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Anisotropic Thermal Expansion of Indium

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In order to resolve differences in the reported data on thermal expansion, the lattice parameters of pure indium have been redetermined as functions of temperature over the range 27° to 106°C. The work was done independently on two cameras with good agreement in the results. The principal coefficient of thermal expansion along the **a** and **b** directions of the tetragonal structure is found to be independent of temperature and equal to $60{\cdot}5\times10^{-6}$ °C^{-1}. A negative coefficient, which increases in magnitude with temperature, is obtained for the expansion along the tetragonal axis. The results are compared with those from earlier reports and discussed in relation to the available data on the elastic behaviour of the metal.

Many conflicting reports on the thermal expansion data of indium have been published. Some give the coefficient of expansion along the c axis (α_c) of the tetragonal cell as a positive quantity and some others give a negative value for α_c. In view of this, in the present work, a careful study of the temperature variation of the lattice parameters and the principal coefficients of thermal expansion, has been made. The work was done independently on two cameras, a flat-plate camera (A) and a Unicam 19 cm diameter high-temperature camera (B). The mutual consistency in the results obtained by the two cameras gives an indication of the dependibility of the final data.

Pure metal obtained from J.M was used for obtaining the X-ray powder photographs at different temperatures. The experimental technique and the method of evaluating the lattice parameters were the same as reported earlier [Deshpande & Mudholker (1960); Deshpande & Pawar (1962)]. In Table 1, the values of the lattice parameters at different temperatures, obtained by the two cameras are given.

Fig. 1 shows that the variation of the a parameter with temperature is linear but that the variation of the c parameter is not. Least-squares treatment of the temperature-parameter data gave the temperature independent coefficient of expansion perpendicular to the c axis as $\alpha_a=60{\cdot}5\times10^{-6}$ °C^{-1} and the following equation for the temperature-dependence of the c parameter:

$$C_t=4{\cdot}9465-33{\cdot}45\times10^{-6}(t-20)-11{\cdot}17\times10^{-7}(t-20)^2\,.$$

Here t is the temperature in °C and the c parameter is expressed in Å units.

The thermal expansion of indium has already been studied by many workers. Their results have been summarized in Table 2 for the sake of comparison. It can be seen that the values of the mean principal expansion coefficients obtained in the present study agree well with those given by Betteridge (1938) over a similar range of temperature. Similarly the values at 25°C from the present study are in satisfactory agreement with those reported by Graham, Moore & Raynor (1955) and Vernon & Weintroub (1953). Graham *et al.* (1955) have pointed out that the c parameter passes through a maximum value in the neighbourhood of room temperature. The flattening of the c-t curve, observed in the present investigation at about the same temperature, probably corresponds to the maximum in the c value noticed by Graham *et al.* (1955).

Recently, Huntington (1958) has calculated the elastic coefficients of In from the elastic constant data of Winder & Smith (1958). Using these values, the linear compressibilities of In along the two crystallographic directions are obtained by the method suggested by

Table 1. *Values of the lattice parameters and axial ratio of* In *at different temperatures obtained by the two cameras*

Temperature °C	Camera	a (Å)	c (Å)	c/a
27	A	4·6002 ± 0·0001*	4·9463 ± 0·0002*	1·0752
28	B	4·6004	4·9459	1·0751
50	B	4·6050	4·9452	1·0739
60	B	4·6103	4·9431	1·0722
80	B	4·6142	4·9409	1·0708
80	A	4·6153	4·9405	1·0705
90	B	4·6179	4·9378	1·0693
106	A	4·6228	4·9358	1·0677

* Standard errors calculated by the usual statistical method (Jette & Foote, 1935).

Table 2. *Thermal expansion coefficients of* In *obtained by various workers*

Author	Temperature (°C)		$\alpha_a \times 10^6$ °C^{-1}	$\alpha_c \times 10^6$ °C^{-1}
Betteridge (1938)	Between	20–100	64	−25·0
Frevel & Ott (1935)	Between	25–141	56	13·0
Shinoda (1933)	Between	23–87	45	11·7
Schneider & Heymer (1956)	Between	18–130	56·4	12·6
Graham *et al.* (1955)	At	27	57·0	−5·5
Vernon & Weintroub (1953)	At	30	50·0	−7·5
Present work	Between	27–106	60·5	−26·9
Present work	At	25	60·5	−8·1

Boas & Mackenzie (1950). They are:

$$K_c = 0{\cdot}64 \times 10^{-12} \text{ cm}^2 \text{ dyne}^{-1},$$
$$K_a = 0{\cdot}86 \times 10^{-12} \text{ cm}^2 \text{ dyne}^{-1}.$$

From the point of view of anisotropy, thermal expansion is analogous to linear compressibility because in both cases the strains produced in the crystals are homogeneous (Nye, 1957; Wooster, 1949). However, the results given above show that while the linear compressibility of indium along the two directions is positive, the thermal expansion in the basal plane is a large positive quantity and that along the tetragonal axis is a small negative quantity. Perhaps this apparent anomaly in the anisotropic behaviour of In arises from the following reasons. As the calculation of the linear compressibilities along the two directions shows, both these values are small differences in two large and almost equal quantities. Any error in the values of the individual elastic coefficients will, therefore, have a large effect on the values of the linear compressibilities. A rough estimate shows that if the values of the elastic coefficients are assumed to be uncertain by about 2·5% then a negative value for the linear compressibility along the **c** direction becomes a possibility. The authors feel, therefore, that a redetermination of the elastic constants of In is necessary to resolve the discrepancy.

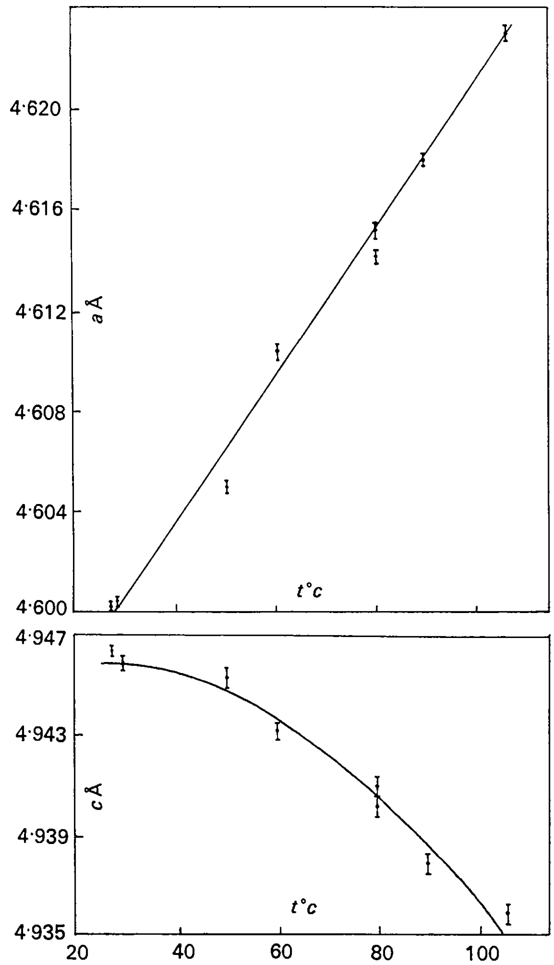

Fig. 1. Temperature variation of the lattice parameters of indium.

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