INFLUENCE OF IMPURITIES AND ELECTRIC FIELDS ON 
THE KINETIC CHARACTERISTICS OF THE EXPANSION 
OF DISLOCATION HALF-LOOPS IN NaCl : Ca²⁺ CRYSTALS 

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The effect of the concentration (C) of Ca²⁺ impurity ions and electric fields up to 50 kV/cm on 
the kinetic characteristics of the expansion of edge and screw dislocation half-loops in un-
annealed and quenched NaCl crystals is studied. It is confirmed that 1) the concentration depen-
dence of the rate \( v \) of expansion of screw half-loops takes the form \( v = v^* \exp (-AC^{1/2}) \); 2) 
with increasing field strength \( E \) the velocity \( v \) increases linearly in pure NaCl crystals; in 
impure crystals for \( E > 5 \) kV/cm the rate of expansion of the edge half-loops increases and 
that of the screw half-loops diminishes as \( \sim \exp (E) \). The extent of the latter effect depends 
on the concentration of Ca²⁺ impurity ions in the crystals and also on their heat treatment. 
The exponential change in \( v \) with field \( E \) is apparently a consequence of the reorientation of 
the "Ca²⁺ ion--cation vacancy" dipoles in the electric field. The activation energy for the re-
orientation of the dipoles is estimated. The linear increase in the rate of expansion of the 
half-loops is explained as being due to the reduction in the number of steps in the dislocation 
under the influence of the electric field.

When studying the velocity \( v \) of the dislocations in NaCl crystals with different concentrations of Ca²⁺ [1] 
and Sr²⁺ [2] impurities as a function of applied shear stress, it was found that small quantities of impurities 
greatly reduced the value of \( v \). This may be attributed to the presence of "M²⁺--cation vacancy" dipoles and their complexes in alkali halide crystals containing divalent substitutional impurities, creating strain fields of tetragonal symmetry and preventing the movement of the dislocations [3, 4]. A calculation of the energy 
of elastic interaction between a dislocation and a dipole [5, 6] shows that this depends on the orientation of the 
dipole relative to the dislocation. Hence external actions leading to the orientation of the dipoles in one particu-
lar direction in the deformed crystal should change the velocity of the dislocations very considerably. A 
study of the effect of an electric field on the mobility of the edge dislocations in NaCl crystals [7-9] in fact 
shows that the change in the mobility of the dislocations cannot be explained simply by the action of the field 
on charged dislocations; it is also essential to allow for its influence on the "M²⁺ ion--cation vacancy" dipoles, 
which are capable of becoming oriented in an electric field [10-12]. However, no detailed study of the action 
of an electric field on the dipoles leading to a change in the mobility of the dislocations has yet been carried 
out. This paper constitutes an attempt at solving this problem by studying the influence of Ca²⁺ concentration 
and electric field on the kinetic characteristics of the expansion of edge and screw dislocation half-loops (EDH 
and SDH) in NaCl crystals.

We used NaCl crystals containing Ca²⁺ -5 -10⁻³, 10⁻², 3 -10⁻² mol. % and also "pure" crystals with a total 
content of divalent impurities (chiefly Mg²⁺) no greater than 10⁻³ mol. %. All the crystals were annealed for 
48 h at 650°C and cooled at a rate of 5 deg/h in order to reduce the dislocation density in the crystals to \( \sim 10^3 \)
Fig. 1. Rate of expansion of screw dislocation half-loops (v) as a function of the concentration C of Ca\(^{2+}\) impurity ions in annealed NaCl crystals for a shear stress of \(\tau = 120\) g/mm\(^2\); the arrangement of the half-loops in the crystal is also shown.

Fig. 2. Rate of expansion \(v\) of screw dislocation half-loops as a function of the electric field \(E\) in annealed NaCl crystals containing Ca\(^{2+}\) impurity ions and subject to a shear stress \(\tau\): 1) "pure" crystals, \(\tau = 25\) g/mm\(^2\); 2) \(5 \times 10^{-3}\) mol. \%, \(\tau = 0\) g/mm\(^2\); 3) \(10^{-2}\) mol. \%, \(\tau = 100\) g/mm\(^2\); 4) \(3 \times 10^{-2}\) mol. \%, \(\tau = 120\) g/mm\(^2\).

Some of the annealed crystals were air-quenched from 300°C (quenching rate \(\sim 60\) deg/h). By rolling a steel sphere over the freshly cleaved (001) surface of the crystal, dislocation rosettes were obtained; on polishing these surfaces, individual EDH and SDH were left in the (110) and (011) planes respectively (Fig. 1) [13]. The 10-30 \(\mu\)m wide half-loops so introduced expanded under the action of shear stress applied by loading the crystals on the principle of four-point bending in a crystal-distorting machine [14]. The electric field vector \(E\) was directed along the [100] direction when studying its influence on SDH and along the [\(\bar{1}0\)] when studying EDH. The experiments on the quenched crystals were carried out immediately after quenching, so as to avoid the effects of aging.

RESULTS AND DISCUSSION

1. Influence of Ca\(^{2+}\) Impurity Content

Under the influence of an applied shear stress the screw components of the SDH move in opposite directions [100] and [\(\bar{1}00\)] (Fig. 1) so that the half-loop expands. The velocity of the half-loop components differ from one another, so that the average velocity of the two components is taken as the velocity \(v\) of the expansion of the half-loop. The rate of expansion \(v\) of the SDH in NaCl crystals in the presence of a shear stress \(\tau = 120\) g/mm\(^2\) is shown as a function of the Ca\(^{2+}\) impurity content \(C\) in Fig. 1. Each point on the \(v(C)\) curve corresponds to the mean rate of expansion of 40-50 half-loops. In coordinates of \(\log v \sim C^{1/2}\) the results of the measurements fall on a straight line, so that the \(v(C)\) relationship takes the form

\[ v = v^* \exp \left( -AC^{1/2} \right) \]

where \(v^*\) is the velocity of the dislocations in the pure crystals and \(A\) is a constant. This agrees with the theoretical relationship deduced by Gilman [15] when considering the mechanism of overcoming dislocation barriers created by point defects by means of thermal fluctuations.