EFFECT OF EXTERNAL FIELDS ON ANGULAR CORRELATIONS IN CONSECUTIVE ELECTROMAGNETIC TRANSITIONS

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Submitted to JETP editor March 13, 1963

J. Exptl. Theoret. Phys. (U.S.S.R.) 45, 706-708 (September, 1963)

The level scheme of an atom (or nucleus) under the simultaneous action of an electric field (or of quadrupole splitting) and a magnetic field is considered. It is shown that if certain conditions are met the angular correlations may change strongly even when small magnetic fields are turned on.

1. We have previously considered [1-3] the joint effect of an electric and magnetic field on the resonance scattering of light. We have shown that in the case of parallel fields a change due to interference occurs in the intensity of the scattered light if the values E and H are chosen such that some of the energy levels of the excited state of the atom "cross." A similar phenomenon occurs also for $\gamma\gamma$ coincidences in the presence of an external magnetic field and quadrupole splitting of the levels of the intermediate state. It is assumed here that the radiating nuclei are situated in a single crystal whose symmetry axis is parallel to **H**. In view of the complete analogy, we shall speak henceforth for concreteness only of the joint effect of **E** and **H** on the resonance scattering of the light by the atoms.

This raises the question of the accuracy with which the fields must be kept parallel. Let us assume, for example, that the excited state has a spin $J = 3/2$. Turning on the electric fields splits the initial quadrupole level into two double levels with $m = \pm 3/2$ and $m = \pm 1/2$, as shown in Fig. 1a. Turning on a magnetic field parallel to the electric field results in additional splitting (see Fig. 1b). The energy of the level with $m = -3/2$ decreases linearly with the magnetic field, while that with $m = +1/2$ increases; at some value H_0 the levels "cross," after which they diverge, each continuing to move in its previous direction, and retaining its previous value of m. At the "crossing" point, when δ is equal to zero, there is an interference variation of the intensity of the scattered light.

Let now the magnetic field have a slight transverse component **h**, which in itself can cause a Zeeman level splitting, $\epsilon \ll \Delta$. This component does not play a noticeable role so long as $\delta \gg \epsilon$.

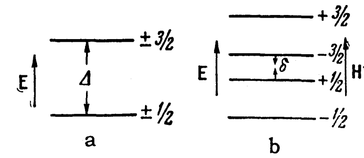

FIG. 1

However, as $H \to H_0$ the inequality is reversed, and under these conditions the presence of even a small **h** leads to a radical change in the entire picture. From the point of view of interest to us, the principal change is the absence of "crossing" (see also [4,6]). The levels $m = -3/2$ and $m = +1/2$ come short of reaching the "crossing point" by a distance δ_0 and reverse their direction of motion (see Fig. 2). It is also important to note that after reversing direction both levels experience a change in m at a sufficiently large distance from the "crossing region," viz: the level with $m = -3/2$ goes over into $m = +1/2$ and vice versa; near the "crossing region" the stationary states have no definite values of angular-momentum projections in the longitudinal direction at all[1)].

The absence of "crossing" should influence the interference variation of the intensity. It is merely necessary to take account of the fact that the levels under consideration have a certain natural width Γ, which we assume small compared with Δ. It is clear that all the statements made above also hold when $\Gamma \ll \delta_0$. In the opposite limiting case, the transverse magnetic field plays no role at all, and the resonance scattering of the light is the same as for parallel **E** and **H**.

[1)]It is not excluded that the described phenomena can be employed, for example, to repolarize nuclear targets or to obtain systems with inverted level population (see also [5]).

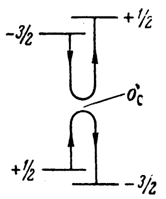

FIG. 2

Let us assume for concreteness that the longitudinal field is $H = H_0$. Then the value of the splitting is determined by the transverse field h. It can be shown that when $h \ll H_0$ the splitting is equal to $\Delta h^2/H_0^2$, i.e., "crossing" occurs if the condition

$$\Gamma/\Delta \gg h^2/H_0^2 \tag{1}$$

is satisfied, and does not occur when the inequality is reversed. It also follows from (1) that the permissible angle θ between the electric and magnetic fields is determined by

$$\theta \ll (\Gamma/\Delta)^{1/2}. \tag{1'}$$

In the opposite case no interference change in scattered-light intensity should be observed.

Similar phenomena occur for atoms with other values of excited-state spin. For example, in the case when $J = 1$ we have "crossing" of the levels with $m = 0$ and $m = -1$. When $H = H_0$ the splitting is equal to $\sqrt{2}\,\Delta h/H_0$, i.e., we must write in place of (1)

$$\Gamma/\Delta \gg \sqrt{2}\, h/H_0, \tag{2}$$

and in place of (1′)

$$\theta \ll \Gamma/\sqrt{2}\,\Delta. \tag{2'}$$

As already noted, analogous relations pertain also to the joint influence of the Zeeman and quadrupole splittings on the $\gamma\gamma$ correlations in the case of de-excitation of nuclei in single crystals. The case of polycrystals calls for a separate analysis.

2. We have seen that when $H \approx H_0$ even a small transverse field leads to a radical "mixing" of the eigenfunctions of the excited state. We can therefore expect the intensity of the strongly scattered light in this region to depend on the value of h. This is indeed the case.

Let us assume that the ground state has no spin, and that the spin of the excited state is $J = 1$. Let the polar axis coincide with $\mathbf{E}$, and let the directions of the incident and scattered light correspond to angles (θ_1, φ_1) and (θ_2, φ_2), with the azimuthal angles measured from the direction of the transverse field h. The intensity of the scattered light is then determined for $H = H_0$ by

$$\begin{aligned} I \sim 1 + \tfrac{1}{4}\{&\sin^2\theta_1 \sin^2\theta_2 + 2[\tfrac{1}{4}(1+\cos^2\theta_1)(1+\cos^2\theta_2) \\ &+ 2\sin\theta_1 \sin\theta_2 \cos\theta_1 \cos\theta_2 \cos\varphi_1 \cos\varphi_2] \\ &+ [(\cos\theta_2 + 2^{-1/2}\sin\theta_2 e^{i\varphi_2})(\cos\theta_1 + 2^{-1/2}\sin\theta_1 e^{-i\varphi_1}) \\ &\times(\cos\theta_2 - 2^{-1/2}\sin\theta_2 e^{-i\varphi_2})(\cos\theta_1 - 2^{-1/2}\sin\theta_1 e^{i\varphi_1}) \\ &\times\Gamma/(\Gamma + i\Delta_{-1,0}) + \text{c.c.}]\}, \end{aligned} \tag{3}$$

where

$$\Delta_{-1,0} = \sqrt{2}\,\Delta h/H_0 \tag{4}$$

is the splitting of the levels with $m = -1$ and $m = 0$ under the influence of the transverse field h.

If, for example, $\theta_1 = \theta_2 = \varphi_1 = \varphi_2 = 0$, then it follows from (3) that

$$I \sim \tfrac{3}{2} + \Gamma^2/2(\Gamma^2 + \Delta_{-1,0}^2), \tag{5}$$

i.e., turning on the transverse magnetic field produces a radical change in the intensity. This circumstance can of course be used also for an experimental determination of Δ and Γ.

Unlike the interference change in intensity described in [1-3], the effect discussed here attains an appreciably large value and occurs also in a different region of angles [2)]. In particular, for the angles chosen above, the change in the longitudinal magnetic field does not influence the resonance scattering of the light at all.

In conclusion we note that relation (3), like all other relations of similar type, do not change in the presence of a Doppler broadening of the levels under consideration (see, for example, [3]).

The authors are grateful to S. Gershteĭn for valuable remarks and L. Keszthelyi, a conversation with whom has raised the question considered in the first part of the present work.

[2)]The change in intensity can be even greater if the incident and scattered light are circularly polarized.

[1] M. I. Podgoretskiĭ, Preprint, Joint Inst. Nuc. Res. R-491, 1960.

[2] L. G. Zastavenko and M. I. Podgoretskiĭ, JETP 39, 1023 (1960), Soviet Phys. JETP **12**, 711 (1961).

[3] L. G. Zastavenko and O. A. Khrustalev, Optika i spektroskopiya **11**, 441 (1961).

[4] L. D. Landau and E. M. Lifshitz, Quantum Mechanics, Pergamon, 1958.

[5] L. G. Zastavenko and M. I. Podgoretskiĭ, Preprint, Joint Inst. Nuc. Res., 1963.

[6] G. F. Drukarev, JETP 45, 1484 (1963), Soviet Phys. JETP 18, in press.

Translated by J. G. Adashko
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