[1]J. A. Earl, Phys. Rev. Letters 6, 125 (1961).
[2]P. Meyer and R. Vogt, Phys. Rev. Letters 6, 193 (1961).
[3]P. Meyer and R. Vogt, J. Geophys. Research 66, 3950 (1961).
[4]J. A. Earl, Midwest Cosmic-Ray Conference, St. Louis, 1961 (unpublished).
[5]R. Vogt, Phys. Rev. 125, 366 (1962).
[6]H. Carmichael and T. F. Steljes, Atomic Energy of Canada, CRGP-1056 (unpublished), and Proceedings of the International Conference on Cosmic Rays and the Earth Storm, Kyoto, Japan, September, 1961 [Suppl. J. Phys. Soc. Japan (to be published)].
[7]J. A. Simpson (private communication).
[8]A. Baischat and J. F. Denisse, Compt. rend. 245, 2193 (1957).

SOLAR FLARE HELIUM IN SATELLITE MATERIALS

O. A. Schaeffer* and J. Zähringer
Max-Planck-Institut für Kernphysik, Heidelberg, Germany
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Pieces of Discoverer satellite material have been used to search for helium produced in the material or extraterrestrial helium particles which are stopped in the material. Positive results were found for Discoverer 17, which was flown during the intense solar flare of November 12, 1960. Both aluminum and lead were used. The aluminum was part of a flange with approximate dimensions 0.6 cm thick, 3 cm×3 cm, and a 0.1-cm thick aluminum sheet attached to the flange. The flange and aluminum sheet were under a 1-2 g/cm^2 heat shield. The lead was from a 0.6-cm sheet which was under the aluminum sheet and adjacent to the lead used for previous radioactive studies.[1,2]

The helium was extracted by melting a sample in a vacuum system attached to a sensitive mass spectrometer. After purification with Ca and Ti getters, the helium was measured in the mass spectrometer under static vacuum conditions. In addition to pieces from Discoverer 17, pieces of aluminum from Discoverer 25 and vacuum-melted lead flown in Discoverer 29 were also studied. The He^3 results are presented in Table I.

Small amounts of He^3 were found in all pieces of Discoverer 17 melted, but no He^3 was detected in material from the other satellites or in unflown aluminum. The amounts of He^3 found in the flange varies from piece to piece, as might be expected, because one side of the satellite was always toward the earth and thus shielded.

The He^4 results are uncertain because of the relatively large amount of atmospheric helium contained in the sample and that released during the melting of the sample. As a result, the He^3/He^4 ratio is variable; however, in no case was a ratio less than 0.02 observed. In the case of the flange II from Discoverer 17, a value of 0.2 is estimated for the ratio He^3/He^4. The atmospheric helium was subtracted from that found by assuming that the concentration of atmospheric helium was the same in all the aluminum. As the correction was large, about 80% of the He^4 is atmospheric; the ratio has a corresponding uncertainty.

The He^3 found in Discoverer 17 flange could not be produced by proton interactions with the aluminum. It has been estimated from balloon and satellite counter measurements[3] that Discoverer 17 received a total integrated flux of 10^9 particles/cm^2. In order to produce 10^8 atoms of He^3 per

Table I. Helium-3 in satellite material.

Satellite	Material	Weight (g)	He^3 (10^6 atoms/g)
Discoverer 17	aluminum flange I	60	100 ± 20
Discoverer 17	adjacent sheet I	32	60 ± 30
Discoverer 17	aluminum flange II	80	250 ± 20
Discoverer 17	adjacent sheet II	80	20 ± 20
Discoverer 17	lead	92	13 ± 10
Discoverer 25	aluminum sheet	20	≤20
unflown	aluminum	125	≤10
Discoverer 29	lead	60	≤20

gram of flange material, the He^3 proton production cross section would have to be at least 10 barns, while for high-energy protons it is of the order of 0.1 barn. It is concluded that the He^3 represents stopped particles from the solar flare burst.

The fact that so much smaller an amount of He^3 is found in the aluminum sheet II than in the aluminum flange II adjacent, even though the sheet has a larger cross-sectional area per gram, indicates that the He^3 particles have energy sufficient to penetrate the 1-2 g/cm heat shield which surrounds the capsule as well as the 0.1-cm aluminum sheet, but not sufficient energy to penetrate the flange. Range-energy curves show that for normal incidence, He^3 particles with less than 140 MeV will stop in the heat shield, He^3 particles with 140-160 MeV will stop in the aluminum sheet, and He^3 particles with 140-360 MeV will stop in the flange. On this basis the geomagnetic cutoff can be approximated to be roughly 200 MeV. The satellite was in a polar orbit which passed about 20° from the geomagnetic poles.

As the surface of the sun has a He^3/He^4 ratio[4] of less than 0.02, it is concluded that the Discoverer 17 helium with a He^3/He^4 ratio of about 0.2 was produced during the solar flare. It has been suggested[5] that He^3 can be produced during solar activity either by a chain reaction $H^1(n,\gamma)H^2(p,\gamma)He^3$ or by the high-energy reactions $He^4(p,d)He^3$ and $He^4(p,pn)He^3$. Fireman et al.[1] have suggested that the tritium they find in Discoverer 17 lead arises from the reaction $He^4(p,2p)H^3$ and estimate that 0.4% of the solar flare particles are tritons. Since H^3 has not been measured in the same samples, a direct comparison is not possible. The present results only indicate that He^3 might be more abundant and is about 10% of the solar flare particles. Because of the unknown location of the flange in the satellite and hence the difficulty of estimating the solid angle as well as the uncertainties in the total particle flux,[3] this value is probably only accurate to a factor of 3. The H^3 and He^3 produced by proton reactions is likely to be of comparable probability. By further investigations of this kind it should be possible to decide whether the He^3 arises from the chain mechanism or from high-energy proton reactions.

The He^3/He^4 ratio of about 0.2 for the helium in the flange of Discoverer 17 can be compared to the ratio of 0.7 observed[6] for low-energy cosmic rays (200-400 MeV/nucleon). In addition, the He^3 found trapped in the Discoverer 17 flange represents about 10% of the solar flare particle flux, while in low-energy cosmic rays[6] about 7% of the particle flux is He^3. These considerations suggest that low-energy cosmic-ray helium might originate from solar activity and support the hypothesis that low-energy cosmic rays originate from the sun.

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*On leave from Brookhaven National Laboratory, Upton, New York.

[1] E. L. Fireman, J. DeFelice, and D. Tilles, Phys. Rev. 123, 1935 (1961).

[2] R. W. Dodson, G. Friedlander, J. Hudis, and O. A. Schaeffer, Bull. Am. Phys. Soc. 6, 277 (1961).

[3] J. Van Allen, Bull. Am. Phys. Soc. 6, 276 (1961).

[4] J. L. Greenstein, Astrophys. J. 113, 531 (1951).

[5] W. A. Fowler, J. L. Greenstein, and F. Hoyle, Geophys. J. 6, 148 (1962).

[6] M. V. K. Appa Rao, Phys. Rev. 123, 295 (1961).