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Observations of Acoustic-Wave-Induced Superluminescence in plasma

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Recently, the researching of the higher layers of the atmosphere of the globe (mainly of ionosphere and the ozone layer) has got a big progress. The researching of the processes being performed in that layers are of a unique interest from the scientific and application points of view. Several phenomena taking place in the ionosphere are mostly interesting, which are the results of flows different by their natures and shapes. The phenomenon observed by us is very much alike to phenomena that are observed in the ionosphere and cosmic objects [1-3], where an ionized environment of some density and temperature exists. Such a situation can arise, when, e.g. the cosmic shuttles re-enter the atmosphere[4].

Last years, an interesting effect of abrupt change of radiation spectrum under action of sound wave in dense (p $\sim$ 100 Torr) argon discharge plasma was observed in our laboratory [5,6]. Several seconds after cutting out of sound wave, the light flashes were observed during several minutes in different points of the discharge tube in the bulk of positive column, that apparently corresponded to some transitions between electronic levels of atomic argon. An assumption was made about the autogeneration (single-pass generation) of appropriate lines in the argon spectrum.

The studies of the change of a radiation spectrum under the influence of acoustic waves were conducted using low-temperature argon gas discharge plasma (pressure – 100 Torr, discharge current - 50 mA, voltage on electrodes 2 kV).

The investigations showed that variations of argon plasma radiation are manifested as flashes with duration of 15 – 20 ms. The flashes are of orange and blue colour. These flashes arise independently one of the other. The orange flashes appear on the outer side of the border of discharge pinch, whereas the blue flashes burst inside the discharge pinch.

An analysis of the spectral composition of flashing radiation showed that these correspond to three transitions between energy levels of atomic argon:

$$7d^{-}\ 4p \text{ wave length } 4876 \text{ Å},$$

$$7s^{-}4p \text{ wave length } 5882 \text{ Å},$$

$$6s\ ^{-}\ 4p \text{ wave length } 5888 \text{ Å}.$$

The dependence of radiation intensity on the acoustic wave intensity on 190 Hz frequency is seen to show the hysteresis-type behavior.

Thus, summarizing the above experimental data one can draw a qualitative conclusion about the mechanism of this effect.

As shown in [7-9], in the field of a standing acoustic wave, acoustic vortices are generated. It is also known that at sufficiently high pressures (P$>$10 mm Hg), virtually the only process of bulk neutralization of charged particles in the gas-discharge plasma, which is competitive with the diffusion process, is the dissociative recombination [11] of electrons and molecular ions. In an inert gas discharge the molecular ions are predominant at high pressures (P$>$10 mm Hg) and relatively low gas temperatures (T$<$1000^{o}K). So, we may assume that our experiment proceeds via the following processes:

$$Ar^{+} + 2Ar = Ar_2^{+} + Ar$$

$$Ar_2^{+} + e = Ar^{*} + Ar$$

These processes run at very high rate and lead to efficient formation of excited atoms of inert gas. It is known that highly excited atoms are produced as a result of electron impact dissociation of molecules [11,12]. This process was widely used in early investigations of Rydberg atoms.

So, taking into account the aforesaid we may make the following assumptions: The flows formed are directed in some places to walls and in some places to the center of tube. These flows carry the particles in and out of the discharge range. In this process the particles may be found in the regions of discharge tube, where the temperature of electrons and neutral particles are notably lower than in the discharge range. Hence, hot electrons are quickly cooled mainly due to elastic electron-atom collisions. Then there the recombination of electrons with ions takes place, and basically with molecular ions. An analogous intense recombination occurs also in places, where the acoustic flows are directed to the center of tube. When and where the particles of cool gas get in the discharge, they cause an intense recombination. It turned out that during these recombination events, i.e., during the dissociative recombination, highly excited long-lived atoms are produced. So, in the indicated places the accumulation of highly excited atoms occurs.

Now consider the destruction of such highly excited long-lived states of the atom as a result of collisions with atoms and molecules.

In conformity with the theory of atomic collisions [13], the probability of transition between two states strongly depends on the Messi parameter ξ (the probability is $\sim$ exp(-ξ)). Let us estimate the value of Messi parameter for transition *nl* $\rightarrow$ *n′l′*, where *n′*= n-1. The difference in energy for this transition is $\Delta\varepsilon \sim (\delta_l - \delta_{l'})/n^3$, where δ_l is the quantum defect, n – the first quantum number. The Messi parameter is [14]

$$\xi = \Delta\varepsilon a / v_a \sim \delta_l / n v_a$$

where a is the size of the strongly excited atom, ν_a - the velocity of nucleus motion. For *n, l* $>>$1 the Messi parameter turns out small due to the smallness of quantum defect δ, and the probability of appropriate transitions is high. The situation is different when the highly excited states have orbital momentum *l* ≥ 0. In these cases the Messi parameter $\xi \geq 1$ for moderate values of n. Then the probability of transition at the collision is much less than that in the former case.

Owing to the quenching of highly excited states at collisions with atoms and molecules, the levels with *n, l* $>>$1 are quickly emptied, whereas the levels with n $>>$1, *l* $\geq$ 0 are occupied. In this experiment the levels $7s$,$6s$,$7d$ are occupied. Due to this fact an increase in radiation intensity from transitions $7s \rightarrow 4p$, $6s \rightarrow 4p$, $7d \rightarrow 4p$ was observed. As for the flashes and locations of their formation, these are, presumably, due to the superluminescence that takes place when the overpopulation threshold for autogeneration is overpassed.

Finally we arrive at the following conclusion about the dynamics of this effect. The acoustic vortices that arise in case of sufficiently intensive acoustic field transfer cool neutral atoms and charged particles in the radial plane in the discharge tube. At a definite value of the velocity of these motions some regions emerge at specific locations of the tube (either in the discharge pinch or out of it), where an intense recombination of charged particles takes place (in this case the dissociative recombination). As a consequence of this recombination the concentration of highly excited atoms in the mentioned locations abruptly increases. Due to quenching of highly excited atoms at the collisions with atoms and molecules, the population of levels $6s$, $7s$, $7d$ is increased. The observed flashes occur when the overpopulation threshold for superluminescence between levels $6s \rightarrow 4p$, $7d \rightarrow 4p$, $7s \rightarrow 4p$ is overpassed.

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