NUCLEAR MAGNETIC RESONANCE IN PLASTICALLY DEFORMED ROCK SALT

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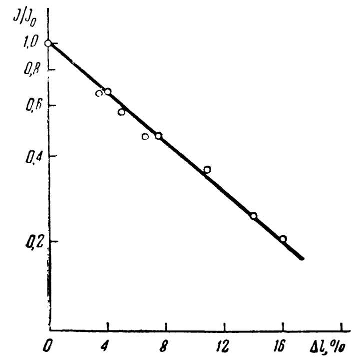
The intensity of the nuclear magnetic resonance line of Na^{23} was measured in plastically deformed rock salt crystals as a function of the degree of deformation.

THE magnetic resonance of nuclei possessing quadrupole moments is very sensitive to different kinds of crystal defects and, in particular, to defects due to plastic deformation. The effect of plastic deformation on the resonance of Br and I nuclei in KBr and KI crystals has been studied in a number of papers.[1,2] However, the quadrupole interaction of these nuclei is so large that even in the original undeformed crystals only the central line is observed, while the satellites are completely smeared out, owing to the presence of defects arising during the process of crystal growth. Therefore, in the case of KBr and KI crystals, we are unable to observe the behavior of the satellites under plastic deformation. At the same time, an investigation of the effect of plastic deformation on the satellites is of considerable interest, particularly because a number of papers[3,4] report analogous investigations carried out on crystals with impurities. Apparently it is possible to observe the behavior of the satellites under plastic deformation only in a crystal in which either the concentration of the growth defects is smaller than in KBr and KI crystals, or the quadrupole interaction of the nuclei whose resonance is being investigated is less than the quadrupole interaction for the Br and I nuclei. A suitable crystal, from the last mentioned point of view, is rock salt, NaCl. Experiments on the measurement of the intensity of the absorption line due to Na^{23} in NaCl crystals, carried out by Kawamura et al.,[3] have shown that in these crystals both the central line and the satellites can be fully observed. Thus, in the case of rock salt there exists a possibility of studying the effect of plastic deformation on the satellites.

The measurements to be described have been carried out utilizing an apparatus of Pound's type.[5] The rock salt crystals were deformed by a linear compression along the [001] direction. As a rule, only one pair of mutually perpendicular glide systems took part in the deformation, so that the deformed samples had the shape of a double-ended barrel. For each sample the measurements were carried out for three different orientations of the magnetic field: parallel to the [100], [110] and [010] directions. No angular dependence was observed in the course of these measurements.

The diagram shows on a semilogarithmic scale the relative intensity of the satellites (i.e., the total intensity minus the intensity of the central line) as a function of the degree of deformation. Each point represents an average of measurements corresponding to the three orientations mentioned previously. Deviations from these average values do not exceed 6%.



Dependence of the relative intensity of the satellites on the degree of deformation.

As can be seen from the diagram a decrease in the intensity of the satellites occurs as a result of plastic deformation. It must be emphasized that the width of the "total" line remains, within experimental error, the same as for undeformed samples.

Defects arising in the course of plastic deformation are linear ones, with a definite orientation in the crystal (dislocations). However, the absence of any angular dependence compels us to regard them in our case either as approximately equiaxial (short segments of dislocations), or as randomly oriented ones. The former case appears to us to be more probable, and therefore we shall speak henceforth not of dislocations but of some centers of distortion.

Taking this into account, and also the absence of any broadening of the absorption line, we can, just as in the case of crystals with impurities, utilize the critical-sphere model.[3,4] According to this model, the intensity of the satellites in the case of a random distribution of centers of distortion must be proportional to the probability of the center of distortion lying outside the critical sphere, i.e.,

$$J/J_0 = (1-c)^{v_c/v_0}, \qquad (1)$$

where J and J_0 are the intensities of the satellites in deformed and undeformed crystals respectively, c is the concentration of centers of distortion, v_0 is the volume occupied by a center of distortion, and v_c is the volume of the critical sphere. On taking the logarithm of (1), and on taking into account the fact that c is small we have

$$\ln(J/J_0) \approx -cv_c/v_0. \qquad (2)$$

It appears natural to assume that the concentration of the centers of distortion is proportional to the degree of deformation. Then, a plot of $\ln(J/J_0)$ vs. the degree of deformation should be a straight line, and this is indeed the case as can be seen in the diagram. Since c and v_0 are not known we can not determine v_c from our experimental data. Nevertheless, we have the possibility of making a rough estimate of the dimensions of the critical sphere by utilizing the data of Kawamura et al.,[3] who determined, on the basis of their experimental results, the radius of the critical sphere for Na^{23} nuclei in mixed NaCl-NaBr crystals.

Following Bloembergen,[6] we can write the expression for the electric field gradient in the lattice in the cases of a mixed and of a plastically deformed crystal. In a mixed NaCl-NaBr crystal the gradient at a distance r from an ion of the Br^- impurity is given by

$$eq = 6e(a_{\text{imp}} - a_0)\, a_0^2/a^3r^3, \qquad (3)$$

where a_{imp} and a_0 are the radii of the Br^- impurity and of the principal Cl^- ion, and a is the lattice constant of NaCl. In plastically deformed NaCl, the gradient at a distance r from a dislocation is given by

$$eq = 6e/a^2r. \qquad (4)$$

At the surface of the critical sphere the two gradients must be equal. On equating (3) and (4), and on taking into account the fact that in the former case the radius of the critical sphere is approximately equal to 6 A, we find that in plastically deformed NaCl the radius of the critical sphere is of the order of 10^3 A. Of course this figure requires experimental verification.

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[6] N. Bloembergen, Reports of the Conference on Defects in Crystalline Solids, Bristol, 1954, London, 1955, p. 1.

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55