Laser recombination transitions in Ca II and Sr II

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(Submitted January 9, 1973)
Zh. Eksp. Teor. Fiz. 64, 2017-2019 (June 1973)

It was established that the excitation of some violet and ultraviolet transitions in Ca II and Sr II, giving rise to coherent radiation, resulted from impact-radiative recombination of doubly charged metal ions. Superelastic collisions with slow electrons were found to provide a sufficiently effective additional mechanism for the depletion of the lower levels of these transitions.

We shall show, by considering some laser transitions in Ca and Sr, that collisions with electrons in a decaying plasma can ensure a sufficiently high degree of population inversion and emission of coherent radiation. This is best illustrated by the existence and properties of the stimulated emission resulting from transitions between the deepest S and P terms of calcium and strontium ions (Fig. 1):

$$5^2S_{1/2} - 4^2P_{3/2}\text{Ca II } 3737\ \text{Å},\ 5^2S_{1/2} - 4^2P_{1/2}\text{Ca II } 3706\ \text{Å},$$
$$6^2S_{1/2} - 5^2P_{3/2}\text{Sr II } 4305\ \text{Å},\ 6^2S_{1/2} - 5^2P_{1/2}\text{Sr II } 4165\ \text{Å},$$

but the situation is approximately similar for other investigated transitions in Ca, Sr, and Ba, which will not be described here.

At first sight these transitions do not seem very suitable for laser action because they terminate in resonance levels of ions which should be filled effectively by cascades from higher D and S levels and by self-absorption in resonance transitions. If we bear in mind that the wavelengths of the resonance radiation are approximately equal to the wavelengths of the stimulated emission transitions, it seems unlikely that inversion can be achieved simply on the basis of the radiative lifetimes. These conclusions are supported by the calculations of the probabilities of the optical transitions carried out by the Bates and Damgaard method.

The situation changes if we consider collisions with electrons in the afterglow of a pulse discharge. The impact-radiative recombination of Ca^{2+} and Sr^{2+} populates the relevant levels and superelastic collisions of the second kind with electrons provide a sufficiently effective additional mechanism for the depletion of the lower laser levels. The last point is worth special attention. Suggestions for using relaxation processes during the cooling of a plasma have been made in[1,2].

The recombination nature of the population of the laser levels was deduced from the experimentally established features of the stimulated and spontaneous emission. The stimulated emission from calcium and strontium was observed only in the presence of helium and the gain was found to increase with the helium pressure in the 2–40 Torr range. At optimal metal vapor pressures (6×10^{-3} Torr) and for optimal pulse currents (120 A for Ca and 70 A for Sr in the case of pulses of 1 μsec duration) the gain for the strong components of the doublets was 12 dB/m, for the 3737 Å line of Ca II and 30 dB/m for the 4305 Å line of Sr II. At helium pressures in excess of 17 Torr the latter line gave rise to superradiance (the active length was 60 cm and the tube diameter was 8 mm). The stimulated emission from all the lines was observed in the afterglow of a discharge after a delay of 0.3–1 μsec at the end of a current pulse. The output radiation pulse coincided in time with the maximum in the afterglow of the lines (Fig. 2), which was due to the impact-radiative recombination of Ca^{2+} or Sr^{2+} (this was deduced by superimposing a weak heating current pulse at any time during afterglow, which produced a dip in the afterglow curve and stopped stimulated emission). The concentrations of the doubly charged metal ions in all the mixtures was quite high because the double ionization potential was less than the ionization energy of helium. This circumstance and the high rate of recombination of multiply charged ions[3] was responsible for the high intensity and short duration of the recombination peak. The prolonged decay of the intensity which followed this peak was due to the recombination of Ca^{2+} and Sr^{2+} generated in the afterglow by the double ionization caused by the helium ions.[4]

A characteristic feature of the Ca II, Sr II, and Ba II spectra was the presence of a metastable D term (Fig. 1), whose energy is less than that of the lower level in the laser transitions. The transition from the lower P level to the D term is optically allowed but its probability is slight since the separation between these levels (in the case of Ca and Sr) is small. However, this last circumstance is responsible for the fact that, at sufficiently high values of n_e, the electron de-excitation depletes strongly the lower laser level (the efficiency of this de-excitation process rises considerably with decreasing electron temperature and, particularly, with decreasing distance between the levels). In the case of Ba, the metastable term is located too low, almost next to the ground state of the ion, and the energy difference between the P and D terms is relatively large. Consequently, the electron de-excitation process

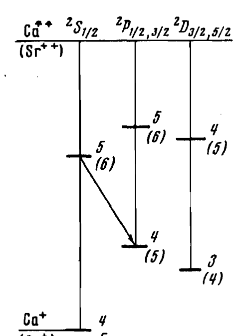

FIG. 1

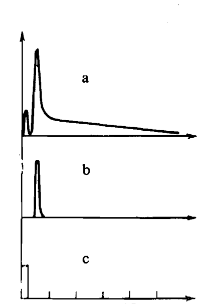

FIG. 2

FIG. 1. Simplified energy-level scheme of Ca II and Sr II. The arrows identify the laser transitions.

FIG. 2. a–Spontaneous emission of ionic lines of metals; b–stimulated emission pulse; c–current pulse.

becomes ineffective and there is therefore no stimulated emission as a result of such transitions in Ba. This is confirmed by our calculations of the rates of decay of the laser levels carried out allowing for the electron de-excitation, which indicate that the ratios of the lifetimes for the relevant Ca II and Sr II levels improve approximately by a factor of 1.6 for $n_e > 10^{13}$ cm^{-3} (which corresponds to our experimental conditions), whereas there is practically no improvement in the case of Ba II.

The advantage of helium over other buffer gases is the considerably faster cooling of electrons in the afterglow, which helps in the rapid establishment and effective occurrence of the electron de-excitation and recombination processes.

The results of the present investigation together with the theoretical estimates given in[5] suggest that it should be possible to achieve stimulated emission by analogous S–P transitions in Be II at $\lambda = 1776$ Å.

[1] L. I. Gudzenko, Yu. K. Zemtsov, and S. I. Yakovlenko, ZhETF Pis. Red. 12, 244 (1970) [JETP Lett. 12, 167 (1970)].
[2] L. I. Gudzenko and L. A. Shelepin, Dokl. Akad. Nauk SSSR, 160, 1296 (1965) [Sov. Phys.-Dokl. 10, 147 (1965)].
[3] I. S. Veselovskiĭ, Zh. Tekh. Fiz. 39, 271 (1969) [Sov. Phys.-Tech. Phys. 14, 193 (1969)].
[4] E. L. Latush and M. F. Sém, ZhETF Pis. Red. 15, 645 (1972) [JETP Lett. 15, 457 (1972)].
[5] L. I. Gudzenko and S. I. Yakovlenko, Kratk. Soobshch. Fiz. FIAN No. 7, 3 (1970).

Translated by A. Tybulewicz
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