SPONTANEOUS TRANSITIONS ACCOMPANYING THE PASSAGE OF LIGHT THROUGH ANISOTROPIC MEDIA

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It is shown that electromagnetic waves are radiated with a frequency $\Omega = \omega \Delta n/n_0$ when light of frequency ω passes through a doubly refracting medium.

In an anisotropic medium there are different refractive indices corresponding to different light polarizations. This is equivalent to the presence of an energy difference ΔE between the two polarization states at one and the same wavelength[1]. As was shown earlier[1], this causes the polarization of light passing through an anisotropic medium to experience, under the influence of a high-frequency electric or magnetic field, resonance changes accompanied by a change of frequency at a fixed wavelength. At the same time, absorption or stimulated emission of photons of the corresponding energy takes place. From the well known Einstein relation it follows therefore that there ought also to exist a spontaneous photon emission connected with the spontaneous change of polarization of light in an anisotropic medium[1].

In order to determine the spontaneous-transition probability it is necessary to find the operator for the interaction between transmitted light and a medium situated in electric and magnetic fields. The quantity playing the role of interaction with the medium has the form

$$V_{ik} = \hbar \frac{\omega}{n_0} \left(\frac{b \varepsilon_{ikl} H_l}{2n_0} + a \frac{E_i E_k}{2n_0} \right), \tag{1}$$

where ϵ_{ikl} is an antisymmetric tensor of the third rank, H and E are the field strengths, n_0 is the isotropic part of the refractive index, and the quantities a and b are connected with the constants of Kerr and Verde.

By analogy with the usual theory of radiation, the interaction (1) ought to lead to spontaneous electromagnetic transitions. It is clear here that in the absence of external fields the first member is associated with the emission of one photon, the second with the emission of two photons[1)]. Let light pass through a doubly refracting crystal in a direction perpendicular to the optic axis. Going over to second quantization, it is not difficult to write down the following expression for the matrix element:

$$M = \frac{2\pi Rc}{n_0} \mathbf{n} \left[\frac{\mathbf{k}}{k} \mathbf{e} \right] \sqrt{\frac{2\pi\hbar\omega'}{V}} \delta(\Omega - \omega'), \tag{2}$$

where $R = \omega b/2cn_0$ is Verde's constant[2], $\mathbf{n} = \mathbf{e}_1 \times \mathbf{e}_2$, ω is the frequency of the incident light, $\mathbf{e}_1$ and $\mathbf{e}_2$ are the polarization vectors of the ordinary and extraordinary rays, $\mathbf{e}$ is the polarization vector of the emitted photon, $\mathbf{k}$ is its wave vector, $\Omega = \Delta E/\hbar = \omega \Delta n/n_0$, V is the normalization volume, c is the velocity of light in a vacuum. It is therefore evident that the angular distribution is determined by the quantity $\sin^2\theta$, where θ is the angle between the direction of incidence of the original beam and the momentum of the emitted photon.

With the help of (2) we obtain for the full emission probability per unit time the expression

$$P = \frac{4}{3} \frac{\hbar\Omega^3}{c} \left(\frac{R}{n_0} \right)^2. \tag{3}$$

The intensity of photon emission accompanying spontaneous changes of polarization is

$$J(\Omega) = J(\omega) P l n_0 \Omega / c\omega, \tag{4}$$

where l is the length of the sample and $J(\omega)$ is the intensity of the incident light.

The relationships obtained are valid if $l\Omega/c \ll 1$. If this condition is not fulfilled the emitted photons are not monochromatic. The distribution about the frequency ω' has the form

$$dP_{\omega'} = \frac{8}{3} \hbar\omega'^3 \left(\frac{R}{n_0} \right)^2 \frac{\sin^2 n_0 l(\omega' - \Omega)}{2c\pi n_0 l(\omega' - \Omega)^2} d\omega'. \tag{5}$$

The total transition probability is described, as before, by formula (3).

The ratio $J(\Omega)/J(\omega)$ is in general very small. One may however hope to detect experimentally spontaneous radiation of the type mentioned if laser light beams are employed. For $\Omega \sim 10^{14}$ sec^{-1},

1) Upon the application of an external electric field the second member of the expression (1) can also lead to single-photon transitions.

which for visible light corresponds to $\Delta n \sim 0.1$, $R \sim 10^{-5}$ rad/cm-G (guaiacol $C_6H_4(OCH_3)OH$, for example, possesses such parameters) and $l = 10$ cm, the intensity ratio is

$$J(\Omega)\,/\,J(\omega) = 10^{-15} - 10^{-16}.$$

Analogous transitions take place also where there is artificial anisotropy which can be created by means of a constant electric or magnetic field. The splitting in this case is considerably less, and the frequency of the electromagnetic radiation lies in the radio-frequency range. As a consequence of the smallness of the splitting, the intensity of the effect is very small.

[1] V. G. Baryshevskiĭ, V. L. Lyuboshitz, and M. I. Podgoretskiĭ, Yadernaya fizika 1, 27 (1965), Soviet JNP 1, 19 (1965).

[2] M. V. Vol'kenshteĭn, Molekulyarnaya optika (Molecular Optics) Gostekhizdat, 1951.

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