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NARROW RESONANCES OF LASER-INDUCED γ-RAY EMISSION AND ABSORPTION BY NUCLEI

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The narrow emission of absorption resonances of recoilless quanta in nuclear transitions in crystals are well known. In this article we propose a method for obtaining narrow nuclear resonances in a gas. The method is based on modulating the frequency of the nuclear transition in molecules that are vibrationally excited by a coherent light wave and have the same velocity projection on the wave-propagation direction. The method makes it possible to obtain resonances both in nuclear absorption and emission, with a width smaller by a factor 10^2 - 10^4 than the Doppler width, and to tune their frequency in a band $\Delta\omega/\omega_\gamma \simeq 10^{-5}$, which greatly exceeds the tuning band of the Mossbauer resonances.

We consider the molecules in a low-pressure gas with inhomogeneous broadening of the vibrational-rotational absorption line ω_0 belonging to a certain i-th vibration. Using a coherent light wave with frequency ω and wave vector $\vec{k}_0 = \vec{n}(\omega/c)$, we can excite molecules with strictly defined projections of the velocity $\vec{v}$ [2]:

$$\mathbf{k}_0 \mathbf{v} = \omega - \omega_0 = \Omega . \tag{1}$$

The density of the excited molecules is given by

$$N_2(v) = \frac{q}{2} N_0(v) \frac{x}{1+x} ; \quad x = \frac{G\Gamma_0^2}{(\Omega - \mathbf{k}_0 v)^2 + \Gamma_0^2} , \tag{2}$$

where $N_0(\vec{v})$ is the Maxwellian distribution of the molecule population on the lower vibrational level in the absence of a field; Γ_0 is the homogeneous width of the optical transition, determined by the molecule collisions and (at very low pressure) by the finite time of flight of the molecules through the light beam; G is the saturation parameter of the transition and is determined by the light-wave intensity; $q = g_j z_{rot}^{-1} \exp[-(E_j/kT)]$ is the number of molecules on the lower rotational level E_j and is determined by the degeneracy of the level g_j and by the partition function of the rotational states z_{rot}.

The atoms in the vibrationally-excited molecules execute forced oscillations of frequency ω_0 and amplitude

$$r_{is}(t) = r_{is}^{(0)} \cos(\omega_0 t + \phi) , \tag{3}$$

where $\vec{r}_{is}^{(0)}$ is the displacement amplitude of the s-th atom upon excitation of the i-th normal vibration of the molecule; this amplitude depends on the force constants and the form of the molecule vibration and on its orientation relative to the light-wave polarization vector. The amplitudes of the atom displacements vary in a rather wide range, from 10^{-9} to 10^{-11} cm. The most important fact is that the average displacement $r_{is}^{(0)}$ is of the same order as the given wavelength λ_γ of γ quanta of energy from 10 keV to 1 MeV. Lattice vibrations of this amplitude should cause an appreciable frequency modulation of the γ radiation.

The spectral line of a nucleus moving with velocity $\vec{v}$ has a center at the frequency $\omega_{nuc}^{(0)} = \omega_\gamma \pm \Delta\gamma + \vec{k}_\gamma \cdot \vec{v}$ ($\Delta\gamma$ is the recoil energy, the plus and minus signs correspond to absorption and emission, and $\vec{k}_\gamma$ is the γ-quantum wave vector) splits up into a number of spectral components with frequencies $\omega_{nuc}^{(0)} \pm \omega_0 m$ ($m = 0, 1, 2, \ldots$), and the intensity of the m-th component is given by

$$I_m = \left\langle J_m^2\left(\frac{r_{is}^{(o)} n}{\lambda\!\!\!^{-}_\gamma}\right)\right\rangle , \qquad (4)$$

where J_m is the Bessel function of order m, while the averaging is over all the molecule orientations. It can be assumed approximately that $I_m \simeq J_m^2(r_{is}^{eff}/\lambda\!\!\!^{-}_\gamma)$, where r_{is}^{eff} is the rms projection of the displacement of the s-th atom on the direction of the light wave exciting the i-th vibration of the molecule.

If the direction of observation of the nuclear transition is collinear with the light wave ($\vec{k}_\gamma = \vec{k}_0(\omega_\gamma/\omega_0)$), out of the entire Doppler-broadened nuclear-transition line only a narrow spectral interval at the frequency $\omega_{nuc}^{(0)}$ will be modulated; the width of the interval is

$$\Gamma_{nuc} = \Gamma_0 \sqrt{1 + G}\,\frac{\omega_\gamma}{\omega_0} \qquad (5)$$

As a result, the shape of the inhomogeneougly-broadened line will be noticeably distorted. At the frequency

$$\omega_{nuc}^{(o)} = \omega_\gamma \pm \Delta_\gamma + \mathbf{k}_0 \mathbf{v}\,\frac{\omega_\gamma}{\omega_0} \qquad (6)$$

a dip is produced, having a width Γ_{nuc} at half-height and a depth

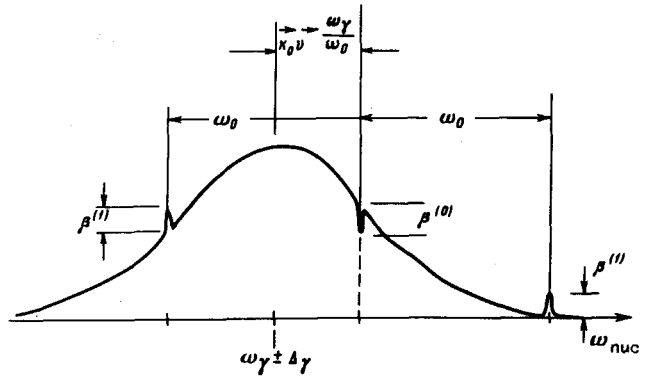
$$\beta^{(o)} = 1 - \frac{q}{2} J_0^2\left(\frac{r_{is}^{eff}}{\lambda\!\!\!^{-}_\gamma}\right)\frac{G}{1+G} , \qquad (7)$$

whereas at the frequencies $\omega_{nuc}^{(m)} = \omega_{nuc}^{(0)} \pm m\omega_0$ there are produced peaks having the same width and relative heights

$$\beta^{(m)} = \frac{q}{2} J_m^2\left(\frac{r_{is}^{eff}}{\lambda\!\!\!^{-}_\gamma}\right)\frac{G}{1+G} . \qquad (8)$$

The shape of the nuclear absorption line when observed in the direction of a light wave saturating the vibrational-rotational transition of the molecule is shown in the figure.

Owing to the relatively small fraction $(q/2)[G/(1 + G)]$ of



Shape of spectral absorption (emission) lines of the γ quanta in a nuclear transition in a gas in a light-wave field $\mathcal{E} \cos(\omega_0 t + \vec{k}_0 \cdot \vec{r})$ when observed in the $\vec{k}_0$ direction.

molecules that resonate with the coherent light wave (the factor q usually lies in the interval 10^{-1} for simple molecules to 10^{-3} for complex ones), the relative amplitudes of the narrow resonances lie in the interval 0.1 - 10%. A very important factor is the automatic tuning of the resonance frequencies when the light-wave frequency is scanned along the Doppler contour of the optical transition, the absolute tuning range of the γ-radiation resonance frequencies being ω_γ/ω_0 larger than the range of the optical transitions.

Since the coefficient of the resonant absorption on nuclear transitions is small for a rarefied gas, the proposed method is most convenient for the production of narrow γ-radiation lines with tunable frequency. The intensity of the emission line with width Γ_{nuc} is narrower by a factor 10^2 than the Doppler width from a tube with gas filled with molecules with radioactive nuclei at a pressure 10^{-2} Torr ($q = 10^{-2}$, $G \simeq 1$, tube length 100 cm, diameter 1 cm, observation solid angle 10^{-4} sr) is equal to $10^7\,\tau$ gamma quanta/sec, where τ is the radiative lifetime of the excited state of the nucleus.

The proposed method permits the performance of a number of fundamental experiments. For example, by tuning a narrow γ-radiation resonance $\omega^{(1)}_{nuc} = \omega_\gamma - \Delta_\gamma - \vec{k}_0\cdot\vec{v}(\omega_\gamma/\omega_0) + \omega_0$ in the vicinity of the $\omega_\gamma + \omega_\gamma$ absorption line of the nucleus and the target, it is possible to measure exactly the recoil energy of the nucleus and the shape of the phonon spectrum [3]; the latter permits a detailed investigation of the vibrations of the nuclei in the crystal. Since the quantity $\vec{k}_0\cdot\vec{v}$ can be measured with very high accuracy by measuring the deviation Ω of the light-wave frequency from the center of the Doppler contour, the frequency of the γ-radiation resonance can be tuned with accuracy $\delta\omega_\gamma/\omega_\delta = \delta\Omega/\omega_0$, which can reach in principle $10^{-11} - 10^{-13}$. This makes possible absolute measurements of the γ-quantum energy with accuracy ω_γ/ω_0 $(10^{-11} - 10^{-13})$, which can reach, in principle, values 10^{-8}, and thus relate, with the same accuracy, the energy scales of the optical and γ-ray bands. Naturally, the proposed method makes possible γ spectroscopy in the region of nuclear transitions $10^{-9} < |(\omega_{nuc}/\omega_\gamma) - 1| < 10^{-5} - 10^{-6}$, which has heretofore been inaccessible to modern methods. We note that it is applicable also for transitions in which the Mossbauer effect does not occur (for example, at a γ-quantum energy much higher than 100 keV).

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CONTRIBUTION OF NUCLEON-TRITIUM CHANNEL TO THE 0^+ STATE OF FOUR PARTICLES

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We discuss in this article the cluster approximatinn (CA) "4 = 3 + 1" in the integral equations for four particles. We have considered the variant of integral equations proposed in [1], which coincide for four particles, accurate to the free terms, with equations of the Omnes type [2]. For a discrete spectrum, these equations, written out for the components of the form factor $F = G_0\Psi$, take the form

$$\lambda F^{\alpha\alpha} = \tilde{\tau}^{\alpha} G_0 \sum_{\beta\neq\alpha,\ \beta\supset b} F^{\beta b}, \qquad (1)$$