Intense x-ray emission in the interaction of a laser plasma with a solid surface

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(Submitted 3 June 1982)

Pis'ma Zh. Eksp. Teor. Fiz. **36**, No. 2, 38–40 (20 July 1982)

When the burst of hot laser plasma reaches a solid surface, there is intense x-ray emission. Specifically, the lines of the principal series of hydrogenlike and heliumlike ions are several times more intense than the emission in the same lines in the hot core of a laser plasma. The observed effect is attributed to a charge exchange of multiply charged ions with neutral atoms and low-charge ions near the solid surface.

PACS numbers: 52.40.Hf, 52.25.Ps

Vinogradov and Sobel'man[1] have drawn attention to the possibility of using the propagation of a laser plasma into a buffer gas to produce intense emission in the far-UV and near-x-ray regions through the charge exchange of multiply charged ions with atoms. An alternative approach, which has been proposed for achieving the same

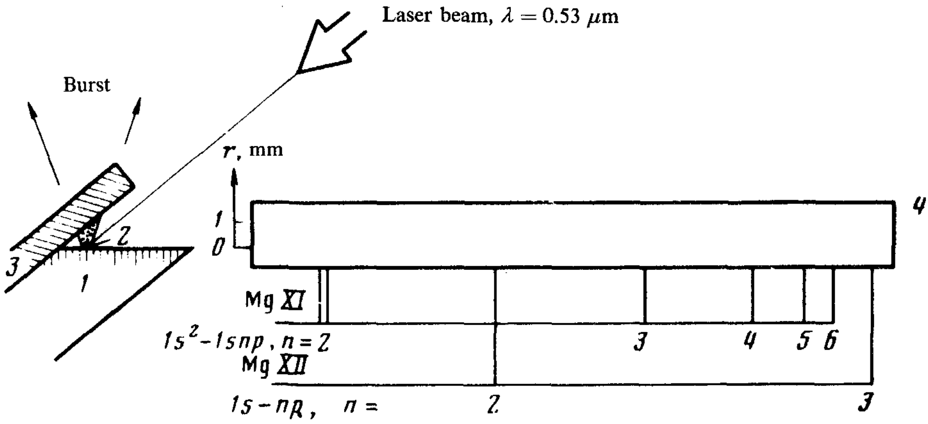

FIG. 1. The experimental arrangement. 1—Magnesium target; 2—laser plasma; 3—polyethylene or aluminum plate; 4—spectrogram showing the emission of the magnesium ion.

effect, is to use the propagation of a plasma burst in a vacuum, under conditions such that the upper levels of ions are populated through three-body recombination as the plasma cools.[2] Experiments [3–6] have shown that both of these suggestions hold promise. The experimental result has been some intensification of one of the higher-order lines of a principal series, but its intensity is still considerably lower than that of the resonance line emitted in the laser plasma burst.

In the present experiments we placed a solid surface in the propagation path in the laser plasma and observed a substantial increase in the total emission intensity in the resonant lines of the hydrogenlike and heliumlike ions. The experimental arrangement is shown in Fig. 1. The plasma is produced by making use of the second harmonic ($\lambda = 0.53\ \mu$m) of a neodymium-glass laser.[7] The energy of the laser pulse can be varied up to 10 J; the pulse length is 5 ns. The beam is focused by a lens with a focal length of 300 mm on to the plane surface of a magnesium target, oriented at 45° from the axis of the incident laser beam. A polyethylene (or aluminum) plate is placed in the path of the laser burst, 1 mm from the focal spot along the normal to the plate surface. The x-ray emission is analyzed with a Gamosh spectrograph, which forms an image of the burst in the light of the spectral lines. The mica crystal used in the spectrograph was bent to a radius of curvature of 20 mm. All the spectrograms are recorded in a single laser shot. The orientation of the spectrograph corresponds to an imaging of the plasma along the direction in which the laser burst is expanding. The x-ray emission is recorded on UV-VR photographic film, whose sensitometric characteristics were described in Ref. 9. It can be seen from the spectrogram in Fig. 1 that when the laser burst touches the surface of the polyethylene, $(CH_2)_n$, there is intense emission in the lines of the principal series of hydrogenlike and heliumlike magnesium ions. There is no emission in satellite lines. Between the bright core of the burst ($\sim 100\ \mu$m from the magnesium target) and the region of intense emission near the surface, there is a region essentially devoid of x-ray emission. The relative intensities of the emission in the pertinent parts of the spectrum of the burst and of the surface region are 1 and 1.3 for the resonance line of the hydrogenlike ion MgXII ($\lambda = 8.42$ Å), and they are 1.1 and

3.6 for the resonance line of the heliumlike ion MgXI ($\lambda = 9.17$ Å). The resultant intensity of the resonance lines of the MgXI and MgXII ions near the surface is thus 2.5 times their intensity in the hot burst core. This effect does not depend on the surface material: The spectrum does not change when the polyethylene is replaced by aluminum. In the latter case, we might note, there was no emission in the lines of the hydrogenlike and heliumlike ions of aluminum. This result implies that the electrons near the surface were at a low temperature. This inference is supported by the fact that in the case of the polyethylene plates we observe emission in the lines of the ions CII–CIV in the visible part of the spectrum near the surface; this emission corresponds to an electron temperature ~ 10 eV. An estimate based on the Stark broadening of the CIII line[10] ($\lambda = 5696$ Å) puts the electron density at $N_e = 4 \times 10^{16}$ cm^{-3}. Under the assumption that the degree of ionization corresponding to the temperature of the hot burst core ($T_e \sim 6 \times 10^6$ K) is "frozen" during the plasma expansion, we find the relative concentrations of nuclei, hydrogenlike ions, and heliumlike ions of magnesium to be 0.3:1:1.

These experimental data show that the emission in the surface region results from the capture of electrons to high-lying levels of multiply charged magnesium ions, followed by a cascade process due to radiative and collisional processes. The capture mechanisms are charge exchange with atoms and low-charge ions in the surface layer, charge exchange near the surface, three-body recombination, and photorecombination. If we assume that the expansion velocity of the laser plasma is at least 10^{-7} cm/s, that the total density of atoms and low-charge carbon ions is $\sim 4 \times 10^{17}$ cm^{-3}, and that the electron temperature is $T_e \sim 10$ eV, we can calculate the following probabilities: for charge exchange, $W_{ex} \gtrsim 10^{10}$ s^{-1}; for three-body recombination, $W_r \lesssim 2 \times 10^9$ s^{-1}; and for photorecombination, $W_{ph} < 10^9$ s^{-1}. Ions with a charge $Z = 10$–12 which reach the solid surface capture electrons from surface atoms with a probability of order unity distances ~ 10 Å. Under these conditions the charge-exchange mechanism is predominant; the levels of the hydrogenlike and heliumlike magnesium ions with principal quantum number $n = 5$–7 are populated preferentially. Three-body recombination may make some contribution to the population of higher-lying levels.

These results demonstrate a new way to produce intense x-ray emission through the interaction of a laser plasma with a solid surface.

We are deeply indepted to M. A. Mazing for many useful discussions of these results.

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Translated by Dave Parsons
Edited by S. J. Amoretty