HYPERFINE STRUCTURE OF GAMMA RAYS PRODUCED BY QUADRUPOLE INTERACTION IN A CRYSTAL LATTICE

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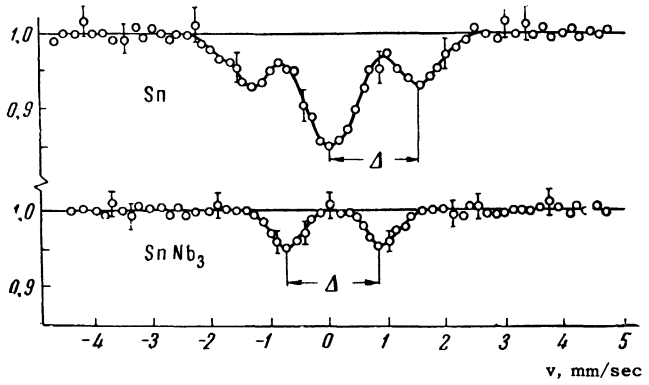
As was recently shown in the experiments of Mössbauer,[1,2] emission (or absorption) of γ rays by nuclei bound in a crystal lattice can occur without energy loss to nuclear recoil. The most interesting result was obtained by Mössbauer with a moving source.[2] If the source is given a velocity v with respect to the absorber, the energy of the radiated quanta is changed because of the Doppler effect by the amount Ev/c; the shift of the radiated line with respect to the absorption line results in a corresponding change in the effective cross section for resonance absorption. This makes it possible to measure directly the shape of the resonance line, whose half-width (for a thin absorber) is equal to twice the natural width of the level.[2,3] Recently, by a similar method, the hyperfine structure of the excited state at 14 kev in Fe^{57} was studied. This hyperfine structure is the result of the interaction of the magnetic moment of the nucleus with the internal magnetic field of the domains in iron.[4]

Alikhanov and Lyubimov observed[5] the resonance absorption of the 23.8 kev γ quanta of Sn^{119} and noted the influence of an external magnetic field on the size of the effect. In the present work we have investigated the hyperfine structure of the 23.8-kev excited state of Sn^{119} resulting from the interaction of the quadrupole moment of the nucleus in its excited state with the internal electric field in the tin crystal.

The measurements were carried out with a source of Sn^{119m} (metallic tin), which was set in motion with respect to the absorber. Unlike the equipments previously described,[2-4] where the source was given a definite fixed velocity, in our experiment the velocity of the source varied linearly in time within definite limits. The law of motion of the source, which was at liquid nitrogen temperature, was determined by a rotating cam of definite profile. The limits of variation of the source velocity are determined by the angular speed of rotation of the cam. The x rays of tin (26 kev) were almost completely absorbed by a characteristic filter — a plate of palladium 0.06 mm thick. The γ quanta passing through the absorber (which was also at liquid nitrogen temperature) were recorded by a NaI(Tl) crystal 2 mm thick. The pulses from a single channel pulse analyzer entered a circuit which modulated the height of the pulses according to a linear law synchronously with the change in velocity of the source. The modulated pulses were recorded in an AI-100 hundred-channel pulse-height analyzer, each channel of which thus recorded a definite value of the source velocity. Such an arrangement enabled us to measure simultaneously the entire absorption spectrum (i.e., the dependence of the absorption on the source velocity over the whole selected velocity interval from $-v_{max}$ to $+v_{max}$). The measurements were made with absorbers containing Sn^{119} in two different compounds: metallic tin and an alloy of $SnNb_3$.

The dependence of the resonance absorption on source velocity for the case of an absorber of tin 20 mg/cm^2 in thickness is shown in the upper part of the figure (the ordinates give the transmission in relative units). Three absorption maxima are observed whose peaks correspond to source velocities of 0 and ±1.46 mm/sec. This result can be



explained as the presence of a hyperfine structure of the 23.8-kev level of Sn^{119}, caused by interaction of the quadrupole moment Q of the nucleus in the excited state with the electric field in the tin crystal. The ground state of Sn^{119}, which has a spin $\frac{1}{2}$, cannot have such a hyperfine structure; the excited state (spin $\frac{3}{2}$) splits into two levels corresponding to absolute values of spin projection equal to $\frac{1}{2}$ and $\frac{3}{2}$. Since the splittings in the source and absorber are the same, at zero velocity of the source the radiated line and the absorption line coincide, which corresponds to the central absorption maximum. The maxima at velocities of ±1.46 mm/

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.

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ELECTRON PARAMAGNETIC RESONANCE OF VANADIUM IN RUTILE

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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 non-equivalent 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 ($S = 1/2$; $I = 7/2$):

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

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 non-equivalent 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:

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

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 Hamil-