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Abstract

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On the Possibility of Induced Amplification of Characteristic X-ray Radiation

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The rapid growth of the photoionization cross sections of the inner electron shells of atoms with decreasing principal quantum number at unchanged quantum energy was proposed for use in creating an inverted population of inner shells ([1]). The possibility of creating an inverted population of inner electron shells under pumping by X-ray radiation was also considered in ([2]). The authors of ([1]) showed that in this case, in principle, observation of induced amplification of characteristic X-ray radiation is possible. The necessary rates of increase of the pumping intensity were estimated under the assumption that the lifetime of the inverted state does not exceed the lifetime of a vacancy in an isolated atom. However, a detailed consideration of the structure of the inner electron shells of atoms and of transition probabilities shows that, in a number of cases, at a matter density close to that of a solid, it is possible to obtain a quasi-stationary inverted population with multiple use of each atom. This makes it possible sharply to increase the lifetime of the inverted state and to reduce the necessary rates of increase of the pumping intensity.

The condition for maintaining a quasi-stationary inverted population of two inner electron levels of an atom can be written in the form

$$W_{AB} < W_{B\Sigma}, \tag{1}$$

where W_{AB} is the total probability of transition of a vacancy from the lower level A to the upper B; $W_{B\Sigma}$ is the probability of filling a vacancy at level B from higher-lying levels.

According to known data on the widths of the inner electronic levels of atoms ([3–5]), condition (1) is fulfilled for vacancy transitions $1s_{1/2} \to 2p_{1/2}$ (the $K_{\alpha 2}$ line) in atoms of elements with $Z \lesssim 47$, and $1s_{1/2} \to 2p_{3/2}$ (the $K_{\alpha 1}$ line) for $Z \lesssim 36$. The favorable ratio of level widths in this range of Z is due mainly to radiationless transitions of vacancies from the $2p_{1/2}$ and $2p_{3/2}$ levels (Auger and Coster–Kronig effects ([4,6])).

Maintenance of a stationary inverted state is possible in a range of temperatures at which the probability of radiationless recombination onto valence levels W_p

([7–9]) is not less than the probability of vacancy transitions between the levels used. In the hydrogen-like approximation ([7])

$$W_p \simeq 8.75 \cdot 10^{-27} Z_i^3 N_e^2 / T^{9/2} > W_{AB}, \tag{2}$$

where Z_i is the ion charge in units of the elementary charge; N_e is the electron concentration, cm^{-3}; T is the electron temperature, eV.

In the range of Z under consideration, the removal of several valence electrons does not lead to a shift of the $K_{\alpha 1,2}$ lines beyond their natural width ([3,10]). This makes it possible, at a solid-state density of the amplifier material, to preserve the inverted state up to temperatures $\approx 30 \div 100$ eV. The lifetime of the inverted population will obviously be determined by the–

by satisfying condition (2), since the process of photoionization of the K-level is inevitably associated with significant energy release due to the kinetic energy of photoelectrons and Auger electrons.

The elementary cross section of induced emission $\sigma_{1,2}$ of the $K_{\alpha 1,2}$ lines can be estimated from the known experimental data on level widths:

$$\sigma_{1,2} = \frac{\lambda^2}{2\pi} \frac{\Delta K_{2,3}}{\Delta K + \Delta L_{2,3}}, \tag{3}$$

where λ is the wavelength; $\Delta K_{2,3}$ is the part of the radiative component of the width of the K-level corresponding to the transition $K \to L_{2,3}$; ΔK is the total width of the K-level; $\Delta L_{2,3}$ is the width of the $L_{2,3}$ level.

Comparison of the cross sections for induced emission with the absorption cross sections of resonance quanta on the overlying electron shells [(3)] shows that amplification is possible if, in the excited state, there are simultaneously $\approx (2 \div 3) \cdot 10^{-3}$ of the total number of atoms.

A quasi-stationary inverted population can also be obtained for other lines of the X-ray spectrum (for example, for the K_β series); however, the oscillator strengths of these transitions are usually insufficient for the observation of amplification.

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Note: Figure translations are in progress. See original paper for figures.