this is the largest voltage that could be generated despite attempts to induce larger persistent currents in this cylinder. In this particular cylinder the maximum measured persistent current[4] is nearly six times larger (1.5 amperes). These data were taken on a tin cylinder 1 cm diameter, 1 mm long, and 1200Å thick. Similar results have also been obtained from a 1-cm cylinder 5 mm long and 450Å thick.

These experiments tend to confirm the adiabatic invariance of the fluxoid under small thermal perturbations. On a two-fluid model such a behavior indicates that the electrons condense only into a particular current-carrying state—the flux changing in such a way as to keep the fluxoid constant. The implication that adiabatic invariance under these perturbations applies only to flux changes less than one quantum is being investigated.

*Now with the National Science Foundation.

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ELECTRON SPIN RESONANCE OF THE R CENTER*

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van Doorn[1,2] has proposed a model for the R center in the alkali halides, Fig. 1, which is a cluster of three F centers forming an equilateral triangle lying in a (111) plane. Although this model predicts that the R center should be magnetic, extensive investigations by electron spin resonance of systems containing R centers[3-4] have not revealed the resonance nor given any conclusive evidence that the center is paramagnetic. Under conditions of low temperature (~2°K) and large applied uniaxial stress (~3kG/mm^2) the resonance can be observed as described below, lending considerable support to the van Doorn model.

Results of optical studies of the zero-phonon line of the R_2 band[6] with applied uniaxial stress[7] are consistent with the model of van Doorn. These studies further suggest that in a static lattice the lowest electronic state of the center would be orbitally doubly degenerate. If one includes the ion motion, a dynamic Jahn-Teller effect results[8] which still leaves a degenerate electronic-vibronic state lowest.

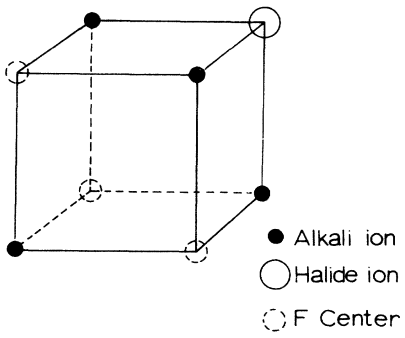

FIG. 1. The van Doorn model of the R center.

This degeneracy is probably lifted by residual strains in the crystal to give finally two Kramers' doublets with g tensors of almost axial symmetry along the [111] direction. The $\delta g_\perp$ should be of the order of the F-center g shift while the $\delta g_\parallel$ contains two terms, one inversely proportional to the Jahn-Teller splitting, the other inversely proportional to the strain splitting if that splitting is sufficiently large. The two Kramers' doublets are strongly coupled by the phonon field, and it is postulated that the electron spin resonance is normally broadened beyond observability because of T_1 processes involving the direct relaxation among these levels in a Finn-Orbach type process.[9] This postulate suggests an experiment under conditions of large applied stress, which gives a large energy separation, Δ, between the two Kramer's doublets, and low temperature, in order to suppress the relaxation process which varies as $\exp(-\Delta/kT)$.

Figure 2 shows the change in resonance signal produced by a [110] stress with the static magnetic field parallel to the $[1\bar{1}1]$ direction. The strong line is the saturated F-center resonance while the weaker line, which develops with application of the stress, is the R-center reso-

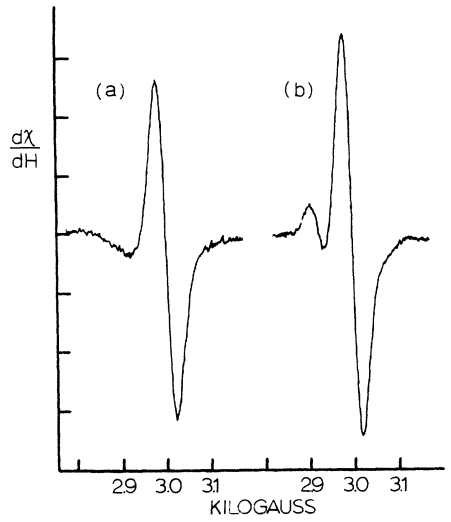

FIG. 3. Resonance with H_0 along (a) $[1\bar{1}1]$ and (b) $[\bar{1}11]$ directions after bleaching with light parallel to $[\bar{1}11]$; other conditions roughly as in Fig. 2.

nance. Because $g_\perp$ is approximately that of the F center, the R resonance is resolved from the F only for those R centers for which the static field is nearly parallel to the symmetry axis. In Fig. 2, only the centers with a $[1\bar{1}1]$ symmetry axis[10] are observed, giving $g_\parallel = 2.06$; the centers with axes along [111], $[\bar{1}11]$, and $[11\bar{1}]$ contribute intensity to the stronger resonance and are not resolved. The R resonance is not seen at 4°K at the same applied stress suggesting that the observability relates to the suppression of the relaxation process and not to the stabilization of particular g values by establishing an applied stress large compared to the internal stresses.

The positive g shift is not to be interpreted as resulting from a holelike resonance. In a defect, such as this, in which the electron moves on several centers, the sign of the spin-orbit coupling depends on the sense of circulation of the electrons around the individual positive ions relative to the sense of net circulation about the symmetry axis. These two circulations may have opposite sign and thus, even for a defect which is clearly electronlike, in the sense that the excited states which yield the g shift correspond to electron, not hole, excitations, the g shift may have either sign. This effect is closely analogous to the inverted spin-orbit splitting for the excited state of the F center deduced from the Faraday effect.[11,12]

The assertion that the resonance is indeed due to the R center and not some other defect is based on several observations.

(1) Although the angular variation of the g value has been followed only over a small range of angles because of the extensive overlap with the F resonance, the available data are consistent with the symmetry of the van Doorn model using $g_\parallel = 2.06$ and $g_\perp \approx 2.0$.

(2) The important features of the R-center model which led to the prediction of the qualitatively observed stress and temperature dependence of the relaxation rate and angular dependence of the g value were the [111] axis of symmetry and the orbital degeneracy of the ground state. It would seem unlikely that another defect would also be present showing similar properties.

(3) To establish the identification on an even firmer basis the following experiment was carried out. Okamoto[13] has shown that one can alter the relative populations of the four equivalent orientations of the R center by bleaching with polarized light in the R bands at room temperature. The R-band transition moments are perpendicular to the symmetry axis of the defect[14,7] so that bleaching with $[\bar{1}11]$ light enhances the population of $[\bar{1}11]$ centers, which do not absorb this light, at the expense of centers with [111], $[1\bar{1}1]$, and

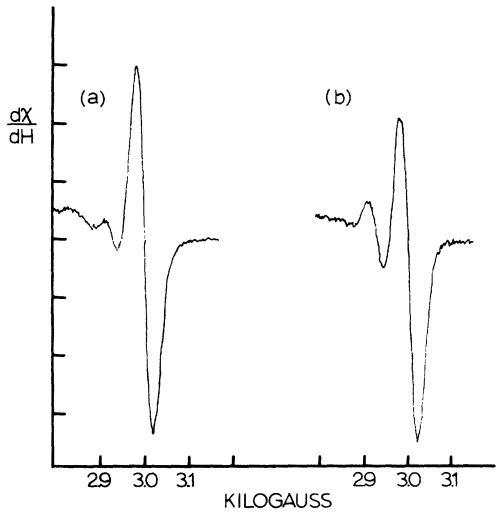

FIG. 2. Electron spin resonance of colored KCL under the following conditions: X-ray Harshaw KCL treated to remove O_2^- centers, initial F concentration approximately 1.4×10^{17} cm^{-3}, optically bleached to give ratio of R to F peak optical absorption of 2:5 at room temperature. Temperature is 2.2°K, static magnetic field, H_0, parallel to crystal $[1\bar{1}1]$ axis. Stress applied along crystal [110] axis. Note that there is also a weak backgound resonance. (a) $\sigma \sim 0$; (b) $\sigma \sim 2.5$ kg/mm^2.

$[11\bar{1}]$ symmetry. Since the resonance either of the $[\bar{1}11]$ centers or of the $[1\bar{1}1]$ centers may be observed by appropriate orientation of the magnetic field, if the resonance is indeed associated with the R center, the polarized bleaching must enhance the $[\bar{1}11]$ resonance at the expense of the $[1\bar{1}1]$ resonance. The curves of Fig. 3 confirm this prediction. Since the magnetic field cannot be applied along the [111] and $[11\bar{1}]$ directions in the present resonance rig, a quantitative comparison with the optical dichroism is not possible, but the degree of polarization indicated by Fig. 3 is consistent with the optical dichroism.

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GAMMA-RAY SPECTRA FROM SPONTANEOUS FISSION OF ^{252}Cf†

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In this note we report preliminary results of experiments that show well-defined prompt γ-ray peaks ($\tau < 10^{-9}$ sec) associated with fission fragments of selected masses. The dependence of the Doppler shift of the energy of the radiation on fragment direction and mass is found to be a valuable aid in the interpretation of the spectra. These results are of special interest because it has generally been assumed on the basis of early measurements that the gamma spectra would be sufficiently complex to preclude observing distinctly resolved spectra.[1] The identification of discrete gamma spectra offers the hope of obtaining nuclear energy-level data in a neutron-excess region not accessible by other means, and may also contribute to knowledge concerning the spins and de-excitation processes of the primary fragments.

Our results have come about through measurements of the energies of both members of pairs of fragments and of coincident gamma rays from single fission events. A weightless ^{252}Cf fission source which was prepared by self-transfer onto thin nickel foil was used in the measurements. The energies of the two fragments were measured and the direction of fission was defined by means of two solid-state counters located about 1 cm from the source. The energies of the γ rays were measured with a 3-by-3-in. NaI(Tl) counter placed at the desired angle with respect to the direction of motion of the coincident fragments. The coincidence resolving times were adjusted to accept γ rays emitted within ±50 nsec of the time of fission. The data were recorded in three dimensions by using a multidimensional pulse-height analyzer, and were stored event by event in correlated form on magnetic tape. The results were sorted by using an IBM-7094 computer in such manner that the individual gamma-ray energy spectra were obtained separately for fragment energy ratios of 1.05 to 1.15, 1.15 to 1.25, 1.25 to 1.35, and 1.35 to 1.45. The fragment energy ratio, R, approximately equals the mass ratio and is referred to hereafter as the mass ratio. The sorting interval above corresponds to about four mass units.

Figure 1(a) shows the gross gamma spectrum in prompt coincidence with fission fragments of all energies (NaI detector at 0 deg with respect to fission). There is some evidence of peaks in