$$F(k_z) = \frac{8pR^3}{\pi} \int_0^1 K_0^2 (p \sqrt{1 + k_z^2/\alpha^2}\, \zeta) (\sin^{-1} \zeta + \zeta \sqrt{1 - \zeta^2}) \zeta d\zeta, \quad (5)$$

where $K_0(x)$ is the modified Bessel function, E_0 is the energy of the incident deuteron, and M the neutron mass.

In the limiting case $p \gg 1$ this formula becomes the Serber formula

$$d\sigma_n^s(k_z) = (\pi / 4) RR_d \alpha^2 dk_z / (\alpha^2 + k_z^2)^{3/2}. \quad (6)$$

Let us determine also the deuteron absorption cross section σ_a. Since[2]

$$\sigma_a + \sigma_n + \sigma_p = \sigma_t / 2,$$

where

$$\sigma_t = 4\pi R^2 \left\{ 1 - \int_0^\infty \frac{p}{\xi} \tan^{-1} \frac{\xi}{p} \frac{J_1^2(\xi)}{\xi} d\xi \right\},$$

is the integral cross section for all the interactions between fast deuterons and nuclei, then

$$\sigma_a = 2\pi R^2 \int_0^\infty \frac{p}{\xi} \tan^{-1} \frac{\xi}{p} \frac{J_1^2(\xi)}{\xi} d\xi. \quad (7)$$

When $p \gg 1$ we get

$$\sigma_a = \pi R^2 - \pi RR_d / 2. \quad (8)$$

It is possible to determine the influence of the Coulomb field and of the semi-transparency of the nucleus, as was done in Ref. 2. It is easy to see that the Coulomb field affects neither the total cross section nor the energy distribution of the particles. The semi-transparency of the nucleus decreases the stripping cross section. If the absorption is large, i.e., $|b|R \gg 1$ and if $p \gg 1$, then

$$\sigma_n = (\pi / 2) RR_d \{1 - (1/2 |b|^2 R^2)\}. \quad (9)$$

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PARAMAGNETIC RESONANCE IN NEODYMIUM NITRATE

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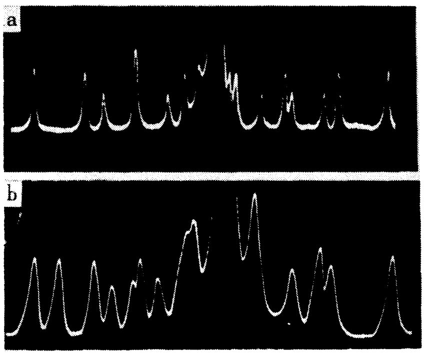
THE paramagnetic resonance spectra of rare-earth ions have been intensely investigated in recent years by Bleany and his colleagues. The measurements were made primarily on ethyl-sulphates $M(C_2H_5SO_4)_3 \cdot 9H_2O$, where M is a rare-earth ion. A study of the paramagnetic resonance of rare-earth ions in other compounds is also of great interest. At the suggestion of S. A. Al'tshuler and B. M. Kozyrev, we began an investigation of the nitrates of rare-earth elements, $M(NO_3)_3 \cdot 6H_2O$.

The measurements were made at a wavelength of 3.2 cm at liquid-hydrogen temperatures using a balanced superheterodyne radio-spectroscope of the type described by Manenkov and Prokhorov.[1] We investigated the paramagnetic resonance spectrum of neodymium nitrate, diluted with lanthanum in the ratio Nd : La = 1 : 200.

The spectrum consists of one intense line and 16 weak lines of the hyperfine structure (see diagram). This is in full agreement with the measurements of the paramagnetic resonance spectrum of neodymium in ethyl sulphate.[2,3]

Natural neodymium has isotopes with atomic weights 142, 143, 144, 145, 146, 148, and 150. The hyperfine structure is due to the odd isotopes 143 and 145. The remaining isotopes have a nuclear spin I = 0 and yield one strong line. The Nd^{143} content is 12.2%, and that of Nd^{145} is 8.3%. Accordingly, the hyperfine structure is broken up into two groups, each consisting of eight lines. This corresponds to a nuclear spin $I = 7/2$ for each isotope. The line intensity in one group is approximately 1.5 times greater than that in the other group. The stronger lines were therefore attributed to Nd^{143} and the weaker ones to Nd^{145}.



Oscillograms of paramagnetic-resonance spectrum in neodymium nitrate: (a) x axis parallel to the constant magnetic field; hyperfine splitting lines almost equidistant; (b) y axis parallel to the constant magnetic field; strong second-order shifts are visible.

The line width varied linearly from 13 to 18° K, and broadened so much at 20° K to become unobservable. It must be noted that in ethyl sulphate practically no line broadening due to spin-lattice relaxation was observed even at 20° K.

The line width in the nitrate was inversely proportional to the g-factor even at 13° K. This indicates that the spin-lattice relaxation makes the major contribution to the line width.[4]

The spectrum is described by the following spin Hamiltonian:

$$\mathcal{H} = \beta (g_x H_x S_x + g_y H_y S_y + g_z H_z S_z) + A_x S_x I_x + A_y S_y I_y + A_z S_z I_z + P_x I_x^2 + P_y I_y^2 + P_z I_z^2,$$

where S is the effective spin, equal to $1/2$; g_x, g_y, g_z are the principal values of the g-factor; H_x, H_y, H_z are the components of the constant magnetic field, A_x, A_y, A_z and P_x, P_y, P_z are the constants of the hyperfine and quadrupole interaction, I is the nuclear spin, and β is the Bohr magneton.

To find the x, y, and z axes we worked out together with A. M. Prokhorov and simple procedure, consisting essentially of first setting the crystal, mounted in an arbitrary manner, to the extremal value of the g-factor, cutting it in the plane of the axis of rotation and the magnetic field plane, and mounting it in this plane (provided the extremal g-factor is close to the principal value).

The principal values of the g-factors are

$$g_x = 3.88 \pm 0.01, \; g_y = 1.72 \pm 0.01, \; g_z = 0.74 \pm 0.01.$$

The following values were obtained for the hyperfine splitting constants (in units of 10^{-4} cm^{-1}):

$$\text{isotope 143: } A_x = 432 \pm 2, \; A_y = 193 \pm 2, \; A_z = 82 \pm 10,$$
$$\text{isotope 145: } A_x = 270 \pm 2, \; A_y = 119 \pm 2, \; A_z = 51 \pm 10.$$

It is possible to estimate the upper limit of the quadrupole coupling constants $|P_x - P_z| < 50 \times 10^{-4}$ cm^{-1} and $|P_y - P_z| < 50 \times 10^{-4}$ cm^{-1} for both isotopes.

It is easy to see that the hyperfine splitting constants obey the following approximate equality:

$$A_x : A_y : A_z \approx g_x : g_y : g_z.$$

The ratios

$$A_x^{143} / A_x^{145} = 1.60 \pm 0.02, \; A_y^{143} / A_y^{145} = 1.62 \pm 0.04$$

are numerically equal to the ratios of the magnetic moments of the Nd^{143} and Nd^{145} nuclei and are in good agreement with results obtained by Bleaney et al. within the limits of experimental accuracy.[2,3]

In conclusion the author expresses his gratitude to E. L. Andronikashvili, A. M. Prokhorov, G. R. Khutsishvili, G. M. Mirianashvili, and A. A. Manenkov for valuable advice, counsel, and constant interest in this work, and also to D. S. Tsakadze, M. Koloch, and G. A. Tsinadze for taking part in the measurements.

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RADIATION CORRECTIONS TO PARTICLE SCATTERING IN EXTERNAL FIELD AND TO COMPTON EFFECT IN SCALAR QUANTUM ELECTRODYNAMICS

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THE expression for the single-photon mass operator of a scalar particle, obtained by one of the authors,[1] was used to calculate the radiation corrections to the scattering of a scalar particle in an external electromagnetic field and to the Compton effect. The following expressions were obtained thereby for the differential cross sections.

1. The differential scattering cross section (in the first Born approximation) has the following form

$$d\sigma / d\Omega = (d\sigma / d\Omega)_0 + (d\sigma / d\Omega)_{\Delta M} + (d\sigma / d\Omega)_{A'}, \qquad (1)$$

where $(d\sigma/d\Omega)_0$ is the differential scattering cross section without allowance for radiation corrections, and the indices ΔM and A' distinguish the radiation corrections from the mass operator and from the polarization of vacuum, respectively.[2,3] For the first correction in (1) we have the following formula

$$(d\sigma / d\Omega)_{\Delta M} = -(2\alpha / \pi)(d\sigma / d\Omega)_0 [2y \coth 2y (h(2y) - h(y)) - y \tanh y + \ln \lambda (1 - 2y \coth 2y)],$$

$$h(y) = y^{-1} \int_0^y \varphi \coth \varphi d\varphi; \ \sinh^2 y = (p_1 - p_2)^2 / 4m^2, \qquad (2)$$

where λ is the photon mass in units of m; p_1 and p_2 are four-dimensional particle momenta before and after scattering, and $\alpha = e^2/4$. (We use a system of units in which $\hbar = c = 1$.)

For the second correction we have

$$(d\sigma / d\Omega)_{A'_0} = \frac{\alpha}{\pi}\left(\frac{d\sigma}{d\Omega}\right)_0 \left[\frac{4m^2 + (p_1 - p_2)^2}{3(p_1 - p_2)^2}(1 - y \coth y) + \frac{1}{9}\right] \qquad (3)$$

if the vacuum polarization is due to particles with zero spin, and

$$(d\sigma / d\Omega)_{A'_{1/2}} = -\frac{2\alpha}{\pi}\left(\frac{d\sigma}{d\Omega}\right)_0 \left[\frac{4m^2_{1/2} - 2(p_1 - p_2)^2}{3(p_1 - p_2)^2}(1 - y_{1/2} \coth y_{1/2}) + \frac{1}{9}\right], \quad \sinh^2 y_{1/2} = (p_1 - p_2)^2 / 4m^2_{1/2}, \qquad (4)$$

if the vacuum polarization is due to particles with spin $1/2$.

When λ approaches zero, formula (2) diverges logarithmically. This divergence is offset by an analogous divergence in the inelastic-scattering differential cross section of the particle with emission of a single soft photon.

$$(d\sigma / d\Omega)_{\mathrm{inel}} = -\frac{2\alpha}{\pi}(d\sigma / d\Omega)_0 \left\{(1 - 2y \coth 2y)\left[\ln\left(\frac{K_{\max}}{\lambda}\right) - \frac{1}{2}\right] + 4y \coth 2y (h(2y) - 1)\right\}, \qquad (5)$$