

## Behavior of Young's Modulus of Beta-Brass Single Crystals at Low Temperature

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Young's modulus for seven single crystals of beta-brass has been measured at liquid oxygen, and dry ice and acetone temperatures. The reciprocals of the moduli in different directions in the crystal lattice were found to vary linearly with temperature down to  $-183^{\circ}\text{C}$  and the anomalous behavior of these quantities, observed at room temperature, persisted.

### INTRODUCTION

RECENTLY the author<sup>1</sup> reported measurements made upon the temperature dependence of Young's modulus of beta-brass single crystals above room temperature in a study of the effect of disordering upon this quantity. Incidentally, these measurements showed that at temperatures above room temperature (but before disordering is appreciable), Young's modulus behaved differently for different directions in the crystal lattice. The reciprocals of the modulus in the three directions,  $[111]$ ,  $[110]$ , and  $[100]$ , varied linearly with temperature, but whether it increased or decreased with rising temperature depended entirely upon the direction in the crystal lattice. Beta-brass is known to be extremely highly anisotropic<sup>1,2</sup> with respect to the value of Young's modulus in differ-

ent directions of the crystal lattice. The ratio in the two extreme directions, at room temperature, is about 8.2. A plot of this anisotropy against temperature showed it to be increasing fairly rapidly at room temperature. The author felt, perhaps, that at lower temperatures the material might behave in a more normal fashion, i.e., all three  $1/E$  versus temperature curves might assume a positive (or negative) slope and the material become more isotropic. For these reasons measurements of Young's modulus were made at temperatures below room temperature on the same seven crystals used in the former investigation.<sup>1</sup>

### MEASUREMENTS AND RESULTS

The only change made in the apparatus and method of measurement from that of the previous investigation was the substitution of a cryostat in place of a furnace for varying the temperature of the crystals. This cryostat consisted of a suitably insulated test tube into which the crystal holder and crystal could be placed and the whole immersed in a bath of the low temperature mixture. Two baths were used, dry ice and acetone, and liquid oxygen. In each case the crystal was left in the low temperature mixture sufficiently long to be reasonably certain that it had reached temperature equilibrium. The temperature of the crystal, when placed in the dry ice and acetone bath, was measured with

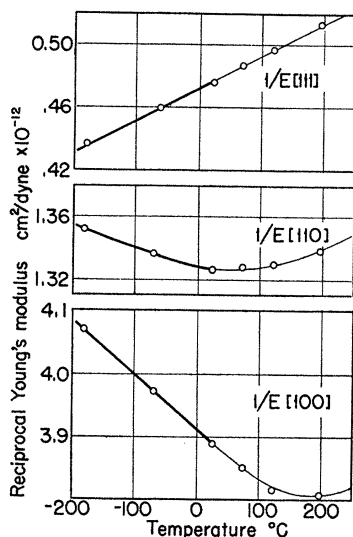


FIG. 1. Reciprocals of Young's modulus in the three principal directions of the crystal lattice versus temperature. Heavy part of curves shows region investigated in this study.

TABLE I. Reciprocal of Young's modulus in principal directions in crystal lattice.

TEMPERATURE ( $^{\circ}\text{C}$ )	$-183$	$-68$
$1/E[111]$ ( $\text{cm}^2/\text{dyne}$ )	$0.436 \times 10^{-12}$	$0.459 \times 10^{-12}$
$1/E[110]$ ( $\text{cm}^2/\text{dyne}$ )	1.352	1.336
$1/E[100]$ ( $\text{cm}^2/\text{dyne}$ )	4.069	3.968

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<sup>1</sup> J. S. Rinehart, Phys. Rev. 58, 365 (1940).

<sup>2</sup> W. Webb, Phys. Rev. 55, 297 (1939).

a copper-constantan thermocouple. In the second case, it was assumed that the crystals had acquired the temperature of the liquid oxygen.

The results are given in Table I and are shown graphically in Figs. 1 and 2, in which are plotted the values of  $1/E[111]$ ,  $1/E[110]$ ,  $1/E[100]$  ( $=s_{11}$ ), and  $E[111]/E[100]$ . It is evident from Fig. 1 that the reciprocal of Young's modulus varies linearly with temperature in the three different directions in the crystal lattice down to at least liquid oxygen temperature. There is no evidence whatsoever that the material is becoming more isotropic. On the contrary,  $1/E[100]$  continues its anomalous behavior clear up to the end of the region investigated. At  $-183^\circ\text{C}$  Young's modulus in this direction, i.e., along the cube edge, is about seven percent lower than at room temperature. This means that cooling the material makes it considerably less rigid in this particular direction. In the  $[111]$  direction the reciprocal of the

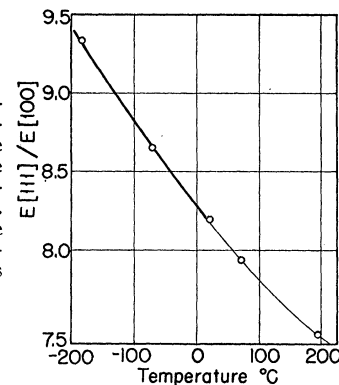


FIG. 2. Anisotropy of Young's modulus in two extreme directions in the crystal lattice versus temperature. Heavy part of curve shows region investigated in this study.

modulus acts normally, hence the anisotropic character of the material becomes even more pronounced, as is shown in Fig. 2.

In conclusion, the author wishes to thank the Physics Department of the State University of Iowa for the facilities placed at his disposal, and Professor E. P. T. Tyndall for many helpful suggestions.

## On the Theory of Volume Magnetostriction

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Volume magnetostriction is considered on the basis of the molecular field theory. Instead of the assumption of a saturation magnetization independent of volume at absolute zero ( $I_0$ ), made in the original interpretation by Becker and Kornetzki, another procedure is adopted. The dependence of saturation magnetization ( $I$ ) on temperature for coupled ( $j=1$ ) and uncoupled ( $j=\frac{1}{2}$ ) electrons is assumed to be given by a Brillouin function. With the experimental data on the magnetostriction of iron this method allows us to obtain values for (a) the molecular field "constant"  $N$ , (b) its dependence on the relative change of volume,  $(1/N)(\partial N/\partial\omega)$ , and (c) the dependence on volume of the saturation magnetization at  $T=0$ ,  $(1/I_0)(\partial I_0/\partial\omega)$ . The value of  $N$  and  $(1/N)(\partial N/\partial\omega)$  agrees with that obtained from the magneto-caloric measurements. The dependence of  $I_0$  on volume agrees with the value expected from the change of density. Another check on the value of  $(1/N)(\partial N/\partial\omega)$  is made by considering the "magnetic" specific heat, a part of which is shown, by thermodynamical considerations, to be proportional to this quantity. All quantitative checks of our theory, including the probable change of the Curie point under pressure are more satisfactory if electrons coupled in pairs ( $j=1$ ) are assumed than if uncoupled ( $j=\frac{1}{2}$ ) electrons are considered.

THERE are two ways to approach the problem of ferromagnetism theoretically. One is based essentially on the classical concepts of elementary magnets and the so-called molecular field. The other uses the methods of the

modern theory of solid state and in particular the structure of the electron bands. The latter, however, is largely undeveloped. The molecular field theory even though models not easily connected with the band structure are assumed,