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SPIN-LATTICE RELAXATION IN CRYSTALS WITH SOFT OPTICAL PHONONS

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As is well know, the spin-lattice relaxation is due to phonon-scattering processes that are accompanied by spin flip. The probability of such processes is proportional to the phonon occupation numbers and also to the relative displacement of the lattice atoms. At low temperatures the main contribution is usually made by the long-wave acoustic oscillations. For such oscillations, the relative displacements of the nearest neighbors are small. The relaxation time is proportional to $(\theta/T)^7$ [1].

In some substances (SnTe, $SrTiO_3$, and $KTaO_3$) the oscillation spectrum has a low-lying optical branch for which $\omega^2(k) = \omega_0^2 + sk^2$. At temperatures $\omega_0 \lesssim T \ll \theta$, the number of thermal optical phonons is of the order of the number of acoustic ones, and the relative displacements of the nearest neighbors are not small even in the case of long waves. Therefore the scattering of the optical phonons will be the principal mechanism of spin relaxation, and the relaxation probability will be proportional to a lower power of the temperature.

The spin-phonon Hamiltonian can be written in the form

$$H_{sp} = \sum_{\substack{\vec{l},\vec{l}' \\ i,i'}} \hat{C}_i^{\alpha\beta}(\vec{l}, i, \vec{l}', i') v_i^{\alpha}(\vec{l}, i) v_i^{\beta}(\vec{l}', i'), \qquad (1)$$

where

$$\hat{C}_i^{\alpha\beta}(\vec{l}, i, \vec{l}', i') = \frac{1}{6}\hat{Q}_{\mu\nu}\frac{\partial^4 V}{\partial R_i^{\mu}\,\partial R_i^{\nu}\,\partial R_{\vec{l}i}^{\alpha}\,\partial R_{\vec{l}'i'}^{\beta}}.$$

We have in mind here the quadrupole relaxation mechanism, which is realized for spins $j \geq 1$. $\hat{Q}_{\mu\nu}$ is the operator of the quadrupole moment that interacts with the gradients of the crystal potential V. $\vec{v}_i(\vec{l}, j) = \vec{u}(\vec{l}, j) - \vec{u}(0, i)$ is the vector of the relative displacement of the atoms type j in the cell $\vec{l}$ and of the atom of type i, which carries the spin, in the cell 0. In the case of ionic crystals $\hat{C}(\vec{l}, j, \vec{l}', j') = \hat{C}(\vec{l}, j)\delta_{\vec{l}\vec{l}'}\delta_{ii'}$.

Using the Hamiltonian (1) we can calculate the probability of the transition between states with spin projections m and m'. It must be taken into account here that the Zeeman energy is low ($\varepsilon_m - \varepsilon_{m'} \ll T$). We obtain finally

$$W_{mm'} = \frac{2}{27\pi}\frac{v_0}{\mu^2 s^3}T^3 \sum_{\vec{l}\vec{l}',\, i\neq i} \langle m'|\, C_i^{\alpha\beta}(\vec{l}, i)|m\rangle \times \qquad (2)$$

$$\times \langle m|\, C_i^{\alpha\beta}(\vec{l}', i)\,|m'\rangle$$

For concreteness, the crystal was assumed to be diatomic and cubic (μ is the reduced mass and v_0 is the volume of the cell), while the soft branch was assumed to be transverse. The sum in formula (2) converges rapidly and we can confine ourselves to allowance for the nearest neighbors in its calculation. As a result we obtain for the relaxation time T_1 the expression

$$\left(\frac{1}{T_1}\right)_{opt} \simeq 6.8\cdot 10^4 \frac{Z^2 e^4 Q^2}{\mu^2 s^3 v_0^{4/3}} \frac{2J+3}{J^2(2J-1)} T^3 . \qquad (3)$$

Comparing with the contribution of the acoustic oscillations [2], we obtain for the time ratio

$$\frac{(1/T_1)_{opt}}{(1/T_1)_{ac}} = 0.9\left(\frac{M}{\mu}\right)^2\left(\frac{a}{s}\right)^3\left(\frac{\theta}{T}\right)^4 \qquad (4)$$

Here M is the mass of the cell and a is the square of the speed of sound.

Thus, the relaxation time due to the scattering of the optical phonons is proportional to $(\theta/T)^3$. This temperature dependence can probably be observed by measuring the relaxation time of the spin of the tellurium nucleus in a SnTe crystal in the temperature interval from 20 to 70°K. All three factors in the right-hand side of (4) are large and for the case of SnTe at $T \sim 20$°K the ratio (4) is of the order of 10^5.

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CRYSTALLINE FILAMENTARY PARTICLE COUNTER

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We report here the development and investigation of a new particle detector - a crystalline filamentary counter.

The problem of producing such a counter with a dense working medium has recently been one of the most pressing ones in experimental physics of high-energy particles. A number of workers [1, 2, 3] have attempted to solve this problem with counters filled with liquid media. It was observed, however, that such counters are subject to various operating instabilities.

One of the present authors has therefore formulated a new program for the development of particle detectors [4], based on total replacement of the liquid by a molecularly ordered structure, viz., crystalline matter in which conducting filaments are frozen. This is just the counter investigated in the present study. The counter had a brass cylindrical cathode of 6 mm diameter and a tungsten filament of 10 μ diameter coated with a thin film of gold. The working volume of the counter could be observed visually through end windows. We used in the experiments crystalline argon and xenon. The crystals were obtained by first condensing the gas in the counter at a temperature above the triple point, and then cooling the liquid slowly to the crystallization point freezing it gradually.