LETTERS TO THE EDITORS

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Possibility of the Quaternary Fission of Uranium-235

IN their classic paper[1] discussing the theory of the fission process, Bohr and Wheeler estimated the energy release to be expected in binary, ternary and quaternary fission of the compound nucleus of uranium-239. In the binary case, for fragments of equal mass, an energy release of 200 MeV. was obtained; for three nearly equal fragments, the energy release is slightly greater, being about 210 MeV., while for division into four comparable parts it falls to 150 MeV.

Experimental observation of the quaternary fission of uranium-235 was claimed by Ho, Tsien, Vigneron and Chastel in 1946[2], when they observed an event in a photographic emulsion which they believed could be represented best as four-particle fission into masses of 81, 99, 36 and 20. In the analysis applied, there are an infinite number of solutions for the mass values but the chosen one gave a kinetic energy release of 114 MeV., which they regarded as fitting the theoretical estimate well. A second case, reported in 1947[3], had three heavy fragments and one light fragment, and the estimated masses were given as 84, 76, 72 and 4, and the total kinetic energy release as 102 MeV. These two events occurred in the examination of 10,000 binary fission tracks, and the frequency of quaternary fission was derived as 0.0002 ± 0.00015 of that binary fission.

In a recent detailed study of the slow neutron fission of uranium-235 with special reference to rare modes of fission[4], more than 600,000 binary fission events have been examined. Some 1,000 ternary events with a long-range light fragment have been observed in this work, but only two events were recorded which could possibly be classed as quaternary fission. The two events concerned are small, having a maximum particle range of 14 μ. This makes measurement difficult, particularly with a heavily ionizing track suffering from multiple scattering, and analysis of the type employed by Tsien *et al.* does not yield satisfying results. It is not possible to determine whether the events are truly quaternary fission or whether they are explicable as due (1) to recoils projected by the pair of fission fragments in the act of separating, or (2) a ternary event with a random track superimposed. In any event, if quaternary fission is a physical possibility, these experiments suggest that the cross-section given by the French group is too high by at least a factor of ten.

Quaternary fission has also been looked for in the fast neutron fission of uranium and thorium[5], and the photo-fission of uranium[6] and thorium[7]. No evidence for fission into four fragments of equal mass has been found in these experiments, although in the photo-fission of uranium[8] and the fast neutron fission of thorium[9] an event consisting of the two heavy fission tracks and a pair of α-particles has been observed. In each case it was possible to show[8,9] that the disintegration could be explained as a ternary fission in which the third nucleus was the unstable beryllium-8 emitted in the ground-state and which immediately broke up into a pair of α-particles.

This body of evidence suggests that quaternary fission is a highly improbable process whatever the nucleus and mode of excitation.

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Viscosity and Thermal Conductivity of Liquid Argon

SOME time ago[1], I put forward certain very simple suggestions concerning the mechanism of the viscosity of liquids. These notions led to, among other things, a formula for the viscosity of simple (monatomic) liquids at the melting point which has been surprisingly successful in representing the melting point viscosity, η_M, of liquid metals[2]. My assumption is that in a simple (monatomic) liquid at melting point the atoms are vibrating about a mean position which very slowly migrates, and that momentum is transferred from layer to layer of the liquid at the extreme librations. This gives for the viscosity at melting point:

$$\eta_M = A\frac{vm}{\sigma}, \qquad (1)$$

where v is the frequency, m the mass of the atom and σ the interatomic distance, while A is a constant the precise calculation of which would be very difficult, but which must be about 1. I took it as 4/3 in my original paper.

Now if this simple theory has any physical meaning, the ratio of the thermal conductivity k to the coefficient of viscosity at the melting point should be given by considerations similar to those which apply in the case of gases. We are led to the formula:

$$\frac{k}{\eta} = Bc_v, \qquad (2)$$

where c_v is the specific heat in cal. per gm. at constant volume and B is again a constant which should be about 1. This formula should apply to monatomic liquids but, among them, not to metals, since with these the heat is transferred mainly by electrons, which transport very little of the momentum.

The recent determination of the thermal conductivity of liquid argon[3] enables us to test (2). The thermal conductivity extrapolates to 3.08×10^{-4} at the melting point, the viscosity[4] to 2.82×10^{-3}, which gives $k/\eta = 0.109$, while c_v at the melting point[5] is 0.138 cal./gm. The value of B therefore comes out to be 0.8, which is as near 1 as we can well expect with an approximate formula of this kind.

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