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INTERNAL FRICTION IN IRON AT LOW TEMPERATURES

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As part of an extensive investigation of dislocation relaxation phenomena in fcc and bcc metals, internal friction measurements have been made on annealed and cold worked iron. Results on other metals including copper, aluminum, and niobium will be published soon.

Measurements have been made over the temperature range 4.2°K to 350°K using iron bars driven in a longitudinal mode of vibration at a resonant frequency of about 25 kc/sec. An electrostatic drive is employed; internal friction is measured by a free decay method.

The data on iron are summarized in Fig. 1; a typical loss curve for cold-worked copper is included for comparison. It will be noted that the results for copper are similar to those initially obtained by Bordoni[1] and later by several other workers.[2-4] It appears that in iron the dislocation relaxation peaks characteristic of fcc metals are absent or at least very much attenuated. Preliminary results on another bcc metal, niobium, indicate a similar absence of such peaks.

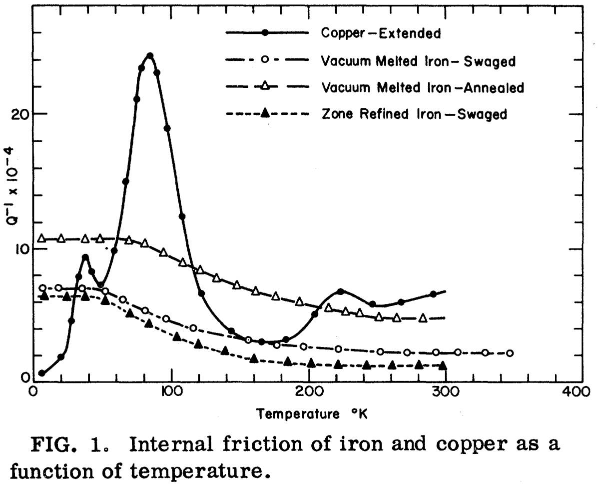

FIG. 1. Internal friction of iron and copper as a function of temperature.

The results on iron are atypical in that the internal friction increases with decreasing temperature, reaching a maximum at around 50°K and maintaining that value to the lowest temperature reached. This behavior is not understood but may be related to the fact that the material is ferromagnetic.

The data presented in Fig. 1 summarize results obtained on two iron specimens. One was prepared from vacuum-melted material, the other from iron which had been zone-refined. The aim was to use material which was as free of interstitial impurities as possible. The results of analysis are given in the following table.

Specimen	O (ppm)	N (ppm)	H (ppm)	C (ppm)
Vacuum-melted iron	9	37		18
Zone-refined iron	17	<2	<0.2	10

The specimen of vacuum-melted iron was reduced in area 8% by swaging prior to the initial measurements. It was remeasured after a four-hour vacuum anneal at 850°C. The specimen of zone-refined material was rolled and swaged from an ingot measuring $1\frac{3}{4}$ in. × $1\frac{1}{4}$ in. × $\frac{3}{4}$ in. to a final diameter of $\frac{3}{8}$ in. to give a total reduction of 90%. No intermediate anneals were required.

The mechanism of dislocation relaxation proposed by Seeger[5] does not seem to offer an explanation for the apparent absence of peaks in bcc metals. A principal difference between dislocations in fcc and bcc metals is that for the latter a dissociation of complete dislocations into symmetric partials is not possible. The insensitivity of the peaks to impurity content indicates that intrinsic point defects such as vacancies may be important. These facts suggest a new mechanism based upon the thermally activated motion of symmetric paired partial dislocations between vacancy-pinning points; minimum energy configurations are those for which the vacancy is immediately above either partial. It is in these positions that its interaction with the dilatational stress field of the partial will be strongest. The activation energy is determined by the energy required for the transition (by glide of the dislocation pair) between the two stable states. This model will be discussed in detail in a forthcoming publication.[6]

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CRYSTAL STABILITY AND THE THEORY OF FERROELECTRICITY

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The condition that a crystal should be stable for all small deformations is that all the normal modes should have real frequencies.[1] The limit of stability against a particular mode of vibration is approached as the corresponding frequency approaches zero. In what follows we show that there is reason to believe that a ferroelectric transition, at least in certain crystals, is associated with such an instability or near-instability. The condition for a ferroelectric transition is therefore a problem in lattice dynamics, and when it is treated as such new insight into the problem is obtained. We illustrate this by means of a simple example, in which it is shown that it is possible for a diatomic cubic crystal to exhibit properties which are remarkably similar to those of barium titanate.

A shell model for the ions in an alkali halide crystal, proposed by Dick and Overhauser,[2] has been found to give a satisfactory explanation of the dielectric properties of alkali halides[3,4] and of the lattice dynamics of sodium iodide.[5] A similar model accounts quite well for the observed relation between frequency ω $(=2\pi\nu)$ and wave vector $\vec{q}$ $(q=2\pi/\lambda)$ of certain of the normal modes of germanium.[6] The theory of Woods, Cochran, and Brockhouse,[5] based on this model, gives the following expressions for the frequencies of the transverse optic (T.O.) and longitudinal optic (L.O.) modes of wave vector zero in a diatomic cubic crystal:

$$\mu\omega_T^2 = R_0' - 4\pi(\epsilon+2)(Z'e)^2/9v, \tag{1}$$

$$\mu\omega_L^2 = R_0' + 8\pi(\epsilon+2)(Z'e)^2/9v\epsilon. \tag{2}$$

Here μ is the reduced mass of the ions, ϵ the high-frequency dielectric constant (the square of the optical refractive index), and v the volume of the unit cell. $Z'e$ is the effective ionic charge, while $R_0'\vec{u}$ is the restoring "short-range" force on any one atom when the two lattices carrying the nuclei of different type are displaced a small relative distance $\vec{u}$. Primed quantities depend explicitly on the parameters of the shell model. In a crystal such as sodium iodide the two quantities on the right of Eq. (1) are of the same order of magnitude, but the term R_0' which arises from the short-range interaction is about twice as great as the other, which arises from the Coulomb interaction. Let us consider the