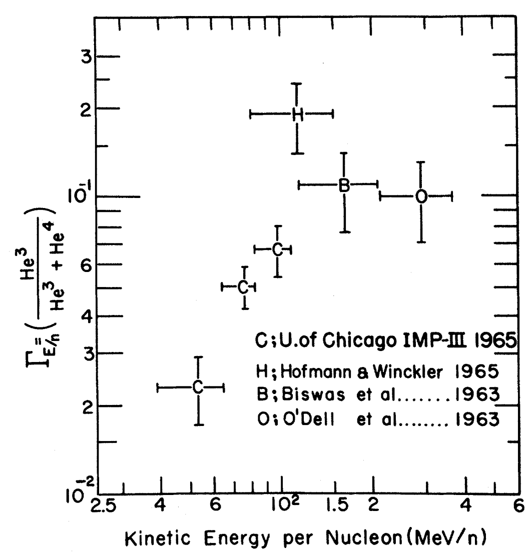


FIG. 3. $\Gamma_{E/n}$ is obtained after an estimated solar $He^4$ component was subtracted from the [$He^3 + He^4$] spectrum.

unaffected. (b) If solar modulation is to produce the energy dependence in $\Gamma_{E/n}$, it must depend on the charge-to-mass ratio $Z/A$ and the velocity of the particle. Solar modulation such as proposed by Webber[13] for energies above 100 MeV/nucleon will not substantially change the energy variation of $\Gamma_{E/n}$ as seen outside the solar system[14] (i.e., $\Gamma = 0.02$ becomes 0.034 and $\Gamma = 0.07$ becomes 0.10). (c) If, finally, the modulation depends on both the velocity and the magnetic rigidity of the particle, then solar modulation would produce a strong energy dependence in $\Gamma_{E/n}$.[15] In fact, with this modulation $\Gamma_{E/n}$ in the local galactic space would be constant, independent of energy, with a value of 0.15.

At present, it is not clear which is the correct form for the solar modulation. If either (a) or (b) is the case, then one must invoke factors 1 and 2 to explain the energy dependence of $\Gamma_{E/n}$. But if (c) is the case, then modulation alone will account for the observed energy dependence of $\Gamma_{E/n}$.

Although there is good agreement among three independent measurements[4,8] for the absolute flux of $[He^3 + He^4]$ above 80 MeV/nucleon, as shown in Fig. 2, there is a discrepancy of a factor 2 between our $He^3$ differential flux and that obtained by Hofmann and Winckler[4] in the energy interval 80-100 MeV/nucleon. We find that this discrepancy cannot be explained by the variation introduced by solar modulation in the time period between the two measurements.[16]

It would be possible to bring both sets of measurements into agreement if the $He^3$ spectrum were to rise sharply over the combined energy range of the two measurements. However, other measurements of the abundance of $He^3$ at somewhat higher energies must be taken into account.[2,3] The combined results displayed in Fig. 3 are consistent with a gradual rise in $\Gamma_{E/n}$ from a value of about 0.02 to 0.1 in the energy range of 40 to 400 MeV/nucleon.

A value for $\Gamma_{E/n}$ of 0.07 at 200 MeV/nucleon was predicted by Badhwar and Daniel[12] on the assumption that the amount of interstellar gas traversed by the cosmic rays was 2.5 g/cm$^2$ as derived from the measured abundance ratio of the light to medium nuclei in the cosmic radiation. If solar modulation is not important, then our measured value at 80-100 MeV/nucleon agrees with their predicted value. Consequently, low-energy $He^4$ need not have passed through more interstellar matter than ~3g/cm$^2$.

For the integration of our experiment into the IMP-III satellite and its launching, we are grateful to the Goddard Space Flight Center staff, especially Paul Butler and Frank McDonald. Within our Laboratory for Astrophysics and Space Research, we wish to thank Remi Jacquet for the engineering, S. Tado for the checkout of our instrument before launch, and A. Tuzzolino and J. Kristoff for the development of the new solid-state detectors.

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[6]We assumed a continuous background distribution and a Gaussian shape for each of the helium-isotope mass distributions. The width $\sigma_4$ and the mean $m_4$ of the $He^4$ peak were determined statistically from the data. For the $He^3$ distribution, we derived these parameters using theoretical calculations of the peak separation $(m_4 - m_3)$, as well as the $\sigma_4$ and $m_4$ determined for the $He^4$ peak.

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[13]W. R. Webber, in Proceedings of the Ninth International Conference on Cosmic Rays, London, 1965 (to be published).

[14]For this type of modulation, we assumed the follow-

ing dependence on charge to mass ratio, $Z/A$:

$$\frac{\mu_E}{\mu_\infty} = \exp\left[-\frac{Z}{A}\left(\frac{1}{\gamma^{n-1}\beta^n}\right)K(t)\right],$$

where $\mu_E$ and $\mu_\infty$ are the respective particle densities at earth and outside the solar system, and $\beta$ is the velocity of the particle in units of the velocity of light, $\gamma = (1-\beta^2)^{-1/2}$; $K(t)$ is a constant depending only on time $t$, and is taken to be unity; $n = 1$.

[15]Same form as in Ref. 14 except $n = 2$. Again we take $K(t) = 1$.

[16]This is concluded from the fact that there is no large time variation in this period for the $[He^3 + He^4]$ spectrum as is evident in Fig. 2. The greatest change in the proton flux observed on IMP-III within the time interval 20 May–20 September was less than 10% and, hence, represents the upper limit for the change of $He^3$ fluxes over this time period.

## COSMIC BLACK-BODY RADIATION AT $\lambda = 2.6$ mm*

George B. Field and John L. Hitchcock

Astronomy Department, University of California, Berkeley, California

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Penzias and Wilson[1] have shown that at $\lambda = 7.4$ cm there exists an approximately isotropic background radiation component whose equivalent black-body temperature is $3.5 \pm 1$°K; Roll and Wilkinson[2] have obtained $3.0 \pm 0.5$°K at $\lambda = 3.2$ cm. In this Letter we obtain values in the range 2.7 to 3.4°K at $\lambda = 2.6$ mm by measurements of the spectra of the two stars $\zeta$ Ophiuchi and $\zeta$ Persei, further supporting the suggestion by Dicke et al.[3] that the universe is filled with 3°K black-body radiation as a result of processes occurring early in cosmic history. We shall show that this postulate is the best way to explain the data.

It has been known for many years that absorption lines in the spectrum of $\zeta$ Oph due to CN molecules in interstellar space exhibit excitation of the $J = 1$ rotational state corresponding to a temperature, $T_E$, of over 2°K[4] as indicated by the ratio of the $R(1)$ and $R(0)$ lines of the transition $B\,^2\Sigma^+ - X\,^2\Sigma^+$ (0, 0), at $\lambda = 3874.00$ Å and $\lambda = 3874.61$ Å, respectively.[5] Pure rotational absorption at $\lambda = 2.6$ mm could account for the excitation, but it was shown,[6] also many years ago, that dilute starlight, which has a spectral energy distribution corresponding to about $10^4$ °K, is too weak at $\lambda = 2.6$ mm to give a population ratio $N_1/N_0$ much greater than $10^{-12}$, whereas 0.3 was observed. Interest in this problem has again arisen, after a lapse of 25 years, because of the radio measurements mentioned above.

Dr. G. H. Herbig kindly placed at our disposal six plates of $\zeta$ Oph (2 Å/mm) and one of $\zeta$ Per (1.3 Å/mm), which he obtained at the Coudé spectrograph of the Lick Observatory 120-inch telescope. Our measurements were supplemented by independent measurements of the $\zeta$ Oph data by Dr. Herbig. The equivalent widths found were $W_0 = 9.20 \pm 0.2$ mÅ and $W_1 = 3.37 \pm 0.2$ mÅ for $\zeta$ Oph, and $W_0 = 10.9 \pm 1.1$ mÅ and $W_1 = 3.5 \pm 0.7$ mÅ for $\zeta$ Per. For $\zeta$ Oph the quoted error is the scatter range of the measurements, while for $\zeta$ Per it is estimated from the grain noise on the microphotometer tracing. Since $N_1/N_0 = \lambda_0^2 f_0 W_1/\lambda_1^2 f_1 W_0$ and $f_1/f_0 = \frac{2}{3}$, $N_1/N_0 = 0.55 \pm 0.05$ in $\zeta$ Oph and $N_1/N_0 = 0.48 \pm 0.15$ in $\zeta$ Per. Since $g_1/g_0 = 3$ and $h\nu/k = 5.47$°K for the $J = 0 \rightarrow 1$ transition, $T_E = 3.22 \pm 0.15$°K in $\zeta$ Oph and $T_E = 3.0 \pm 0.6$°K in $\zeta$ Per. These data, derived on the assumption that the lines are unsaturated, are subject to uncertainty on that account. However, even if the lines are really as narrow as the narrowest line ever found in interstellar space—0.3 km/sec rms—$T_E$ would still be 2.7°K. We conclude that $T_E$ is between 2.7 and 3.4°K for both stars.

Only recently a theory of the origin of interstellar CN molecules has appeared[7]; the observed densities can be explained in spite of the short lifetime toward photodissociation if chemical exchange reactions are postulated to occur at the surfaces of interstellar grains. According to the theory, production occurs in H I (neutral hydrogen) regions. For purposes of calculation we shall assume that the CN is located in typical H I regions, where $N_H = 10$ cm$^{-3}$ and $T_K$ (kinetic) = 100°K. The radiation field due to stars at 3900 Å is equivalent to that of the sun at $10^4$ A.U.[8]

We have considered excitation due to collisions with H atoms, fluorescence, and pure rotation-