curves correspond to the different values of the magnetic field given in the figure. While for small values of the field the angular dependence $E_q(\theta)$ approximately satisfies Eq. (1), at large values of the field (H > 6000 oe) it behaves anomalously. The value of the emf goes through a minimum at $\theta = \pi/2$, shows a maximum at $\theta = 54°$ and 126° and decreases to zero at $\theta = 0°$ and 180°.

It is essential to note that the dependence of the even photomagnetic emf on the magnetic field is different for different angles θ, as can be seen from Fig. 2. Along the ordinate axis we have again given the extremum values of the even photomagnetic emf. For $\theta = \pi/2$ (the plane of the specimen is then parallel to the magnetic field) the even photomagnetic emf reaches saturation in relatively small fields, H = 6000 oe. At $\theta = 80°$ the value of the field for which saturation is reached is equal to 10,000 oe. For larger angles θ saturation does apparently not set in until fields which are larger than those attained in our experimental conditions are reached.

Qualitatively similar curves have been obtained for the emf produced when illumination is replaced by an electrical current from an external emf source flowing through the specimen, in the direction of the incident light.

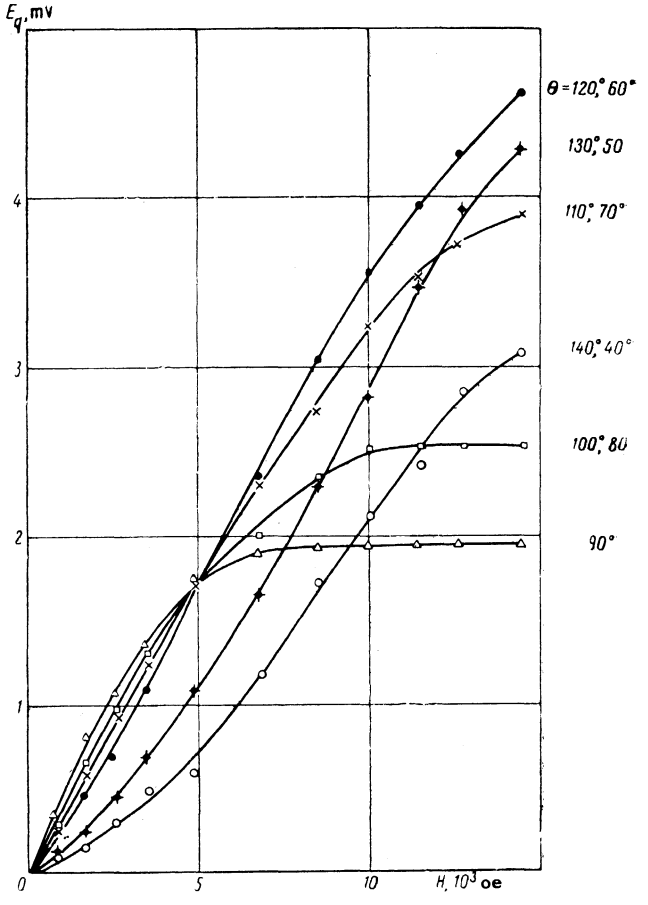

FIG. 2

At the moment we cannot suggest a satisfactory explanation of the observed anomalies. It is possible that they are connected with the presence of many carrier effective masses[4] each of which "shows up" at an appropriate angle θ.

[1] I. K. Kikoin and Yu. A. Bykovskiĭ, Doklady Akad. Nauk SSSR **116**, 381 (1957), Soviet Phys. Doklady **2**, 477 (1958).

[2] Yu. Kagan and Ya. A. Smorodinskiĭ, JETP **34**, 1346 (1958), Soviet Phys. JETP **7**, 929 (1958).

[3] I. K. Kikoin and S. D. Lazarev, Doklady Akad. Nauk SSSR, in press.

[4] Yu. Kagan, JETP **38**, 1854 (1960), Soviet Phys. JETP **11**, 1333 (1960).

Translated by D. ter Haar
265

CONCERNING THE RADIATION OF A NUCLEUS IN THE PRESENCE OF UNEXCITED NUCLEI OF THE SAME TYPE

M. I. PODGORETSKIĬ and I. I. ROĬZEN

Joint Institute for Nuclear Research

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IF the emission of a γ quantum by an excited nucleus takes place in the presence of one or several nuclei of the same type, it becomes possible for the γ quantum to "wander" inside such a system. As will be shown below, in many cases this may lead to a change in the observed frequency and to a damping of the radiation (see also reference 1). It is assumed that the nuclei can be regarded as isotropic classical oscillators.

1. We consider the question of the radiation of a nucleus which is a component of a symmetric diatomic molecule, the axis a of which is fixed in space ($a \gg \lambda$, where λ is the radiated wavelength). The radiation field of such a molecule at a point far from the molecule and at an angle ϑ to its axis (which is assumed directed from the oscillator with dipole moment P_0 to the oscillator with dipole moment P_1), can be determined

by solving the system of equations

$$\ddot{P}_0(t) + \beta\ddot{P}_1(t - a/c) + 2\gamma\dot{P}_0(t) + \omega^2 P_0(t) = 0,$$
$$\ddot{P}_1(t) + \beta\ddot{P}_0(t - a/c) + 2\gamma\dot{P}_1(t) + \omega^2 P_1(t) = 0,$$
$$E(\mathbf{R}_0, t) \sim \frac{1}{R_0 c^2}\left[\ddot{P}_0\left(t - \frac{R_0}{c}\right) + \ddot{P}_1\left(t - \frac{R_0}{c} + \frac{a\cos\vartheta}{c}\right)\right], \quad (1)$$

where $\gamma = \tau/2$, τ is the average lifetime, $\beta = (3/4\pi)(\lambda/a)(\gamma/\omega)$, and the distance $\mathbf{R}_0$ is measured from P_0. For the sake of simplicity we assume here that the radiation is polarized in a plane perpendicular to the axis of the molecule.

We specify the following initial conditions:

$$P_k(t) = \dot{P}_k(t) \equiv 0 \text{ for } t < 0,$$
$$P_k(0) = A\delta_{k0}, \quad \dot{P}_k(0) = 0, \quad k = 0, 1. \quad (2)$$

The solution of the system (1) with initial conditions (2) leads, accurate to quantities of order γ/ω, to the following result:

$$P_0(t) = \tfrac{1}{2}A[\cos\omega_1 t \exp(-|\gamma_1|t) + \cos\omega_2 t \exp(-|\gamma_2|t)],$$
$$P_1(t) = \tfrac{1}{2}A[\cos\omega_1 t \exp(-|\gamma_1|t) - \cos\omega_2 t \exp(-|\gamma_2|t)], \quad (3)$$

where

$$\omega_1 = \omega\left(1 - \tfrac{1}{2}\beta\cos\frac{\omega a}{c}\right), \qquad \omega_2 = \omega\left(1 + \tfrac{1}{2}\beta\cos\frac{\omega a}{c}\right),$$
$$\gamma_1 = -\gamma - \tfrac{1}{2}\beta\omega\sin\frac{\omega a}{c} < 0, \qquad \gamma_2 = -\gamma + \tfrac{1}{2}\beta\omega\sin\frac{\omega a}{c} < 0. \quad (4)$$

Substituting (3) into the expression for the field intensity E from (1), we see that a rather complicated time-dependent situation results and, in particular, the decay curve is non-exponential, becoming such only after the lapse of a time

$$\tau' > 1/|\gamma_1 - \gamma_2| = 1/\beta\omega|\sin(\omega a/c)|.$$

The corresponding decay constant is less than γ by an amount

$$\frac{\beta\omega}{2}\sin\frac{\omega a}{c} = \left(\frac{3}{8\pi}\frac{\lambda}{a}\sin\frac{\omega a}{c}\right)\gamma.$$

It is obvious that the initial assumption, that the position of the molecule axis is fixed in space, is not essential for these conclusions.

2. In order to obtain an idea concerning the radiation of an excited nucleus contained in a crystal, we consider the subsidiary problem of the radiation of an oscillator contained in a one-dimensional chain with a period a. This problem already includes all the characteristic features inherent in the radiation from a crystal. At the same time, it can be completely solved in analytic form.

In order to obtain the radiation field at a certain point, we must know the function

$$F(t) = \sum_k \frac{1}{R_k} P_k\left(t - \frac{R_k}{c}\right), \quad (5)$$

where R_k is the distance from this point to the k-th oscillator, and the summation is carried out over all the oscillators of the chain. It is easy to see that F(t) obeys the following equation

$$\ddot{F}(t) + \beta\sum_k\sum_{n\neq 0}\frac{1}{R_k|n|}\ddot{P}_{k+n}\left(t - \frac{a|n|}{c} - \frac{R_k}{c}\right)$$
$$+ 2\gamma\dot{F}(t) + \omega^2 F(t) = 0. \quad (6)$$

In the case when the distance to the point of observation is much greater than the length of the chain, equation (6) can be rewritten in closed form:*

$$\ddot{F}(t) + \beta\sum_{\substack{n=-\infty\\ n\neq 0}}^{n=\infty}\frac{1}{|n|}\ddot{F}\left(t - \frac{a|n| + bn}{c}\right)$$
$$+ 2\gamma\dot{F}(t) + \omega^2 F(t) = 0, \quad (7)$$

where $b = a\cos\vartheta$, and ϑ is the angle between $\mathbf{R}_0$ and the axis of the chain, which is assumed directed towards positive indices k. If we specify an initial condition analogous to (2), the solution of (7) will have the following form:

$$F(t) \sim A\exp(-|\gamma(\vartheta)|t)\cos\omega(\vartheta)t, \quad (8)$$

where

$$\omega(\vartheta) = \omega\left\{1 + \frac{\beta}{4}\ln\left[4\sin^2\frac{\omega(a+b)}{2c} + \frac{\gamma^2(\vartheta)(a+b)^2}{c^2}\right]\right.$$
$$\left.\times\left[4\sin^2\frac{\omega(a-b)}{2c} + \frac{\gamma^2(\vartheta)(a-b)^2}{c^2}\right]\right\},$$
$$\gamma(\vartheta) = -\gamma + \frac{1}{4}\omega\beta\left\{\left[(2n_1+1)\pi - \frac{\omega(a+b)}{c}\right]\right.$$
$$\left.+\left[(2n_2+1)\pi - \frac{\omega(a-b)}{c}\right]\right\}. \quad (9)$$

Here n_1 and n_2 are integers, which must be chosen such that the absolute values of the expressions in the square brackets in (9) do not exceed π.

It is seen from (8) that at each angle there is a different frequency $\omega(\vartheta)$, and different damping $\gamma(\vartheta)$. It is interesting to note that the character of the dependence of ω and γ on ϑ recalls the distribution of intensity in the case of diffraction by a one-dimensional grating. The change in frequency is

$$\Delta\omega = |\omega - \omega(\vartheta)| \sim \omega\beta/4 = (3/16\pi)\lambda\gamma/a. \quad (10)$$

However, near angles ϑ for which $\sin[\omega(a\pm b)/2c] \sim 0$, its magnitude becomes considerably greater. From (9) we get that

$$\max||\gamma(\vartheta)| - \gamma| \sim 3\gamma\lambda/8a, \quad (11)$$

that is, the change in the damping can become quite appreciable. As time goes on, the radiation remains only at those angles corresponding to minimum damping.

In conclusion, we give an equation for the amplitude $\chi(t)$ of the radiation from a crystal with cubic lattice at a point the direction to which is given by the vector $\mathbf{m}$, $|\mathbf{m}| = 1$:

$$\ddot{\chi}(t) + \beta \sum_{\mathbf{k}\neq 0} \frac{1}{|\mathbf{k}|} \ddot{\chi}\left[t - \frac{a}{c}(|\mathbf{k}| + \mathbf{km})\right] - \beta \sum_{\mathbf{k}\neq 0} \frac{\mathbf{k}}{|\mathbf{k}|^3}\left(\mathbf{k}, \ddot{\chi}\left[t - \frac{a}{c}(|\mathbf{k}| + \mathbf{km})\right]\right) + 2\gamma\dot{\chi}(t) + \omega^2\chi(t) = 0. \quad (12)$$

The similarity between (7) and (12) gives grounds for expecting that their solutions will also be essentially similar. The described variation in frequency can be observed, in principle, by the procedure proposed by Mössbauer.[2,3]

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*For the approximations made in the derivation of (7), it is also necessary that the condition $1 \pm \cos\vartheta \gg 2\pi\gamma/\omega$ be satisfied; this condition is violated only for angles ϑ which are exceedingly close to $\vartheta = 0$ and $\vartheta = \pi$.

[1] M. I. Podgoretskiĭ and I. I. Roĭzen, preprint, Joint Institute for Nuclear Research, R-546g.

[2] R. L. Mössbauer, Z. Phys. **151**, 124 (1958).

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

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266

SCATTERING MATRIX OF NUCLEONS ON A TARGET WITH SPIN 1

P. VINTERNITTS

Leningrad State University

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THE article by Budyanskiĭ[1] contains the general form of the scattering matrix of a particle with spin $\frac{1}{2}$ by a particle with spin 1, and 12 observable quantities are calculated, making up one of the possible complete sets of experiments. It appears to us that this matrix has not been written down quite correctly.

Using the Oehme method[2] we can write the matrix for the scattering of nucleons on any target in the form

$$M = a + b\,\sigma\mathbf{n} + c\,\sigma\mathbf{m} + d\,\sigma\mathbf{l} \quad (1)$$

(the notation is the same as used by Oehme[2]). The coefficients in (1) should have the following form:

$$a = \alpha_1 I + \alpha_2 S_n + \alpha_3 S_m^2 + \alpha_4 S_l^2,$$

$$b = \beta_1 I + \beta_2 S_n + \beta_3 S_m^2 + \beta_4 S_l^2,$$

$$c = \gamma_1 S_m + \gamma_2 (S_n S_m + S_m S_n), \quad d = \delta_1 S_l + \delta_2 (S_n S_l + S_l S_n). \quad (2)$$

If we transform the scattering matrix given by Budyanskiĭ[1] to the form (1), we obtain

$$a = A_1 I + A_2 S_n + A_3 (S_m^2 + S_l^2),$$

$$b = B_1 I + B_2 S_n + B_3 (S_m^2 + S_l^2),$$

$$c = C_1 S_m + C_2 S_n S_m + C_3 S_m S_n,$$

$$d = D_1 S_l + D_2 S_n S_l + D_3 S_l S_n. \quad (3)$$

It is obvious that no general considerations lead to $\alpha_3 = \alpha_4$ and $\beta_3 = \beta_4$. On the other hand, the complete system of orthonormal basis matrices of the spin space of the particle with spin 1 do not contain expressions of the type S_iS_k and S_kS_i individually, but of the type $S_iS_k + S_kS_i$ (see, for example, reference 3), and consequently one must assume $C_2 = C_3$ and $D_2 = D_3$. The number of complex scalar coefficients should actually be 12 (this follows from general relations given by Puzikov[4]), and this is satisfied by the scattering matrix both in form (2) and (3). It is naturally necessary to use the formula (2), and not (3), for all calculations and suitably correct all the expressions for the cross sections, the polarization, and the correlation functions obtained in reference 1.

[1] G. M. Budyanskiĭ, JETP **33**, 889 (1957), Soviet Phys. JETP **6**, 684 (1958).

[2] R. Oehme, Phys. Rev. **98**, 147 (1955).

[3] A. S. Davydov, Теория атомного ядра (Theory of the Atomic Nucleus), M., Fizmatgiz, 1958.

[4] L. D. Puzikov, JETP **34**, 947 (1958), Soviet Phys. JETP **7**, 655 (1958).

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267