RESONANCE REFLECTION OF GAMMA RAYS FROM A CRYSTAL SURFACE

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The time dependence of the intensity of resonance γ rays reflected from a crystal surface is investigated. It is shown that when the resonance frequencies of the radiator and reflector are different the intensity of the reflected γ rays exhibits "beats." The interference between resonant nuclear scattering and Rayleigh scattering by the atomic electrons is treated. The interference disappears when the resonance frequencies of the emitter and reflector coincide.

IN the region of a resonance the index of refraction for γ rays differs markedly from unity; for example, in the case of Fe^{57}, $n - 1 \sim 10^{-4}$ (cf. [1]). It is consequently reasonable to consider experiments on resonance reflection of γ rays at grazing incidence; in the following we shall discuss some features of this phenomenon (cf., also [2]).

The basis of the calculations are the familiar expressions for the amplitude of the reflected monochromatic wave A when there is an incident wave of unit amplitude (cf., for example, [3] Ch. 9). These expressions are quite complicated in the general case. One can show, however, that for sufficiently large grazing angles Φ ($\Phi = \pi/2 - \varphi$, where φ is the angle of incidence) and sufficiently small values of $n - 1$, such that the condition

$$\Phi^2 \gg 2|n-1| \tag{1}$$

is satisfied, they take on a much simpler form.

If the electric vector is perpendicular to the plane of incidence,

$$A = (n-1)/2\cos^2\varphi; \tag{2}$$

and when it is in the plane of incidence,

$$A = (n-1)\cos 2\varphi/2\cos^2\varphi. \tag{2'}$$

On the other hand we know that $n - 1$ is proportional to the amplitude for resonance scattering by an individual nucleus. It follows that we can write in all cases

$$A = k\gamma/(\omega - \omega_0 + i\gamma/2), \tag{3}$$

where k is a constant, $\hbar\gamma$ is the width of the nuclear resonance level, and ω_0 is the resonance frequency. An important conclusion follows from (3): for all questions concerning the frequency dependence of the resonance reflection, when condition (1) is satisfied the results are the same as for resonance scattering by an individual nucleus (cf., [4]).

If a crystal is illuminated with γ rays having a spectral distribution of amplitude $B(\omega)$, the amplitude of the reflected wave is of the form

$$C = k\gamma \int \frac{B(\omega)\, e^{-i\omega t}}{\omega - \omega_0 + i\gamma/2}\, d\omega, \tag{4}$$

and its intensity varies with time according to the law

$$J \sim \left| \int \frac{B(\omega)\, e^{-i\omega t}}{\omega - \omega_0 + i\gamma/2}\, d\omega \right|^2. \tag{4'}$$

Suppose that at time $t = 0$, which is fixed, for example, by the preceding decay act, an excited nucleus is formed, whose γ radiation is recorded after resonance reflection from a crystal surface. Let us assume that there is a Mössbauer effect for the emitted γ quantum; the same assumption also applies of course to the reflection, since we are at the moment considering only coherent processes. To keep the argument general, we shall also assume that because of the slow relative motion of source and reflector, the corresponding resonance frequencies differ by some amount Δ. Under these conditions

$$C \sim e^{-i\omega_0 t} \int \frac{e^{-ixt}dx}{(x + i\gamma/2)(x + \Delta + i\gamma/2)},$$

where $x = \omega - \omega_0$. After a simple calculation, we get

$$C \sim (1 - e^{i\Delta t})\,\Delta^{-1} e^{-i\omega_0 t - \gamma t/2}, \tag{5}$$

which gives for the intensity the expression

$$J \sim (1 - \cos\Delta t)\,\Delta^{-2} e^{-\gamma t}. \tag{6}$$

The periodic variations of intensity with time ("beats") (cf. [5]) are related to the fact that the spectrum of the reflected radiation essentially contains two frequencies, ω_0 and $\omega_0 + \Delta$; we know that under such conditions we always get "beats." If there is no Doppler shift, (6) becomes

$$J \sim t^2 e^{-\gamma t}, \qquad (6')$$

i.e., the intensity shows a maximum which is reached at $t = 2/\gamma$. We should note that the phenomena described here are completely analogous to the well-known phenomena which occur when one records γ rays transmitted through a resonant absorber.[6-11]

Now let us assume that, in addition to the nuclear resonance reflection, there is also reflection associated with Rayleigh scattering by the atomic electrons (cf. [12,13]). The amplitude for the latter process is practically independent of frequency and, at grazing incidence, may be assumed to be real. Under these conditions

$$C \sim \left\{ a\gamma \int \frac{e^{-ixt}dt}{(x + i\gamma/2)(x + \Delta + i\gamma/2)} + b \int \frac{e^{-ixt}dt}{x + i\gamma/2} \right\} e^{-i\omega_0 t}, \qquad (7)$$

where the real numbers a and b characterize the relative contributions of resonance and Rayleigh reflection ($b/a \sim 10^{-2}$).

From (7) it follows that the intensity is

$$J \sim \{2a^2\gamma^2\Delta^{-2}(1 - \cos\Delta t) + b^2 + 2ab\gamma\Delta^{-1}(1 - \cos\Delta t)\} e^{-\gamma t}. \qquad (8)$$

The last term in (8) describes the interference between the two types of reflection. It is interesting to note that when $\Delta = 0$, it disappears (cf. also [13]).

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