sec correspond to overlap of one of the two lines in the spectrum of the radiator with one of the components of the hyperfine structure in the spectrum of the absorber.

Such an interpretation of the result is confirmed by measurements with an absorber in the form of an alloy $SnNb_3$ (30 mg/cm^2), the results of which are shown in the lower part of the figure. The $SnNb_3$ crystal has a crystal lattice similar to the lattice of β tungsten, which is very close to cubic;[6] this gives grounds for assuming the absence of hyperfine structure of the 23.8-kev level of Sn^{119} in such a crystal. At zero source velocity there is no resonance absorption, since the unsplit absorption line in $SnNb_3$ does not coincide with the split line of the source. For source velocities of ±0.73 mm/sec an overlap occurs of one of the components of the hyperfine structure of the radiated line with the line of the absorber, which corresponds to the two absorption maxima in the figure. The separation $\Delta = (eQ/2)\,\partial^2V/\partial z^2$ between the components of the hyperfine structure of the 23.8-kev level was equal to $(1.15 \pm 0.25) \times 10^{-7}$ ev. The size of the quadrupole moment of the 23.8 kev level cannot be determined since we do not know the electric field gradient in the tin crystal.

---

[1] R. L. Mössbauer, Z. Physik **151**, 124 (1958).

[2] R. L. Mössbauer, Z. Naturforsch. **14a**, 211 (1959).

[3] Lee, Meyer-Schutzmeister, Schiffer, and Vincent, Phys. Rev. Lett. **3**, 223 (1959).

[4] Hanna, Heberle, Littlejohn, Perlow, Preston, and Vincent, Phys. Rev. Lett. **4**, 177 (1960).

[5] A. I. Alikhanov and V. A. Lyubimov, Report to the Tenth Annual Conference on Nuclear Spectroscopy, Moscow, 1960.

[6] A. F. Wells, Structural Inorganic Chemistry, (Russ. transl.) IIL, 1948, p. 629.

Translated by M. Hamermesh
46

ELECTRON PARAMAGNETIC RESONANCE OF VANADIUM IN RUTILE

G. M. ZVEREV and A. M. PROKHOROV

Institute of Nuclear Physics, Moscow State University

Submitted to JETP editor May 28, 1960

J. Exptl. Theoret. Phys. (U.S.S.R.) **39**, 222-223 (July, 1960)

AN electronic paramagnetic resonance (EPR) spectrum was observed in single-crystal rutile (TiO_2), containing 0.01% vanadium. The spectrum consists of two lines with characteristic hyperfine structure, corresponding to the isotope V^{51} with nuclear spin $7/2$.

Each line (group of eight hfs components) belongs to its own system of non-equivalent vanadium ions, which are isomorphic substitutions for the Ti^{4+} ions in the crystal lattice of rutile.

The crystallography of rutile was described in detail by Grant.[1] A unit cell contains two titanium ions differing in the placement of the six neighboring oxygen ions, which produce an electric field of rhombic symmetry. When the crystal is rotated 90° about the tetragonal axis, one system of nonequivalent ions goes into the other. Accordingly, when the crystal is rotated about a tetragonal axis oriented perpendicular to the direction of the external magnetic field, the overall appearance of the vanadium spectrum is repeated every 90°. A similar picture is observed also for Cr^3 ions introduced into rutile.[2]

The EPR spectrum of vanadium can be set in correspondence with the following spin Hamiltonian ($S = 1/2$; $I = 7/2$):

$$\hat{\mathscr{H}} = g_x\beta H_x\hat{S}_x + g_y\,\beta H_y\hat{S}_y + g_z\beta H_z\hat{S}_z + A_x\hat{I}_x\hat{S}_x + A_y\hat{I}_y\hat{S}_y + A_z\hat{I}_z\hat{S}_z,$$

where $\hat{S}$ and $\hat{I}$ are the electron and nuclear spin operators, g is the anisotropic factor of spectroscopic splitting, A is the hfs constant, and β is the Bohr magneton. The axes are chosen as follows: the z axis coincides with the tetragonal axis, while the x and y axes are parallel to the [110] and $[1\bar{1}0]$ directions for one system of nonequivalent ions; the x and y axes are interchanged for the second system.

The constants of the Hamiltonian, determined at T = 77°K and 9800 Mcs, are:

$$g_x = 1.955 \pm 0.001, \qquad A_x = 14.15 \pm 0{,}07,$$
$$g_y = 1.913 \pm 0.001 \qquad A_y = 3.09 \pm 0.03,$$
$$g_z = 1.912 \pm 0.001, \qquad A_z = 4.41 \pm 0{,}03.$$

The values of A are given in units of 10^{-3} cm^{-1}.

Experiments carried out at 37,500 Mcs at T = 77°K have shown that the constants of the Hamiltonian are independent of the frequency, while measurements at $T = 4.2°K$ ($\nu = 9800$ Mcs) have shown that they do not change noticeably with the temperature.

No vanadium EPR ions were observed in rutile at room temperature. When the sample is cooled to approximately 135°K, broad lines appear, which gradually narrow down with further decrease in temperature. At $T = 90°K$ the lines reach a width of 3.5 oe. There is no further reduction in the width of the line. This width is probably due to the spin-spin interaction of the paramagnetic ions of vanadium. This is also confirmed by the shape of the line, which corresponds exactly to the Lorentz curve. A line of this shape is expected for magnetically-dilute systems with a concentration of paramagnetic ions less than 1%.[3]

The continuous saturation method was used to measure the spin-lattice relaxation times of the vanadium ion in rutile: $\tau_1 = 2 \times 10^{-1}$ sec at $T = 4.2°$ and $\tau_1 = 6 \times 10^{-6}$ sec at $T = 90°$.

Line broadening was observed at $T = 90°K$ upon saturation, thus confirming again the assumed nature of the observed line width.

The totality of the experimental facts gives grounds for assuming that the vanadium enters the rutile lattice in the form of the ion V^{4+}.

We note that the broadening of the V^{4+} line when heating to temperature above 90°K cannot be due to spin-lattice interaction, since the measurement of τ_1 by the saturation method yields an order of 10^{-6} sec at these temperatures. More detailed investigations of this effect are now in progress.

The authors are grateful to R. P. Bashuk and A. S. Bebchuk for furnishing the samples of rutile with vanadium.

---

[1] F. A. Grant, Revs. Modern Phys. **31**, 646 (1959).

[2] Gerritsen, Harrison, Lewis, and Wittke, Phys. Rev. Lett. **2**, 153 (1959).

[3] C. Kittel and E. Abrahams, Phys. Rev. **90**, 238 (1953).

Translated by J. G. Adashko
47