[1] J. A. Giovdmaine and J. A. Howe, Phys. Rev. Lett. 11, 207 (1963).
[2] Terhune, Maker, and Savage, Phys. Rev. Lett. 14, 681 (1965).

[1)] The preliminary results of such experiments were described in a recent paper [2].

COHERENT EXCITATION OF OPTICAL SPECTRA OF ATOMS PASSING THROUGH A CRYSTAL

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The author has considered in another paper [1] the possible existence of an effect of coherent Coulomb excitation of nuclei passing through a crystal. The same paper contains estimates showing that, owing to thermal motion of the crystal atoms, observation of this effect on nuclei entails (at the present level of the technology of heavy-nucleus acceleration) certain difficulties. A suggestion was made that an effect similar to coherent excitation of nuclear levels can occur when atoms travel through a crystal, wherein the interaction between the traveling atoms and the crystal atoms leads to coherent excitation of the optical levels of the traveling atoms.

Below are presented estimates offering evidence that the observation of such an effect is perfectly feasible. We propose a concrete experiment in which coherent excitation of optical spectra of atoms should be observable. Qualitatively, such an effect is possible because a particle passing through the crystal moves in the periodic electric field of the crystal atoms. The transition of the moving atom to the excited state is due to a time-dependent perturbation, which in this case is the energy of interaction between the traveling atom and the crystal atoms. The dependence of the energy V(t) between the traveling particle and the crystal atoms has the form of a periodic sequence of single bursts (Fig. 1a), each of which is due to the interaction of the traveling particle with one of the crystal atoms. The Fourier frequency spectrum of a single interaction $S_0(\omega)$ is shown in Fig. 1b for two different velocities of the traveling atom. The Fourier spectrum of the perturbation experienced by the atom following interaction with n atoms of the crystal is connected with the spectrum of the single interaction $S_0(\omega)$ by the relation

$$|S_n^0(\omega)|^2 = |S_0(\omega)|^2[\sin^2(\omega T/2)\, n]/[\sin^2(\omega T/2)] \qquad (1)$$

The dependence of the factor $[\sin^2(\omega T/2)n]/[\sin^2(\omega T/2)]$ on ω for n = 2, 3, 4 and for large n is shown in Fig. 1 (c, d, e, f). The resultant spectrum $|S_n^0(\omega)|^2$, for a large number of interactions n and for two velocities of the traveling atom, is shown in Fig. 1g.

From relation (1) and from Figs. 1 (b - g) we see that the spectral density $S_n^0(\omega)$ at the frequencies $\omega_m = 2\pi m/T$ (m = 0, 1, 2, 3, ...) increases in proportion to the number n of the interactions, and the frequency band occupied near each ω decreases simultaneously like 1/n ($\Delta\omega_m \sim \pi/nT$). This change in the spectrum $S_n(\omega)$ with increasing number of interactions n is connected with the coherence of the spectral components $S_0(\omega)$ of the single interactions that

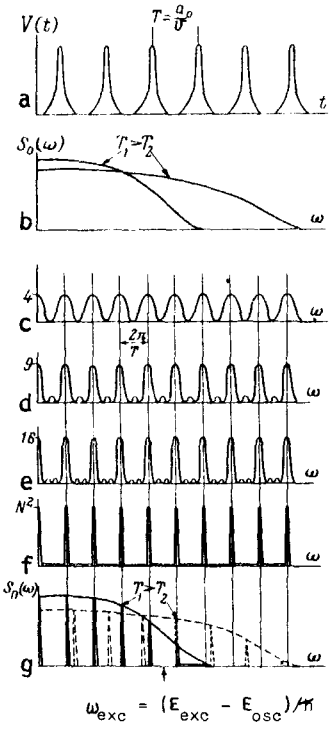

Fig. 1

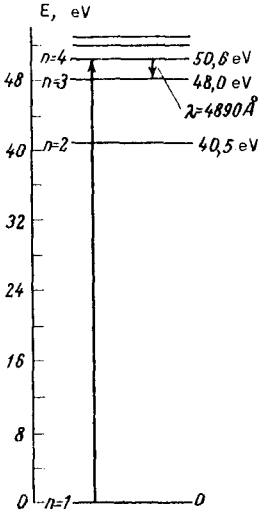

Fig. 2

follow each other periodically (Fig. 1a). It is easy to see that one can always choose suitable conditions (by choosing a crystal with a suitable lattice constant a, or else by changing the velocity of the incoming atom) whereby one of the harmonics $\omega_m = 2\pi m/T$ coincides with the frequency

$$\omega_{exc} = (E_{exc} - E_{gr})/\hbar$$

In this case the probability of the transition of the atom to the excited state increases rapidly

$$W \sim |S_n(\omega_{exc})|^2 = |S_0(\omega_{exc})|^2 n^2$$

Estimates show [1] that the thermal motion of the crystal atoms causes the high-frequency components of the Fourier spectrum $S_0(\omega)$ of the single interactions to cease to be coherent, and the excitation probability W is proportional to $|S_0(\omega)|^2 n^2$ only for harmonics whose number m does not exceed 8 - 10. This is precisely why the energy of the particles at the outputs of modern heavy-nucleus accelerators is insufficient for coherent excitation of the nuclear levels with $\Delta E \sim 100 - 300$ keV.

It is perfectly possible and relatively simple to observe coherent excitation of optical spectra of atoms. For example, the level spectrum of the hydrogenlike helium ion He^+ has the form shown in Fig. 2. If helium ions He^+ with energy ~ 3.7 MeV travel through a thin mica plate (distance between planes $a_0 = 9.9$ Å), then the frequency of the "collisions" between the helium ion and the atoms of the mica plate, $\nu = 1/T = v/a$, is such that $2\pi\nu\hbar = \hbar\omega_0 = 50$ eV. This energy ensures a resonant transition of the electron in He^+ from the ground state with $n = 1$ to an excited state with $n = 4$. Thus, a beam of He^+ passing through a mica plate will contain, besides the atoms excited as a result of single collisions, also a certain admixture of coherently-excited ions of He^+ ($n = 1 \rightarrow n = 4$). These excited ions become de-excited when they leave the mica. The transition $n = 4 \rightarrow n = 3$ lies in the visible region (blue light). It can be separated easily and with high resolution by optical spectrometry (spectrograph, diffraction grating) from the mica background glow, which may be observed in this experiment. Coherent excitation is possible only in the case when the frequency of the "oscillations" between the traveling ions and the crystal atoms is equal to or smaller than the transition frequency by an integer, $\omega_{exc} = (E_{exc} - E_{gr})/\hbar$. Therefore the effect should occur only in a narrow region of incoming He^+-ion energy, near

$$(E_{exc} - E_{gr})/\hbar = \omega = 2\pi/T = (2\pi/a_0)(2E_{He^+}/m_{He})^{1/2}$$

It is best to choose very thin plates of mica, so that the energy lost by the traveling He^+ ions is small. This may determine the narrowness of the He^+ ion beam energy region at which coherent excitation takes place.

[1] V. V. Okorokov, YaF 2, No. 5 (1965), Soviet JNP, in press.

SELF-ACCELERATION OF IONIZING PARTICLES IN AN ELECTRIC FIELD OF A POLARIZING IONIZATION LOOP

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An ionizing particle or a bunch of particles traveling through a medium leaves behind it an ionization trail. Polarization of this trail in an external field may produce a stronger edge field, capable of accelerating the particles inducing the ionization [1]. In the present paper we consider the conditions for the acceleration of particles by means of such a field of an ionization "loop," both in the presence and in the absence of breakdown.

We consider first the case of non-breakdown polarization, when the cascade does not have time to develop within the time when the strong edge field is crowded out. Let us assume that a bunch of N particles passes through a medium, leaving behind it an ionization loop of radius ρ with electron volume concentration $n_e \simeq (N/\pi\rho^2)(dn_1/dx)$, where dn_1/dx is the ionization produced by each particle on a unit path in the medium (for example, for gases at a pressure p we obtain $dn_1/dx \simeq 10^2 p/\beta^2 cm^{-1}$, where $\beta = v/c$ is the relative velocity of the ionizing particles, which for simplicity will be assumed singly-charged).

To intensify the external field behind the particle bunch it is necessary that the plasma of the ionization loop distort the external field rapidly and strongly. The condition for the crowding out (i.e., strong distortion) of the field is the presence of a polarization $P = n_e ex = n_e ekEt \simeq E/4\pi$, where $k = e/m\nu$ is the mobility and ν is the collision frequency of the electrons. The time t of crowding out of the external field by the plasma produced is in this case $t \simeq 1/\sigma$ with $t > 1/\nu$, where the conductivity is $\sigma = n_e e^2/m\nu$. (In the case of "dielectric" screening $t \sim 1/\omega_p$, where ω_p is the plasma frequency). In the case of interest to us, that of screening by conduction current, $t \simeq m\nu\pi\rho^2/Ne^2(dn_1/dx)$ and does not depend on the pressure, since $\nu \sim p$ and $dn_1/dx \sim p$, with $t \sim \rho^2/N$.

The permissible distance X_0 from a bunch of ionizing particles to the front of the intensification of the external field by the plasma trail is defined in such a way that when $X_0 \lesssim \rho$ the field intensity at the bunch is close to the field intensity E at the end of an elongated plasma trail of length l, and can exceed by many times the intensity E_0 of the external field: $E/E_0 \simeq l/\rho \gg 1$ when $l \gg \rho$ for the spherically-rounded-off end of a cylindrical