Letters to the Editor

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Fusion as Hydrodynamic Instability in Thermal Wave Propagation

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THE writer and his associates recently attempted[1] to treat the fusion of metals (at least those with high crystalline symmetry) as being due to an instability of the atomic thermal vibrations.

The formulas obtained by them coincide basically with an old semi-empirical relation of Lindemann, that is easily transformable into the form:

$$KT_M=\sigma EV, \tag{1}$$

(K = Boltzmann's constant, T_M = melting point in °K, E = Young's modulus for polycrystalline quasi-isotropic material, V = atomic volume, σ = constant depending on lattice symmetry).

As is known, Lindemann's formula agrees well enough with experimental results; it is furthermore known that all kinetic theories of melting process give a relation of the same form (1).

This fact has been pointed out by Norzi,[2] who also deduced the same relation in a different manner.

Now, neglecting temporarily the main difficulty of the problem, that is, the "*a priori*" determination of the constant σ, and limiting the scope of this paper to setting forth the problem rather than to resolving it, we shall propose an interpretation of the melting process that gives immediately the fundamental relation (1) and that seems promising of interesting results.

An analogous criterion has been privately communicated to the writer by Norzi,[3] but the one proposed here seems less subject to criticism.

It is clear that the atomic vibrations responsible for the melting of a lattice are the high frequency ones—that is, those corresponding to wavelengths of the order of the period of the lattice (of the order of the atomic diameter, or the distance between nearest neighbors).

If equipartition for kinetic energy holds, as happens at high temperatures, then, remembering some results of the paper quoted,[1] one finds easily:

$$\omega A=(2kT/m)^{\frac{1}{2}}, \tag{2}$$

$$\omega=(Ed/m)^{\frac{1}{2}}. \tag{3}$$

($\omega=2\pi$ times limiting frequency, A = rms value of the amplitude of atomic vibrations, m = mass of atom, d = atomic diameter).

Substituting the experimental data at high temperatures, these formulas—as well as direct x-ray measurements—show that $A/d\approx A/\lambda$ (where λ is the wavelength of the high frequency thermal waves) is not negligible compared to unity. This fact suggests that the propagation of thermal waves for temperatures approaching the melting point should be treated to a higher order approximation than is usual. This could be the method that has been applied by Hugoniot, Fubini-Ghiron *et al.*[4] for continuous media, giving rise to nonlinear equations for the propagation of finite amplitude acoustic waves. A result of these calculations seems to suggest a criterion that may be applied to the melting process.

As a matter of fact, the nonlinear propagation of an elastic wave of finite amplitude in a continuous, homogeneous, isotropic medium, at least in the adiabatic case, is characterized by the fact that a sinusoidal wave is being deformed during its motion, until—at a certain distance from its origin—the wave becomes discontinuous and the propagation laws change abruptly. If c is the propagation velocity ($\simeq$ sound velocity), the distance X from the origin of the wave, at which the discontinuity arises and the acoustic wave of amplitude A behaves as an explosion wave, is given to a good approximation by[5]

$$X=2c^2/A\omega^2. \tag{4}$$

It is now evident that, if an assembly of sources of movement (the nodes of the lattice) is considered, the lattice will abruptly collapse when A is so large that X becomes of the order of the distance d between the sources (or, assuming $X=pd$, when p is near unity).

It is believed that it should be possible to interpret fusion by means of this mechanism.

Two remarks support this viewpoint: (a) If one puts:

$$c=(E/\rho)^{\frac{1}{2}}, \tag{5}$$

where ρ is the density, and

$$A=(2kT/Ed)^{\frac{1}{2}}, \tag{6}$$

one finds immediately that a formula like (1) holds for the melting point. (b) If one assumes for E the Young's modulus for a polycrystalline metal at normal temperature, that is, if one considers longitudinal waves, the agreement between the calculations and the experiments is fairly good for $p\simeq 10$, that is, not a too large number. But if, as seems justifiable, one takes into account the lowering of sound velocity at high temperature, and limits the consideration to transversal waves that travel at a lower speed, and to the crystallographic directions of minimum speed of these waves, the agreement becomes good for $p\simeq 1$.

As has been said, the problem is only set forth and is very far from resolved; but nevertheless there must be here something more than a mere coincidence; and this interpretation of fusion as hydrodynamic instability in the propagation of thermal waves of finite amplitude may give interesting results.

The stated criterion would perhaps be general and independent of the kind of chemical bond; and it would be very interesting—in order to test it—to obtain direct experimental data on the atomic vibration amplitudes and the elastic constants of some substances at temperatures near their melting point.

[1] Bonfiglioli, Ferro, and Montalenti, *Sur la théorie de la fusion des métaux*, presented at the "colloque sur les changements de phase" of the Société de Chimie Physique, Paris, June, 1952.
[2] L. Norzi, Atti accad. sci. Torino **84**, (1949–50).
[3] The suggested criterion was the following: the crystal melts when the maximum velocity of the vibrating atoms becomes comparable to the velocity of elastic waves through the crystal.
[4] H. Hugoniot, J. école polytech. **57**, 1 (1887); **58**, 1 (1889); E. Fubini-Ghiron, Alta Frequenzo, **4**, 530 (1935).
[5] See Fubini-Ghiron (reference 4).

The Mass of Cl^{39} and of A^{39}†

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RECENTLY we have searched for the ground-state proton group from the nuclear reaction $A^{38}(d,p)A^{39}$, using argon analyzing 1.2 percent A^{36}, 1.2 percent A^{38}, and 97.6 percent A^{40}. We have not observed this group, but we would have if its Q value is greater than 5 Mev which would make its range longer than that of the first excited state proton group[1] from A^{37}. At shorter ranges weak proton groups from this argon gas target are obscured by the strong groups from A^{41} and A^{37}. We have also looked for gamma-rays in coincidence with the decay of A^{39} but could find none. Therefore, using the mass of K^{39} as 38.97606 ± 3[2]