FEASIBILITY OF PRODUCING AN INVERTED MEDIUM BY PHOTOIONIZATION OF THE INNER ELECTRONS IN ATOMS

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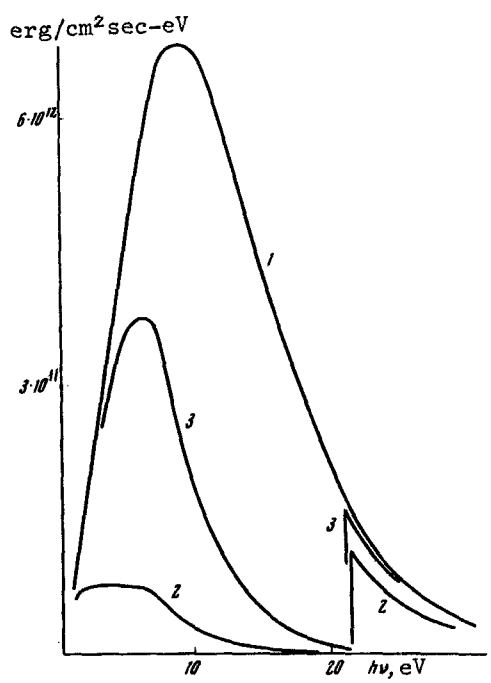
If a photon of sufficient energy is incident on an atom, then the electrons of the outer shell and of the deeper shells become photoionized; in the latter case the ion remains in an excited state.

Duguay and Rentzepis [1] considered the photoionization of 2p electrons in Na (electron configuration $2p^6 3s$) for the purpose of developing an ultraviolet laser. The cross section of 2p-ionization is approximately 100 times larger than 3s-ionization [2], but the choice of Na as a laser medium still remains unsuccessful. The point is that the excited state of the ion ($2p^5 3s$) has a large statistical weight g_2 and is coupled to the ground state ($2p^6$) by an optically allowed transition. In this case the inverted population $N_2/g_2 - N_1/g_1$ becomes rapidly equalized. According to the estimates in [1], a high growth rate of the optical-pumping power (4×10^{18} W/cm^{2}sec) is needed for such a laser to operate on the front of a light pulse.

We wish to call attention to the fact that in a number of cases the photoionozation of the inner-shell electrons results in ions in metastable states, so that accumulation of a sufficient number of excited particles becomes possible at practically attainable optical-pumping powers. The effectiveness of this method of population inversion is determined essentially by the choice of the composition of the pumping-source plasma, for under certain conditions the fraction of hard photons capable of photoionizing deep electrons can reach 50%. The figure shows the theoretical emission spectra of a neon plasma at different optical thicknesses. Similar properties will be possessed by the spectrum of other noble gases, hydrogen, halogens, alkali metals (whose radiation peak lies in the second-ionization region), and a number of other elements. The radiation peak in the hard part of the spectrum of an optically transparent plasma is connected with emission of a photon following capture of an electron and formation of an atom or ion in the ground state.



Emission spectrum at a temperature 36,000°: 1 - black body, 2 and 3 - layer of neon plasma 1 cm thick at particle (atom and ion) densities 4.8×10^{18} and 1.6×10^{19} cm^{-3}.

By tracing the geneology of a given ion in the photoionization process [3], we can establish that in the case of alkali and alkali-earth elements ($np^6(n+1)s^\lambda$, $\lambda = 1, 2$) the hydrogen group, halogens, and noble gases ($ns^2(n+1)p^k$, $k = 4, 5, 6$) the excited ion has an allowed transition to the ground state. The level scheme of the ions of elements of the boron, carbon, and nitrogen groups is listed in Table I, the upward sequence of terms corresponding to an increasing excitation energy. The energy data can be found in [4]. For these elements, the decay of the lower of the excited states is forbidden by multiplicity, corresponding to a decrease of the transition probability by a factor of $10^4 - 10^5$ for light atoms and

Table I

Atom	$ns^2(n+1)p$		$ns^2(n+1)p^2$		$ns^2(n+1)p^3$	
Ion	ns^2	$ns(n+1)p$	$ns^2(n+1)p$	$ns(n+1)p^2$	$ns^2(n+1)p^2$	$ns(n+1)p^3$
		$^1P^o_1$		$^2P_{3/2,1/2}$		$^3S^o_1$
		$^3P^o_{2,1,0}$		$^4P_{5/2,3/2,1/2}$		$^5S^o_2$
					$^1S_0$	
					$^1D_2$	
Ground state	$^1S_0$		$^2P^o_{1/2,3/2}$		$^3P_{0,1,2}$	

10^2 - 10^3 for heavy ones [3]. We note that the threshold for the production of an excited ion with lower multiplicity is much higher, and therefore only ions with larger values of the total spin will be produced if the pump spectrum is suitably chosen.

In the case of elements with d electrons ($nd^m(n+1)s^\lambda$), the ground and excited ion configurations have the same parity, and therefore the transition between them is electric-quadrupole with a probability lower by a factor 10^5 - 10^6 than that of optically allowed transitions [3]. In a number of cases there exists an additional multiplicity hindrance. We note that for elements of the type $nd(n+1)s^2$ the excited ion configuration $(n+1)s^2$ has a statistical weight $g_2 = 1$ and the ground configuration $nd(n+1)s$ (the term ^3D) has $g_1 = 15$. The factor $(N_2/g_2 - N_1/g_1)$ of such elements can be positive even if the ratio N_2/N_1 is small. Interest attaches also to the elements Zn ($sd^{10}4s^2$) and Cd ($4d^{10}5s^2$). The lower-level scheme of their ions is shown in Table II [4]. In the latter transition $nd^9(n+1)d^2D \to nd^{10}(n+1)p^2P^0$ the lower level can become rapidly depleted ($t \sim 10^{-10}$ sec because of the allowed spontaneous decay to the ground state ^2S. Recombination in triple collisions of the ion in the atom makes it possible, in principle, for a continuous regime to exist in such a medium.

In a laser based on an ionic transition with accumulation of particles in the lower state (as in the case of Na [1]), with a pump linearly increasing in time, the inversion is determined by the dimensionless parameter $I\sigma\tau^2/t \gtrsim 1$, where I is the photon flux, σ the photoionization cross section, t the pump

Table II

Configuration	Term	Total momentum	Excitation energy, cm^{-1}	
			Zn	Cd
$3d^{10}4s$	^2S	1/2	0.0	0.0
$3d^{10}4p$	$^2p^o$	1/2	48480.6	44136.08
		3/2	49354.4	46618.55
$3d^9 4s^2$	^2D	5/2	62721.9	69258.91
		3/2	65441.1	74893.66

front duration, and τ the spontaneous lifetime of the upper level. For the realistically attainable quantities $I \approx 10^{23}$ cm^{-2}sec^{-1}, $t \approx 10^{-5}$ sec, and $\sigma \approx 10^{-18}$ cm^2 inversion is possible if $\tau \gtrsim 10^{-5}$ sec, which is attainable for the metastable atoms under consideration.

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RAYLEIGH SOUND FIELD BURSTS IN A METAL IN A MAGNETIC FIELD

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Acoustic Rayleigh surface waves in solids are superpositions of transverse and longitudinal volume acoustic oscillations. Usually these oscillations are localized in a thin layer near the sample surface (cf., e.g., [1]). In pure metals at low temperatures, however, the picture of penetration of the acoustic field in a metal in an external magnetic field may differ greatly from the situation of the normal skin effect. We investigate theoretically in this paper the possibility of existence of sharp bursts of field at distances much larger than the depth of penetration of the sound in the absence of a magnetic field.

1. We choose for the metal a model that is acoustically isotropic. A constant and homogeneous magnetic field $\vec{H}$ is parallel to its surface, the Oz axis is parallel to the vector $\vec{H}$, and the Ox axis to the inward normal to the separation boundary. The equations of elasticity theory are

$$\ddot{u} = s_t^2 \Delta u + (s_l^2 - s_t^2) \nabla \operatorname{div} u + \frac{1}{\rho} f, \qquad (1)$$

where $\vec{u}(\vec{r}, t)$ is the displacement vector, ρ the metal density, s_l and s_t the velocities of the longitudinal and transverse sound, and f the electron force. According to [2], the force f is expressed in terms of the electron distribution function F and the deformation-potential tensor $\Lambda_{\alpha\beta}$ as follows:

$$f_\alpha = \frac{\partial}{\partial x_\beta} \int dr_p \Lambda_{\alpha\beta} F(p, r, t); \qquad dr_p = \frac{2d^3p}{(2\pi\hbar)^3}.$$

We have confined ourselves here to a direct deformation interaction between the electrons and the sound, and have neglected the resultant electric field, with the intention of dealing subsequently with the case of strong spatial dispersion, when $\kappa_l D \gg 1$ (D is the diameter of the electron trajectory, $\kappa_l^{-1} = (k^2 - \omega^2/s_l^2)^{-1/2}$ is the depth of penetration of the Rayleigh wave into the metal, ω is the sound frequency, and $\vec{k}$ is the planar wave vector with components k_y and k_z).

The interaction of the sound waves with the conduction electrons leads to a renormalization of the three-dimensional elastic moduli. It is particularly easy to calculate in the Froehlich model, when the tensor $\Lambda_{\alpha\beta}$ is