shrinkage rate observed by Edington and Smallman (see their fig. 7) at small loop sizes, is most probably unrealistic. In addition, if we assume that $\gamma = 345 \text{ erg cm}^{-2}$, it is readily shown for a 500 Å diameter faulted loop that the contribution of the stacking-fault surface tension to the driving chemical potential $\mu_s$ is about 8-8 times as large as the line tension contribution. Hence, the diffusion limited loop shrinkage rate of a 500 Å diameter loop should only be 1.5 times faster than the loop shrinkage rate of a 4500 Å diameter loop. Thus, the rapid increase in shrinkage rate observed by Edington and Smallman starting at ~1700 Å diameter is not understandable if the stacking-fault energy dominates the loop shrinkage process throughout this size range. It is apparent that the published data for the shrinkage of these faulted loops are inconsistent with the present climb models.

References


REVIEWS OF BOOKS


Many elegant experiments have now been carried out with targets and beams of particles in which the nuclear spin axes are not randomly oriented and some very important experimental results have followed, probably the best known being the non-conservation of parity in $\beta$ decay. The techniques available for the production of nuclear orientation have developed from many traditionally unrelated fields of research, such as low temperature electron and nuclear resonance, atomic beams and nuclear scattering, and few scientists would consider that they are experts in more than one of these fields. For this reason we can welcome this book which contains an excellent account of the underlying theory of all the physical processes responsible for nuclear orientation, as well as a description of the experimental techniques by which beams, targets and radioactive sources are formed with spatially oriented spins. Much of the detail of importance to experimenters is left out of the text but the references are very extensive and well chosen, and an investigator has no difficulty finding out about the systems which had been worked on by the end of 1964. There is no doubt that polarized targets and beams will be more extensively used in the future and that other techniques will be introduced, but this book will continue to be of considerable use to research workers for many years because a significant part of the book is devoted to the foundations of the subject and these are unlikely to change so rapidly.

K. E. Smith


The appearance of the second edition of Volume 3 of the Course of Theoretical Physics by Landau and Lifshitz is very welcome. This volume deals with quantum mechanics and will be a valuable reference book for students and for workers of this subject.

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1. Emission occurs from jogs present on the core at an average concentration of \( \frac{1}{2} \) atom fraction;

2. the emission rate per jog is rapid and is given by Friedel (1956, 1954).

These assumptions are presently untested. Even though it has been widely assumed that the density of aspherical jogs of unit height is \( \frac{1}{2} \) on a dislocation loop which appears circular under the electron microscope (see fig. 8 in Silcox and Whelan), it is clear that an apparently circular shape at this resolution can also be achieved by a lower density of jogs with a height greater than one unit distance. The exact configuration will depend on the energy and entropy of the various topologically possible configurations. It is also clear that the emission rate at a highly relaxed jog could be considerably slower than that given by Friedel (1954).

Subsequent workers in this field (e.g., see Price 1960, Shimomura 1965, Edington and Smallman 1965, Kannan 1965 and Thomas 1965) have all used the Silcox-Whelan emission limited model to interpret their results.

In our opinion the use of this specific model may not be generally justified, and a number of aspects of the problem have not been discussed sufficiently.

In the present note we avoid the problem of attempting to specify unknown climb processes in the core by introducing an 'ideal source' dislocation loop. We visualize the dislocation loop to be in the shape of a torus with a large radius \( r \), which is the same as the radius of the loop and to have a circular cross section which is of atomic dimensions with a radius \( r \). The torus exchanges vacancies with the lattice whenever a vacancy jumps across the surface of the torus. The core is defined as an ideal source when the outward vacancy flux is equal to the balanced vacancy flux which would be received from the lattice if it possessed a vacancy concentration in local equilibrium with the dislocation core. Under non-equilibrium conditions this situation may be achieved, for example, if the core is saturated with the equilibrium vacancy concentration in the presence of a high jog density which is capable of easily creating and destroying vacancies and/or a high rate of vacancy diffusion exists along the core (see Thompson and Balluffi 1963a, b).

However, since so little is known about the details of such phenomena, it cannot be predicted in advance whether either of these situations should persist. It is therefore reasonable to assume an ideal source as a limiting case and examine its behaviour, and compare the results with experiment.

Consider first the emission controlled rate of climb of an ideal source loop lying in the centre of a thin foil of thickness \( 2h \) under the assumed condition that the diffusional loss of the emitted vacancies to the foil surfaces is so rapid that the vacancy concentration is maintained everywhere throughout the foil at the value in equilibrium with the surface. 

\[ \phi = \frac{2\pi r_0 \sigma_0}{\sigma_0} \]

\[ \phi \]

The first bracketed term is the jog volume \( \frac{2r_0}{\sigma_0} \) in the lattice of the foil and the second is the fraction of vacancies of a vacancy across the torus of the lattice is \( \frac{2r_0}{\sigma_0} \), where \( r_0 \) of \( 2r_0 \) atoms, since only \( \frac{1}{2} \) if \( \frac{1}{2} \) of the later four terms is the fractional detailed balance fluxes. The \( \frac{2r_0}{\sigma_0} \) of \( \frac{2r_0}{\sigma_0} \) where concentrations in local equilibrium and \( \frac{2r_0}{\sigma_0} \) are the correct.

Finally, 

\[ -\left( \frac{dr_0}{dt} \right) = \frac{\sqrt{2r_0}}{8\pi r_0} \]

where the self-diffusion coefficient.

Consider next the rate of climb where we assume that the lattice vacancies are able to diffuse at the lattice vacancy concentration locally be reulated at the fraction of the dislocation rate is theory:

\[ -\left( \frac{dr_0}{dt} \right) = \frac{\sqrt{2r_0}}{8\pi r_0} \]

where \( r_0 \) is the effective radius of the lattice vacancy capacity of a conducting geometry as the loop. The geometry can be readily shown, for the vacancy flux between two uninsulated isolated spheres with \( r_0 \) and \( r_0 \).

In arriving at eqn. (8) we ignore diffusion currents in the direct vicinity of the source and should be fairly independent of the diffusion limited shrinking.

The diffusion limited shrinking of a sandwich diffusion flux \( \phi \) in or out of \( D_0 \), with a corresponding flux \( \phi \) is, according to Frenkel (1961): 

\[ \phi \]

(9)
Correspondence

Nitrogen occurs in diamond coat and diamond core (though in different kinds of aggregation according to the results of Faulkner et al). The particulate inclusions are found in coat and in core near the boundary. It seems probable, therefore, that diamonds throughout their entire growth were in a medium which contained both nitrogen and the material of the inclusions. At some stage conditions in the medium might have changed in such a way as to precipitate the inclusion material, some of which would then have been enveloped in the growing diamond. If this precipitate contained silicon carbide or other carbonaceous material, diamond growth could then have been slowed and eventually halted through depletion of the carbon supply. Thus there is an explanation of why there are many diamonds with coat type material on the outside of clear diamonds within, but to my knowledge none the other way round. Presumably the growth rate of most diamonds was limited for most of the time by diffusion of carbon to the growth face, for diamonds of the order of size of 1 mm to 1 cm and are found in kimberlite as crystals of similar size. More than not in great quantity as microscopic crystals (though some such do occur). Thus growth must have been rather slow and nucelation of new diamond crystals difficult. It seems improbable that the only places in the earth suitable for diamond growth were those where near equilibrium conditions of temperature and pressure prevailed, without there being equally suitable regions at greater depth where conditions were unambiguously in the diamond-stable region of the phase diagram, and where nucleation would have been abundant in the presence of excess carbon. Probably, therefore, diamond growth was limited by the availability of carbon in suitable form.

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References


On the Annealing of Dislocation Loops by Climbing

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Abstract

It is pointed out that the only case where the shrinkage rate of a climbing dislocation loop can be predicted without making detailed and untested assumptions about climb processes is that where the creation and destruction of point defects in the core are rapid enough so that somehow the core is capable of acting as an 'ideal source'. The problem is treated in terms of a configuration in which the core is capable of acting as an 'ideal source'. Under these conditions it is found that loop shrinkage, even in thin films suitable for transmission electron microscopy, should usually occur under diffusion controlled conditions. Our present lack of knowledge regarding the variety of mechanisms by which the ideal source condition can be achieved is emphasized.

The detailed and appropriate climb model of Kaiser and Whelan, which has been universally employed in the literature in the treatment of this problem, is shown to depend upon a number of restrictive and untested assumptions. It is shown, however, that this climb model predicts a shrinkage rate which is in close agreement with that of an ideal source shrinking under diffusion controlled conditions.

Selected experimental data are discussed. Observations in the recent experimental data of Eder and Smallman for the shrinkage of hexagonal feldspar loops are pointed out.

Kaiser and Whelan (1966) were the first workers to observe directly the linkage of vacancy type prismatic dislocation loops in thin aluminium with transmission electron microscopy. They treated the problem of dislocation loop shrinkage by employing the Friedel (1966, 1964) climb mechanism and carried out several calculations in order to decide whether the shrinkage rate in thin films (1-1.500 A thick) was limited by either of two processes: (1) the rate at which vacancies were emitted from the dislocation core; or (2) the rate at which the vacancies were able to diffuse from the dislocation loop to the surfaces by lattice diffusion. Their calculations yielded results for the two cases which were sufficiently close together so that a satisfactory clear-cut decision between them was possible. However, they favoured the result that the climb was controlled by vacancy emission and elected to analyse their data on this basis. In their detailed formulation of emission limited dislocation climb loops and Whelan made the following prior assumptions:

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Nitrogen occurs in diamond coat and diamond core (though in different kinds of aggregation according to the results of Faulkner et al.). The particular inclusions are found in coat and in core near the boundary. It seems probable, therefore, that diamonds throughout their entire growth were in a medium which contained both nitrogen and the material of the inclusions. At some stage in the medium might have been charged in such a way as to precipitate the inclusion material, some of which would then have been enveloped in the growing diamond. If this precipitate contained silicon carbide or other carbonsous material, diamond growth could then have been slowed and eventually halted through depletion of the carbon supply. Thus there is an explanation of why there are many diamonds with coat type material on the outside and clear diamond within, but to my knowledge none the other way round. Presumably the growth rate of most diamonds was limited for the same reasons that diamond crystals of size of 1 mm to 1 cm and more, but not in great quantity as microscopic crystals (though some such do occur). Thus growth must have been rather slow and nucleation of new diamond crystals difficult. It seems improbable that the only places in the earth suitable for diamond growth were those where near equilibrium conditions of temperature and pressure prevailed, without the conditions of temperature and pressure prevailing at greater depth where conditions were unambiguously in the diamond-stable region of the phase diagram, and where nucleation would have been abundant in the presence of excess carbon. Probably, therefore, diamond growth was limited by the availability of carbon in suitable form.

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I thank Dr. W. C. Pfefferle for assistance with the gas chromatography and for many valuable discussions.

References


Faulkner, H., 1965, Phil. Mag., 12, 413.


1. Emission occurs from jogs present on the core at an average concentration of a atom fraction, 
2. the emission rate per jog is rapid and is that given by Fredel (1956, 1964).

These assumptions are presently untested. Even though it has been widely assumed that the density of atomic jogs of unit height is \( \sim 1 \) on a dislocation loop which appears circular under the electron microscope (see fig. 1 in Sliouks and Whitman), it is clear that the apparently circular shape of this resolution can also be achieved by a lower density of jogs with a height greater than one unit distance. The exact configuration will depend as usual upon the energy and entropy of the various topologically possible configurations. It is also clear that the emission rate at a highly relaxed jog could be considerably slower than that given by Fredel (1956). Subsequent workers in this field (e.g. see Fritio 1956, Shimomura 1965, Edgington and Smallman 1965, Kastan 1965 and Thomas 1965) have all used the Sliouks-Whitman emission limited model to interpret their results. In our opinion the use of this specific model may not be generally justified, and a number of aspects of the problem have not been discussed sufficiently.

In the present note we avoid the problem of attempting to specify unknown climb processes in the core by introducing an 'ideal source' dislocation loop. We visualize the dislocation loop to be in the shape of a torus with a large radius \( r_l \) which is the same as the radius of the loop and to have a circular cross section which is of atomic dimensions with a radius \( r_a \). The torus exchanges vacancies with the lattice whenever a vacancy jumps across the 'surface' of the torus. The core is defined as an ideal source when the outward vacancy flux is equal to the detailed balance flux which would be received from the lattice if it possessed a vacancy concentration in local equilibrium with the dislocation core. Under non-equilibrium conditions this situation may be achieved, for example, if the core is saturated with the equilibrium vacancy concentration in the presence of a high jog density which is capable of quickly creating and destroying vacancies and for a high rate of vacancy diffusion exists along the core (see Thomson and Balluffi 1962, 1963). However, since so little is known about the details of such phenomena, it cannot be predicted in advance whether either of these situations should obtain.

Consider first the emission controlled rate of climb of an ideal such loop lying in the centre of a thin foil of thickness \( t_s \) under the condition that the diffusional loss of the emitted vacancies to the foil surfaces is so rapid that the vacancy concentration is maintained everywhere throughout the foil at equilibrium with the source.

\[ \phi \approx \frac{2\pi a_s^2 \langle \sigma \rangle_{v} (\sigma_{l})}{a_s} [N] \left[ \frac{\alpha}{3} \right] \left[ \frac{1}{\exp(\mu / kT) - 1} \right] \]

The first bracketed term is the number of atomic sites on the surface of the torus \( n_a \) (the lattice parameter). The second term gives the fraction of these sites which are occupied by vacancies \( [N] \) (the equilibrium atomic fraction of vacancies). The third term is the jump frequency of a vacancy across the toroidal surface (the vacancy jump frequency in the lattice is \( 1/\tau_0 \), where \( \tau_0 \) is the vacancy diffusivity, and the factor of 3 arises, since only \( 2/3 \) of the jumps are in the forward direction). The fourth term is the fractional difference between the outward and inward detailed balance fluxes.

Finally, if the chemical potential \( \mu \) is roughly constant on the foil surface, then

\[ \frac{\partial N}{\partial t} = \frac{\sqrt{3a_s^3}}{2\pi r_a} \phi \approx \frac{4\sqrt{3a_s^2} D_0}{a_s^3} \left( \exp(\mu / kT) - 1 \right) \]

where the self-diffusion coefficient \( D_0 \) is given by \( D_0 = D_s N_s \).

Consider next the rate of climb of an ideal source loop with \( r_l \leq r_a \), where we assume that the shrinkage rate is controlled by the rate at which vacancies are able to diffuse away to the foil surface (i.e. we assume that the lattice vacancy concentration is maintained infinitesimally close to the local equilibrium both at the loop and at the surface). The quasi-steady-state shrinkage rate is then

\[ \frac{\partial r_l}{\partial t} = \frac{\sqrt{3a_s^3}}{2\pi r_a} \approx \frac{2\pi a_s^2}{a_s^3} r_l \left( \frac{\tau_{\text{diff}}}{\tau_{\text{jump}}} \right) D_0 \exp(\mu / kT) - 1 \]

where \( r_{\text{diff}} \) is the effective radius of the loop which is given by the electronic capacity of a conducting body in a large medium having the same geometry as the loop. The capacity in a large medium may be used, once it can be readily shown, for example, that the capacitance of a sphere is given by \( 4\pi r_0^2 \) (Styghe 1960).

In applying eq. (3) we neglected the effects of the strain field on the diffusion currents in the direct vicinity of the loop. However, the results would be fairly independent of that, since, as seen below, \( r_{\text{diff}} \) is almost constant.