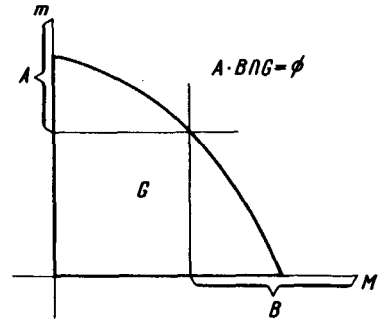
where A_m and A_M are normalization constants, mutually indmissible for arbitrary m_0, Γ_m, M_0, and Γ_M (and all the more for $\Gamma_m \ll \gg \Gamma_M$).



3. Let us consider the main physical consequences. For ordinary unstable particles, owing to the existence of a reaction of the type $\gamma + p \to n + \pi^+$, we arrive by virtue of the theorems of the present paper at the following alternatives: a) the mass distributions do not admit of continuation to the complex plane and as a consequence the decays of unstable particles, particularly of the neutron and the positive pion, should be essentially non-exponential; b) on the other hand, if a careful experiment (see [5] in this connection) shows the decay to be exponential, this means violation of the energy-momentum conservation in reactions in which unstable particles are produced, accurate to within the decay widths. In pair production of resonances, inasmuch as their widths are of the same order, the pole distributions (the Breit-Wigner formulas) are mutually admissible. Exceptions are resonance pair-production reactions in which one resonance is the η meson. Resonances with the same discrete quantum numbers, produced simultaneously with ordinary unstable particles, can no longer be described by simple pole distributions, thus indicating clearly that the resonance mass distribution is dependent on the preparation [2,3]. In this connection, interest attaches to data on the dependence of the distribution of the ρ-meson masses on the preparation [2,5-7]. When account is taken of crossing symmetry, the inadmissibility of pole distributions of the masses for the resonances obviously leaves no hope for the validity of the Regge-pole method.

I am grateful to V. N. Sudakov for interesting discussions of the mathematical problems and for communicating the result of [4] prior to publication, and to the members of the seminars of the divisions of theoretical physics of the Leningrad State University, the Physics Institute of the Academy of Sciences, and of JINR for interesting discussions.

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SPATIAL SYNCHRONISM IN NONSTATIONARY PROCESSES OF THE "PHOTON-ECHO" TYPE

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This article describes several effects that exhibit a number of singularities compared with the well-known "photon-echo" effect, which was recently predicted [1] and investigated

experimentally [2,3] (see also the review [4]).

If an impurity ion of a crystal is in a coherent superposition of two stationary states, i.e., it has a wave function

$$\psi = a\phi_\nu \exp\left(-i\frac{\epsilon_\nu}{\hbar}t\right) + b\phi_\mu \exp\left(-i\frac{\epsilon_\mu}{\hbar}t\right),$$

then a strong resonant field pulse of frequency $\omega \approx \omega_0 = \epsilon_\mu - \epsilon_\nu/\hbar$ and of the form $\vec{E} = \mathrm{Re}\{\vec{E}_0(\omega)\exp(i\vec{k}\cdot\vec{r} - i\omega t + i\Phi)$ causes the ion to go over to another coherent state, the new amplitudes a' and b' being connected with the old ones by the linear transformation

$$\begin{pmatrix} b' \\ a' \end{pmatrix} = \begin{pmatrix} \alpha\exp\left(-i\frac{\Delta}{2}T\right) & \gamma\exp\left(i\mathbf{kr} + i\Phi - i\Delta t_0 - i\frac{\Delta}{2}T\right) \\ \gamma\exp\left(-i\mathbf{kr} - i\Phi + i\Delta t_0 + i\frac{\Delta}{2}T\right) & \beta\exp\left(+i\frac{\Delta}{2}T\right) \end{pmatrix} \begin{pmatrix} b \\ a \end{pmatrix} \tag{1}$$

as can be readily verified by solving the problem of the two-level system in a monochromatic field. Here $\Delta = \omega - \omega_0 \ll \omega$, t_0 is the initial instant of action of the pulse, T the pulse duration, and $\vec{r}$ the center of gravity of the ion. The quantities α, β, and γ depend on Δ, T and $f = (2\hbar)^{-1}\vec{d}_{\mu\nu}|\vec{E}_0(\omega)|$, where $\vec{d}_{\mu\nu}$ is the matrix element of the dipole transition. In the particular case when $f \gg \Delta$, we have

$$\alpha = \beta = \cos\frac{1}{2}fT, \quad \gamma = -i\sin\frac{1}{2}fT.$$

For an arbitrary number of light pulses, the final state can be obtained by successively applying the transformation (1), after which it is easy to calculate the average dipole mement of the atom $\langle\psi|\mathbf{d}|\psi\rangle = \mathrm{Re}\{a^*b\vec{d}_{\mu\nu}\exp(-i\omega t)\}$.

If the ion was initially in the ground state and was acted upon by two pulses, the first at the instant t = 0 of duration T_1 and the second at the instant $t = t_0$ of duration T_2, we get as a result

$$\langle\psi|\mathbf{d}|\psi\rangle = \mathbf{d}_{\mu\nu}\gamma_1^*\beta_1|\gamma_2|^2\exp\{i(2\mathbf{k}_2 - \mathbf{k}_1)\mathbf{r} - i\omega t + i(2\Phi_2 - \Phi_1) + i\Delta(t - 2t_0 + T_2 - T_1)\} + \text{c.c.} \tag{2}$$

The indices 1 and 2 pertain to the first and second pulse, respectively.

We see therefore that the system of resonant ions produces coherent radiation, a "photon echo" at the instant of time

$$t = 2t_0 + T_2 - T_1, \tag{3}$$

which continues for a time $\tau \sim \Delta_0^{-1}$ (Δ_0 - spread of the resonant frequencies of the ions), and for the optical band, where the crystal thicknesses ℓ greatly exceed the wavelength λ, this radiation is maximal when its wave vector is

$$\vec{k} = 2\vec{k}_2 - \vec{k}_1 \tag{4}$$

It is also seen from (2) that for waves having circular polarization the expression

$$\Phi = 2\Phi_2 - \Phi_1. \tag{5}$$

gives the relation between the initial phases, whereas for linearly polarized waves it relates the angles of inclination of the polarization vectors relative to the chosen axis.

We note that $k = k_1 = k_2 = \omega/c(\sqrt{\epsilon(\omega)}$, and consequently the condition (4) is satisfied, strictly speaking, only when all three vectors are directed to one side, which is undesirable, since the time delays are small and it is difficult to separate the pulses from one another. For arbitrary angles between $\vec{k}$, $\vec{k}_1$, and $\vec{k}_2$ the condition (5) can not be satisfied in general, so that the intensity decreases sharply by a factor $(\Delta k\ell)^{-2}$, where $\Delta k = |\vec{k} - 2\vec{k}_2 + \vec{k}_1|$. However, the spatial synchronism can in this case be restored after a third pulse is applied to the crystal (at an instant of time t_0', with duration T_3 and wave vector $\vec{k}_3$). Using the foregoing procedure, we arrive at the following results:

First, two obvious effects arise: "photon echo" from the first and third pulses (at the instant of time $t = 2t_0' + T_3 + T_2 - T_1$ in the direction $\vec{k} = 2\vec{k}_3 - \vec{k}_1$), and "photon echo" from the second and third pulses (for which $t = 2t_0' - t_0 + T_3 - T_2$ and $\vec{k} = 2\vec{k}_3 - \vec{k}_2$).

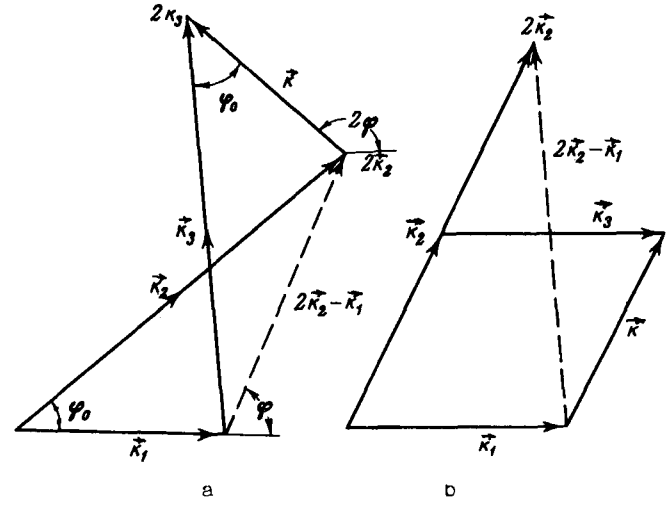
Second, the following new effects are produced: A coherent pulse appears at the instant of time

$$t = 2(t_0' - t_0) + T_3 + T_2 - T_1 \tag{6}$$

in the direction (see figure a)

$$\vec{k} = 2\vec{k}_3 - 2\vec{k}_2 + \vec{k}_1 \tag{7}$$

and in place of (5) we get $\Phi = 2\Phi_3 - 2\Phi_2 + \Phi_1$. There also appears a coherent pulse at the



Vector diagram of coherent decay (wave vector $\vec{k}$) following the action of three light pulses with wave vectors $\vec{k}_1$, $\vec{k}_2$, and $\vec{k}_3$ (see the text).

instant of time

$$t = t_0' + t_0 + T_3 - T_1 \tag{8}$$

in the direction (Fig. b)

$$\vec{k} = \vec{k}_3 + \vec{k}_2 - \vec{k}_1 \tag{9}$$

and in place of (5) we have the relation $\Phi = \Phi_3 + \Phi_2 - \Phi_1$.

We emphasize that the essential feature of the last two effects is that they can be realized when condition (4) is not satisfied and consequently there is no "photon echo" effect. This is demonstrated in the figure.

We see that the first and second pulses produce a coherent state of ions in crystals; this state is in sharp disagreement with the spatial coherence of the light field, inasmuch as the wave vector of the field does not coincide in magnitude with the vector $2\vec{k}_2 - \vec{k}_1$ (dashed lines). However, application of the third pulse in a definite direction, as shown in the figure, restores the spatial synchronism between the coherent state of the system of the ions and the radiation field (conditions (7) and (9) are satisfied). In both cases, the coherence is maintained over the entire length of the crystal, and by varying the direction of the second and third exciting pulses it is possible to attain any direction for the succeeding coherent radiation. To calculate the total radiation energy $\mathcal{E}$ it is necessary to solve the electrodynamic problem. It can be shown that $\mathcal{E} \sim (\lambda n \ell)^2 S \mathcal{E}_0 \sim N^2(\lambda^2/S)\mathcal{E}_0$, where S - the smaller of the cross sections of the pulse beam or the crystal, n - concentration of the sample ions taking part in the process ($N = nS\ell$), and $\mathcal{E}_0 = \hbar\omega W_\tau$ is the energy of the incoherent radiation from one ion in the time τ (W - transition probability).

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NARROWING OF THE DOPPLER WIDTH IN A STANDING LIGHT WAVE

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1. The absorption or emission lines of a low-pressure gas have, in the case of a small radiation width, a Doppler contour determined by the particle velocity distribution. The purpose of the present paper is to show that an intense standing light wave is capable of changing the velocity distribution of the atoms in such a way that an exceptionally narrow peak is produced in the center of the Doppler line when absorption or emission is observed strictly in the direction of the axis of the light wave. Physically this phenomenon is due to "dragging," between the antinodes or nodes of the standing wave, of those atoms which move almost parallel to the wave front. This new effect is of interest for spectroscopy within