Sm^{3+}-Doped CaF_2

The impurity concentration in the last sample studied is an order of magnitude higher than those of the previous crystals. The variation of T_1 with temperature measured for the CaF_2 crystal containing Sm^{3+} (1.59×10^{20} ions/cm^3) is shown in Fig. 6. A minimum occurs around $T=85°K$, but it is shown below that it does not correspond to the conditions $\omega\tau=1$ for the Sm^{3+} relaxation process. Hence we have not calculated D for this sample. Equation (5) has been used to give an estimate of the temperature variation of τ. The values $D=2.5\times10^{-13}$ cm^2/sec, from Eq. (2), and $S=\frac{5}{2}$ have been used with the measured T_1 data to obtain the curve shown in Fig. 7. It is seen that $\omega\tau\ll1$ throughout the temperature range investigated. Once again the mechanisms predominating in the relaxation process of the paramagnetic impurities have not been identified. The anomalous behavior of the T_1-versus-temperature curve below 85°K is not presently understood.

Although the values of τ shown in Fig. 7 cannot be taken too seriously, it is indicated that at the lower temperatures the Sm^{3+} ions in this sample relax much faster than the Tb^{3+} and Tm^{3+} ions in the other two crystals. This may partly be due to the fact that the Sm^{3+} concentration was much higher than the others. Bierig *et al.*[12] have observed a dependence of τ on concentration for cerium in CaF_2. They attribute shorter relaxation times at higher concentrations to variations in the lattice vibrations caused by the introduction of the impurities. For each of our three impurity ions, the lattice defect has both a charge and a mass difference with an associated interstitial fluorine ion.[16] This could cause variations in vibrational amplitudes with associated increased relaxation rates of paramagnetic ions.

V. CONCLUSIONS

It appears that T_1 of F^{19} in the CaF_2 crystals doped with Tb^{3+}, Tm^{3+}, and Sm^{3+} is due to the "slow-diffusion" limit of the impurity relaxation mechanism in the temperature range of our measurements (28–300°K). For both the Tb^{3+}- and the Tm^{3+}-doped samples, minima in T_1 occur near 41°K. The values of the nuclear spin-spin diffusion coefficient D obtained from these minima have been used to calculate the temperature dependence of the spin-lattice relaxation time τ of the paramagnetic impurities. The paramagnetic relaxation measurements are available for Tb^{3+}:CaF_2 only, and these seem to be in reasonable agreement with our calculated values.

ACKNOWLEDGMENTS

The authors wish to thank Dr. Richard J. Lysiak for many helpful discussions and Dr. Charles Blount for his valuable help concerning low-temperature techniques. They would also like to thank Dr. R. F. Raeuchle for the use of his x-ray facility.

[16] J. R. O'Conner and H. A. Bostic, J. Appl. Phys. **33**, 1868 (1962).

Erratum

Logarithmic Terms in the Wave Functions of the Ground State of Two-Electron Atoms, K. FRANKOWSKI AND C. L. PEKERIS [Phys. Rev. **146**, 46 (1966)]. On p. 48, Sec. III, paragraph 1, the fourth sentence should read: "The computations were carried out on the computer GOLEM in 19-decimal accuracy (single precision of the GOLEM), and were checked with double precision of 38-decimal accuracy."