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► **To cite this version:**

L. Alberts, M. Bohlmann, H. Alberts. ELASTIC CONSTANTS OF IRON IN THE VICINITY OF THE CURIE POINT. *Journal de Physique Colloques*, 1971, 32 (C1), pp.C1-415-C1-416. 10.1051/jphyscol:19711146 . jpa-00213965

HAL Id: jpa-00213965

<https://hal.science/jpa-00213965>

Submitted on 4 Feb 2008

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ELASTIC CONSTANTS OF IRON IN THE VICINITY OF THE CURIE POINT

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Résumé. — Des mesures des constantes élastiques d'un monocristal de fer sont faites au moyen d'une méthode du pas différentiel du pulse écho ultra sonique dans la région de 5 à 8 MHz et pour des températures de 300 à 1 160 °K.

Ces constantes $\frac{1}{3}(C_{11} - C_{12})$ et $\frac{1}{3}(C_{11} + 2 C_{12})$ montrent clairement une anomalie au passage du point de Curie, alors que C_{44} ne le fait pas. Il nous semble que il n'y a pas de contribution magnétique dans ce cas. En appliquant ces derniers résultats dans l'expression de Fuch pour C_{44} , on trouve que le fer a une position dans la partie ascendante de la courbe traditionnelle de Bethe-Slater.

Abstract. — Measurements on the elastic constants of an iron single crystal are made by an ultrasonic differential path pulse echo method in the 5-8 megahertz range over the 300-1160 °K temperature range. The constants $\frac{1}{3}(C_{11} - C_{12})$ and $\frac{1}{3}(C_{11} + 2 C_{12})$ clearly show an anomaly in passing through the Curie Point whereas C_{44} does not i.e. there appears to be no resultant magnetic contribution in the latter case. On applying the latter result to Fuchs' expression for C_{44} one finds that iron has a position on the ascending side of the traditional Bethe-Slater curve.

1. Introduction. — In this work measurements on the elastic constants of a single iron crystal, up to 117 °K above the Curie point, are reported for the first time. As one would expect the various elastic constants reveal interesting phenomena in passing through the magnetic phase transition. These results, though difficult to interpret quantitatively, give information regarding the magnetic interaction's contribution to the elastic constants and on the magnetic interactions themselves.

2. Experimental. — A cylindrically shaped single crystal specimen, about 1 cm³ in volume, was cut with the flat end faces in [110] planes and parallel to each other to within 1 minute of arc. A step of 2.3 mm thickness was cut at the one end and the ensuing differential path length employed to make the actual measurements. The other end of the crystal was carefully welded to a steel buffer rod which served as an interpiece between the specimen and the quartz transducer. A specially prepared copper-silver alloy, with a melting point between the Curie temperature and the α - γ transition point for iron, was used to weld the crystal on to the buffer. During measurements the transducer end of the buffer was kept outside the heating furnace and water cooled. The specimen temperature was electronically regulated to within 0.1 °C throughout the whole heating range [1].

Acoustic pulses in the 5-8 M. Hertz range were applied to the specimen and the transit time determined by measuring the frequency of a standing wave system by utilising the interference pattern from the incoming and reflected wave [2]. This technique is highly tolerant of noise and pulse distortion and is easily applied. By a suitable feedback technique the incoming frequency is continuously adjusted to meet the requirement of changing velocity with rise in temperature. The differential path, introduced by the step as described above, gives a transit time which is free from the errors caused by interfaces, adhesives, etc. Knowing the geometric path length, the velocity of shear and longitudinal waves were determined. Corrections for thermal expansion were made by using

the X-ray data of Kohlhaas et al. [3]. The essential merit of this measuring technique is that it provides detection of velocity changes and hence elastic coefficient changes in the order of 1 in 10⁵ with an overall reliability of within 2 % for a given specimen.

The usual well-known equations [4] relating adiabatic elastic coefficients and sound wave velocities were employed. The symbols used are $C = C_{44}$;

$$C' = \frac{1}{2}(C_{11} - C_{12}) ;$$

$B = \frac{1}{3}(C_{11} + 2 C_{12})$; where B is the bulk modulus and the C_{ij} 's have the usual meaning. The experimental results are depicted in figure 1 with an inset show-

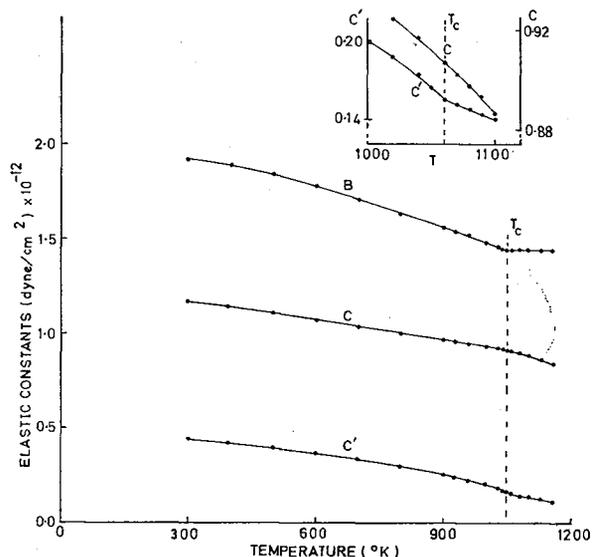


FIG. 1. — Elastic constants for iron at different temperatures. The inset shows the enlarged C and C' behaviour near the Curie temperature T_c .

ing the enlarged behaviour of C and C' in the vicinity of the Curie point.

3. Discussion. — The most interesting behaviour revealed by the results is the anomalous temperature

dependence of B and C' whilst C shows no change when the specimen passes through the Curie point. It thus appears that there is no resultant contribution to the shear modulus C from ferromagnetic interactions.

It seems reasonable to assume that the contribution to the elastic stiffness constants that arise from the magnetic exchange interactions between iron atoms is of the central force type. In Fuchs' theory [5] expressions are derived for these constants on the basis of additive central forces of different nature (overlap forces, Van der Waals forces, etc.). The magnetic contribution to C' can thus be written in terms of Fuchs' equation, with the coefficients as corrected by Isenberg [6].

$$C_{\text{magnetic}} = \frac{8}{9}Nr \frac{d\omega}{dr} + \frac{4}{9}Nr^2 \frac{d^2\omega}{dr^2} + Nr' \frac{d\omega'}{dr'} \quad (1)$$

where the first two terms are contributions from nearest neighbours and the third term that from next nearest neighbours. N is the density of atoms, r the distance between nearest neighbours and r' between next nearest neighbours; ω is the interaction energy between nearest neighbours and ω' that between next nearest neighbours. According to the experimental results the above expression is equal to zero. Using the well-known expression $\omega = -2JS_i \cdot S_j$ for the exchange energy between two atoms and bearing in mind that it is essentially negative, a physically acceptable energy function would be of the form shown in figure 2. Nearest neighbours would be at a

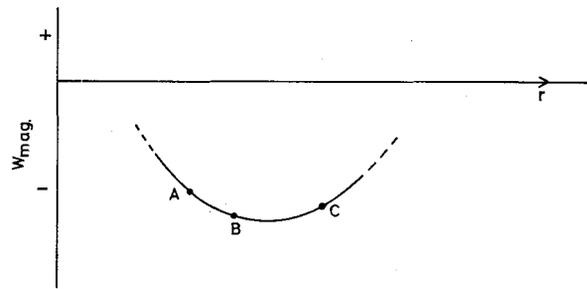


FIG. 2. — Magnetic interaction energy function for iron.

distance apart given by point A and next nearest neighbours, if their interaction energy is not taken to be negligible, at a point such as B or C . At point A the first two terms in equation (1) are of opposite sign and together with the third term can add up to zero. This would not be possible if nearest neighbours were at a point such as C and next nearest neighbours further along, for in such a case all three terms would be positive. This places iron on the ascending branch of the traditional Bethe-Slater curve as based on the Heisenberg interaction between nearest neighbour localised magnetic moments. The same conclusion was reached by Eichmann et al. [7] in their work done on iron with varying degrees of impurities.

Acknowledgements. — It is a pleasure to thank the South African Council for Scientific and Industrial Research for financial aid.

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