Acta Cryst. (1960). **13**, 363

On the contrast of the electron microscopic image due to an edge dislocation.

By Hatsujiro Hashimoto and Michihiko Mannami, *Physical Institute, Kyoto University, Kyoto, Japan*

(*Received* 11 *June* 1959 *and in revised form* 12 *December* 1959)

Edge dislocations have been observed in transmission electron-micrographs as local intensity contrasts in the images of the crystals satisfying Bragg conditions (Hirsch, Horne & Whelan, 1956; Bollmann, 1956), or as extra half-lines in the crystal lattice images (Menter, 1956), or as extra half-lines in the moiré patterns from overlapping crystals (Hashimoto & Uyeda, 1957; Pashley, Menter & Bassett, 1957). In the present paper the intensity contrast due to the edge dislocation is dealt by extending the dynamical theory of electron diffraction.

We assume, for simplicity, that the crystal is of simple cubic lattice having the lattice constant a_0, and that the x- and y-axes are parallel to and the z-axis is perpendicular to the crystal surface. When, we further assume the Burger vector $\mathbf{b}$ is parallel to the x-axis, the elastic displacement $\mathbf{u}(x, y, z)$ of the part around the dislocation has no z-component and is a function of x and y only. The components $u_x(x, y)$ and $u_y(x, y)$ can be calculated by the use of the theory of elasticity (Read, 1953).

So far as the region where the lattice distortion is quite small is concerned, the distorted crystal may be approximated as a composite of many a number of perfect parts, to each of which the dynamical theory of diffraction can be applied. Then the excitation error ζ, which is the separation between Ewald sphere and the reciprocal lattice point and is the parameter characterizing the deviation of the diffraction condition from the exact Bragg condition (Bethe, 1928), may be regarded as varying from point to point. When the incident and diffracted beams of electrons are nearly perpendicular to the crystal surface as is usually the case, $\mathbf{u}(x, y, z)$ is nearly constant along the path of electrons, so that ζ may be regarded as the function of x and y only. For the $(h00)$-reflexions, for instance, the excitation error is approximately given by

$$\zeta_{h00}(x, y) = \frac{\lambda h^2}{2a_0^2}\,\frac{-\partial u_x/\partial x}{(1+\partial u_x/\partial x)} + \zeta_{h00}(\infty)\,, \qquad (1)$$

where $\zeta_{h00}(\infty)$ is the excitation error for the region far from the dislocation line, and λ the wave length of electrons. The approximation in the present theory, applying the dynamical theory to a distorted crystal, is similar to that assumed by Heidenreich (1949) in explaining the equal-inclination fringes in electron-micrographs from a bent crystal.

Following Heidenreich, the intensity of the well-focused electron microscopic image of the crystal is given as a function of ζ in the following form

$$I = 1 - \frac{p^2}{d^2}\sin^2 2\pi d Z\,, \qquad (2)$$

where p is $V_h/2\lambda E$, d is $[(\zeta/2)^2+p^2]^{\frac{1}{2}}$, V_h the Fourier potential concerned, E the acceleration potential of electrons, Z the thickness of the crystal. Substituting (1) into (2), the intensity contrast due to the edge dislocation in the electron microscopic images can be calculated. Fig. 1 shows a few examples of the calculated results choosing the values of the parameters as indicated in the caption. As is clear from these examples, the shape and the extension of the intensity contrast caused by the edge dislocation vary severely with the condition of diffraction. For instance, the higher the order of reflexion, the wider the range of the intensity contrast. It is noteworthy, however, that the main features in the shape of some of the dislocation contrasts which have been experimentally observed (for instance, those found in Fig. 53 of Menter's paper (1958)) can be explained qualitatively well by the present results.

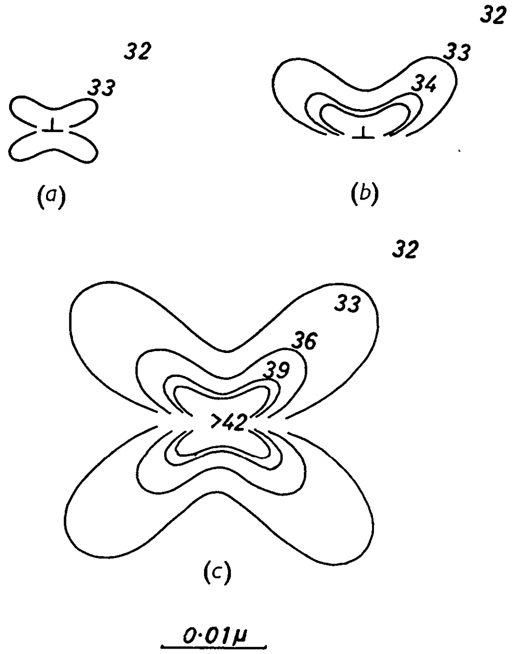

Fig. 1. Calculated intensity contrast of the image due to an edge dislocation, calculated by assuming that $E=50$ kV., $V_{h00}=2$ V., $Z=500$ Å, $a_0=2$ Å and $b=2$ Å.

(*a*) (100)-reflexion, $\zeta_{100}(\infty)=0$.
(*b*) (100)-reflexion, $\zeta_{100}(\infty)=2\times10^3$ cm.$^{-1}$.
(*c*) (200)-reflexion, $\zeta_{200}(\infty)=0$.

Numerals in the figures indicate the intensities of transmitted electrons for the intensity of incident beam 100.

In view of the approximation assumed in the present treatment, the quantitative agreement of the calculated results with experiments may not be expected, in particular for the regions near the dislocation line. However, with a proper precaution the present simple theory may be effectively utilized in interpreting the observed dislocation contrasts. The similar theory can be developed to argue the half-lines in the crystal lattice image and in the crystal moiré.

The authors express their sincere thanks to Prof. K. Tanaka of Kyoto University and Prof. S. Miyake of Tokyo University for their kind encouragements and discussions.

References

BETHE, H. (1928). *Ann. Phys. Lpz.* **87**, 55.
BOLLMANN, W. (1956). *Phys. Rev.* **103**, 1588.
HASHIMOTO, H. & UYEDA, R. (1957). *Acta Cryst.* **10**, 143.
HEIDENREICH, R. D. (1949). *J. Appl. Phys.* **20**, 993.
HIRSCH, P. B., HORNE, R. W. & WHELAN, M. J. (1956). *Phil. Mag.* **1**, 677.
MENTER, J. W. (1956). *Proc. Roy. Soc.* A, **236**, 119.
MENTER, J. W. (1958). *Adv. Phys.* **7**, 299.
PASHLEY, P. B., MENTER, J. W. & BASSETT, G. A. (1957). *Nature, Lond.* **179**, 752.
READ, W. T. (1953). *Dislocations in Crystals*, p. 116. New York: McGraw-Hill.

Book Reviews

Works intended for notice in this column should be sent direct to the Editor (A. J. C. Wilson, Department of Physics, University College, Cathays Park, Cardiff, Great Britain). As far as practicable books will be reviewed in a country different from that of publication.

Studies in Crystal Physics. By M. A. JASWON. Original Papers and Papers Reprinted from *Research*, Vol. 11, 1958. 42 pages. London: Butterworths Scientific Publications. Price 10*s*. 6*d*.

Four of these papers, dealing severally with the geometry of lattice planes, lattice imperfections, X-ray diffraction by imperfect crystals, and the geometry of martensitic phase transformations, are reprinted from *Research*. The fifth, a survey of classical thermodynamics as applied to phase transformations involving crystals, has been specially written for this booklet.

The aim of the collection is to give the non-specialist some idea of the flavour of present-day research in the fields touched upon. However, the level and the degree of compression of the text is variable, and for non-specialists is rather too advanced in places, especially in the third and fourth papers. By way of example, the three short paragraphs devoted to the reciprocal lattice (pp. 17, 18) impart little real feeling for its role in crystal physics.

The second paper offers a good concise survey of some salient features of point and line defects in crystals. However, the most valuable part of the booklet, at any rate for the professional crystallographer, is the first paper, which is itself a précis of a series of three papers, by Dr Jaswon and Dr D. B. Dove, published in *Acta Crystallographica*. This deals with the solution of the mathematical problem of preparing a normal projection of an individual plane, or of a pair of planes, out of a family of lattice planes of specified Miller indices in any crystal system; the solution permits the positions of all lattice points lying in the plane to be computed. This is of much importance in several fields of geometrical crystallography and has not, to the reviewer's knowledge, been adequately dealt with before. A valuable application of this technique to the crystallography of deformation twins is briefly sketched.

Trivial errors only were encountered; in particular, the caption to Fig. 12 (p. 20) appears to be inexact, in that a back-reflexion ring with Mo $K\alpha$ radiation from steel will not have indices 310; and the corresponding paragraph in the text is tantalisingly incomplete. In general, however, printing and presentation are excellent.

R. W. CAHN

Department of Physical Metallurgy
Birmingham University
Birmingham, England

Dendritic Crystallization. By D. D. SARATOVKIN. Translated from Russian by J. E. S. BRADLEY. 2nd edition. New York: Consultants Bureau Inc. Price $6; 50*s*.

This is a rather unusual book presenting the very individualistic viewpoint of the author. It seems that the author's ideas came under severe criticism from his colleagues after the publication of the first edition, and on reading the second edition one is not surprised. The book follows closely the pattern of a Ph.D. thesis giving first a review of literature, almost entirely Russian, then the experimental method and finally the results.

The author's experiments have been concerned with effects of different cooling conditions and organic additives on the modes of dendritic growth of ammonium halides. Precise details of how the experiments were carried out are given and the characteristics of the Russian microscopes for stereo photo micrography are discussed. Within the text a series of stereo pairs are presented, together with instructions for examining these without the aid of a stereo viewer.

The last two sections are of more metallurgical interest. Here the author classifies eutectics as a special form of dendritic growth and then describes experiments to determine the contact fusion temperature of mixed metal powders. This temperature is identified with the eutectic temperature, and from the identity and a topological argument it is then deduced that five component eutectics cannot exist.

The final chapter on the solidification of killed steel (translated as bubble-free steel) is very dull. The author makes somewhat extravagant claims for the ideas he is putting forward, but it is difficult to appreciate just what is original about them.

Whilst the aims of the publishers are very laudable, surely there must be books more worthy of translation from Russian than this one. The typographical monotony makes the book tedious to read, and the chapter headings are almost indiscernable. Altogether the book is very poor value for money and will probably find its way only into the obscure corners of library shelves.

JACK NUTTING

Department of Metallurgy
The University
Cambridge
England