THE

PHYSICAL REVIEW

A journal of experimental and theoretical physics established by E. L. Nichols in 1893

SECOND SERIES, VOL. 105, NO. 3 FEBRUARY 1, 1957

Crucial Experiment Concerning the Origin of Meteorites*

S. F. SINGER
Physics Department, University of Maryland, College Park, Maryland
(Received August 6, 1956)

It is suggested that the He^3:He^4 ratio of iron meteorites be measured after the samples have been heated. It is anticipated that the ratio will be greater than in corresponding unheated samples. Results of such experiments are of importance in dating the breakup of the meteorite's parent planet as well as for estimating the value of the prehistoric cosmic-ray flux.

IN an earlier publication,[1] we have considered the effects of cosmic rays on meteorites, calculated the production of helium, and pointed to the production of a large fraction of He^3. Subsequent experiments[2] have established the presence of He^3 in iron meteorites in amounts consistent with the calculations. This ability of cosmic rays to produce He^3 allows us to separate uniquely the cosmic-ray produced helium from the helium produced by radioactivity. It therefore becomes possible to treat the meteorite as a cosmic-ray meter which accumulates He^3 from the moment of its creation, i.e., when its parent planet is broken up.[1,3] The breakup, and therefore, the commencement of cosmic-ray exposure, must have occurred *after* the *formation* of the parent planet, and *after* the *solidification* of its core.[4]

Some differences have now arisen concerning the interpretation of the experimental data. From the measured uranium content and radiogenic helium content (obtained after subtracting the cosmic-ray produced helium) very low ages of solidification have been obtained, of the order of one hundred to two hundred million years.[5] Comparing this time period with the measured amount of He^3, Martin concludes that the cosmic ray intensity must have been at least three times as large as its present value.[5]

We prefer the following explanation: (i) The uranium-helium solidification ages are too low because most of the radiogenic helium has escaped from the meteorite; (ii) however, very little, if any, of the cosmic ray helium has escaped or diffused out.[4]

This explanation is based on the hypothesis that cosmic-ray helium is produced *throughout* the meteorite and therefore contained in the tight crystal structure whereas radiogenic helium is produced wherever uranium finds itself, mainly on the boundaries of the crystal grains, from where the helium can diffuse out rather easily. The hypothesis is supported by the following facts:

(i) Experimental data[6] indicate a constant cosmic-ray flux in the last 10^5 years; there is no reason, as we shall see, to assume that it has been much higher in the distant past.

(ii) Hurley[7] has pointed out that the ages obtained from mesozoic rock can be explained in terms of the leakage of helium in just the manner described above.

(iii) Experiments by Patterson, Brown, Tilton, and Inghram have shown that if the metal phase of a meteorite is separated from the troilite and other impurities, practically all of the uranium remains with the impurities.[8]

(iv) Urey[9] has given theoretical arguments for supposing that uranium leaves the iron-nickel mass, when the latter cools and solidifies to form the Widmanstätten crystal structure.

* Presented at the IUPAP Cosmic Ray Congress, Guanajuato, Mexico, September, 1955.

[1] S. F. Singer, Nature **170**, 728 (1952).

[2] Paneth, Reasbeck, and Mayne, Nature **170**, 728 (1952); Geochim. et Cosmochim. Acta **2**, 300 (1952).

[3] S. F. Singer, Astrophys. J. **119**, 291 (1954).

[4] S. F. Singer, Sci. American **191**, 36 (1954); American Association for the Advancement of Science, Symposium on the Origin of Meteorites, Boston, December, 1953 (unpublished).

[5] G. R. Martin, Geochim. et Cosmochim. Acta **3**, 288 (1953).

[6] J. L. Kulp and H. L. Volchok, Phys. Rev. **90**, 713 (1953).

[7] P. M. Hurley, in *Nuclear Geology*, edited by H. Faul (John Wiley and Sons, Inc., New York, 1954).

[8] Patterson, Brown, Tilton, and Inghram, Phys. Rev. **92**, 1234 (1953).

[9] H. C. Urey, Nature **175**, 321 (1955).

To the argument advanced here, namely, that radiogenic helium leaks out fairly easily, one might reply that experiments by Paneth[10] show that when meteorite samples are heated, not more than 5% of the helium escapes. On closer examination, however, it will be noted that the meteorite from which the samples were taken was Mt. Ayliff whose helium is practically all cosmic-ray produced. Paneth's experiment therefore supports the hypothesis advanced here, namely, that cosmic-ray helium is retained.

The crucial experiment suggested here is similar to that of Paneth. Let us assume our hypothesis is correct; then if we take a sample from a meteorite whose $He^3:He^4$ ratio is low (indicating the presence of a substantial amount of radiogenic He^4), heating it should drive off the radiogenic He^4 and thus increase the measured $He^3:He^4$ ratio. If therefore we take samples from the meteorites San Martin or Bethany Harvard (which have a $He^3:He^4$ ratio of about 0.17 as compared to Mt. Ayliff's 0.31), we should find after heating to 500 to 1000 degrees an increase in the $He^3:He^4$ ratio.[11]

It will be of great importance for the question of the origin of meteorites to verify this point; at the same time it may clarify the argument concerning the prehistoric cosmic-ray intensity.

[10] F. A. Paneth, Occasional Notes Roy. Astron. Soc. **5**, 37 (1939); Geochim. et Cosmochim. Acta **3**, 257 (1953).

[11] G. W. Reed and A. Turkevich [Nature **176**, 794 (1955)] have demonstrated experimentally the practical absence of uranium in two iron meteorite samples, in conflict with Paneth's measurements. It might therefore be objected that *all* of the helium in meteorites is of cosmic-ray origin so that the crucial experiment proposed here would show a negative result. We do not think so: First, we cannot explain measured $He^3:He^4$ ratios (some as low as 10%) from cosmic-ray production alone [M. Galli and S. F. Singer, Nuovo cimento (to be published)]; more likely, our proposed experiment may succeed in removing the radiogenic helium altogether and thus give the *true* cosmic-ray $He^3:He^4$ ratio. Secondly, the conflicting uranium determinations might be reconciled in the following manner: Paneth had to use much larger samples and may therefore have included some of the troilite; as shown by Patterson *et al.*,[8] the uranium content measured depends on how the sample is selected [see also (iii) above].