DETERMINATION OF LASER PLASMA TEMPERATURE FROM STUDY OF RADIATION IN ROENTGEN AND VISIBLE REGIONS OF SPECTRUM

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A laser plasma temperature of $T_e \approx 20$ eV is determined by the foil method from measurements in the region of soft roentgen radiation. Measurements of radiation intensity in the visible region of the continuous spectrum give values of the temperature of $T \approx 15$ eV for the part of the plasma which is opaque in the visible region of the spectrum.

Plan of Experiment. The plasma was generated with irradiation from impulses of a Nd^{+++} laser with a LiH target 0.1-0.3 mm in size in a vacuum chamber. A variant with flying targets [1] and a variant with the target fixed in the region of the focus at narrow angles were used. The flux density of the laser radiation averaged over the focal spot was $\sim 5 \cdot 10^{10}$ W/cm^2 at the instant of the laser impulse maximum at a halfwidth of ~ 30 nsec. The initial chamber pressure was 10^{-5} torr. The radiation from the plasma studied emerged within a small solid angle at an angle of 45° (opposite) to the axis of the laser beam.

Roentgen Measurements. Preliminary evaluation of the plasma temperature from the data of magnetoprobe measurements gave a value of $T_e \sim 10$ eV. At such low temperatures the main part of the roentgen bremsstrahlung lies in the ~ 500 Å region and measurements using photomultipliers are impractical because of the low efficiency of the scintillators. Therefore to determine the plasma temperature from the roentgen radiation by the foil method [2], a flow-through proportional counter with an argon–methane filling (90% Ar and 10% CH_4) was used for recording the roentgen radiation. The construction of the counter is analogous to that described in [3], with the entrance window covered with a sheet of nitrocellulose 2.5 μ thick.

A necessary condition for proportionality between the signal amplitude from the counter and the registered radiation flux is a sufficiently short duration of the radiation impulse $\tau \ll t$, where t is the collecting time of the electronic component of the counter. Usually $t \geqslant 10^{-7}$ sec, and the value of τ can be assigned as equal to the duration of the laser impulse ~ 30 nsec, so that one can consider the given requirement as fulfilled.

The absorption of the plasma's roentgen radiation was studied in aluminum sheets about 0.45 μ thick deposited on nitrocellulose backings ~ 0.2 μ thick in a vacuum by the method of aluminum evaporation. The thickness of the aluminum layers prepared was measured on an MII-4 microinterferometer with control samples on glass backings. A comparison of the experimentally determined dependence of the flux intensity on the absorbed thickness with calibration curves [2] showed that in the case studied $T_e < 100$ eV. For a more precise determination of the temperature a calculated dependence was constructed for the intensity of the transmitted roentgen radiation on the absorbed thickness for different plasma temperatures. The dependence of the intensity J of the transmitted roentgen radiation on the thickness δ of the attenuator layer and the dependence of the transmission rate R of absorbers of different thicknesses on the temperature are presented in Fig. 1. The points show the experimental values. Curves 1-5 correspond to combinations of layers of aluminum and nitrocellulose with thicknesses (in microns) of (0+2.5)/(0.035+2.7), (0.035+2.7)/(0.14+3.4), (0+2.5)/(0.14+3.4), (0.035+2.7)/(0.22+3.8), and (0+2.5)/(0.22+3.8). The calculations are considerably simplified by the fact that the absorption coefficient of nitrocellulose has a dip in the region of λ = (43-

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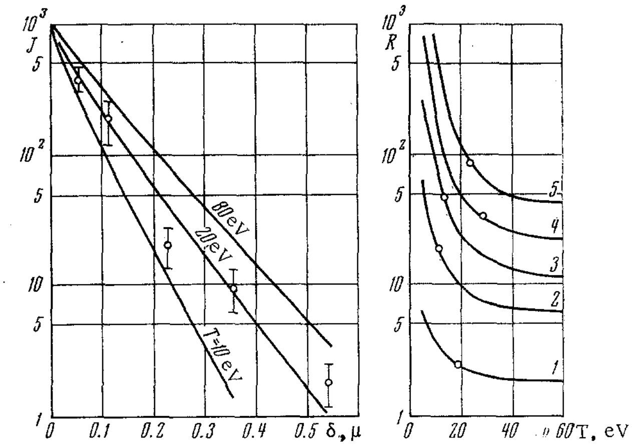

Fig. 1

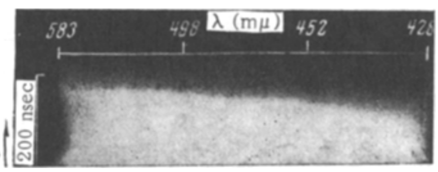

Fig. 2

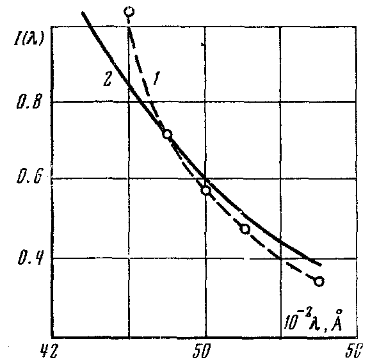

Fig. 3

60) Å, as a result of which the greater share of roentgen radiation lies in this range of wavelengths. The information on the coefficients of absorption of nitrocellulose and aluminum needed for the calculations is taken from [4] and [5], respectively. A comparison with the experimental data (Fig. 1) gives a value of $T_e \approx$ 20 eV for the plasma temperature. A considerable scatter ($\sim \pm 10$ eV) in the temperature values obtained is evidently connected with errors in the measurements of the thickness of the absorbing sheets.

Measurements in Visible Region of Spectrum. A determination of the parameters of a laser plasma from the integral over an impulse of the radiation spectrum was conducted in [6] in the visible region of the spectrum and in [7, 8] in the region of the vacuum ultraviolet. The characteristics developing with time of the spectrum of plasma luminance in the visible region were studied in the present work. A PIM-3 type electronic-optical converter mounted on the output of a monoprismatic spectrograph was used to obtain the time development of the spectrum. The image of the luminous plasma was projected by the objective onto the entrance slit of the spectrograph which was 0.2 mm wide and 0.1 mm high. A photograph of the development of the luminant spectrum of the central region of the plasma having dimensions of ≈ 0.6 mm is shown in Fig. 2. The photographs show that the radiation from the volume of the plasma with dimensions on the order of the diameter of the focal spot in an interval of ~ 100 nsec has a continuous spectrum.

The spectral sensitivity of the ÉOP photocathode needed for determining the spectral density of the radiation curve was determined in a supplementary experiment using an MDR-2 monochromator and an SI10-300 lamp from the ratio of the signal from a VTh-1 vacuum thermoelement mounted on the output slit to the signal from an FÉU, mounted on the ÉOP screen. The curve of the spectral density of the plasma radiation obtained (see Fig. 3, curve 1) was close to the distribution for an absolutely black body in the Rayleigh–Jeans region (Fig. 3, curve 2). From measurements of the spectral intensities one can determine the value of some effective temperature, averaged over the optical depth of the luminant plasma. The size of the averaging region was ~ 0.1 mm, as confirmed by observations in experiments on the sharp drop in luminant intensity in moving away from the focus, as well as by the considerable gradients of the absorption coefficient of the plasma near the zone of opacity [9].

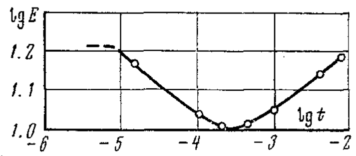

Fig. 4

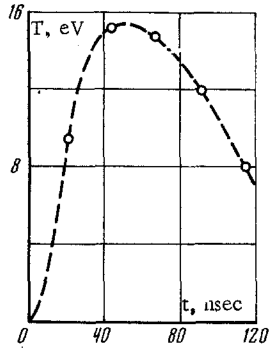

Fig. 5

To determine the temperature of an absolutely black body from radiation in the region of $h\nu/kT \ll 1$, it is necessary to measure the absolute intensity of the radiation. For this purpose the luminant spectrum of an SI10-300 lamp (without scanning) was photographed. On the photographs the sections of the spectrum with identical density relative to the plasma spectrum were selected, then the flux rate in the selected section was measured in comparison with the VTh-1 vacuum thermoelement. The plasma temperature T was determined according to the formula

$$J_1(\lambda_0)\, t_1 = 2\pi hc^2\lambda_0^{-5}[\exp(hc/kT\lambda_0) - 1]^{-1}\Delta\lambda k_1 k_2 t_2$$

Here $J_1(\lambda_0)$ and t_1 are the measured flux rates in the section $\{\lambda_0, \lambda_0+\Delta\lambda\}$ in the comparison spectrum and the exposure time for the photograph of this spectrum, respectively; k_2 is a coefficient taking into account the spectrograph transmission and the experimental geometry; t_2 is the resolution time in scanning the plasma spectrum, which was 4.6 nsec in the experiments; k_1 is a coefficient taking into account the dependence of the film sensitivity on the exposure time. A supplementary experiment was conducted to determine this dependence, in which the luminance of an IFK-2000 lamp was photographed through a nine-stage attenuator with exposure times from 10^{-5} to 10^{-3} sec, accomplished with the use of a Kerr cell, and the intensity of the light flux in the impulse isolated by the shutter was simultaneously recorded with an FÉU. In Fig. 4 the results of the experiment are presented for RF-3 film in the form of an isoopaque line for a density of $S = 0.72$, characteristic for the photographs of the plasma spectrum. The exposure times in scanning the plasma spectrum, which must be taken into account in determining the sensitivity from the curve in Fig. 4, are determined from the luminescence time of the ÉOP screen and equal ~15-20 msec.

From the collection of experimental data obtained, the value of the plasma temperature at the instant of the laser impulse maximum is 15 ± 2 eV, which agrees satisfactorily with the roentgen measurements. The time decrease in the temperature (Fig. 5) after termination of the laser impulse, obtained from the spectral intensity of the plasma radiation integrated over the volume, occurs considerably slower than by the $\sim t^{-2}$ rule which should occur upon adiabatic dispersion of the given mass of gas having an adiabatic index $\gamma = 5/3$ with a radial velocity distribution in the form $v = \dot{R}r/R$, where $\dot{R}$ and R are the asymptotic velocity and radius of the boundary region of the gas encompassed by isomorphic movement. This effect may be partially connected with intense processes of three-part recombination in the dense plasma of the central zone. In addition, the rapid expansion of the outer layers after termination of the laser impulse may be accompanied by a considerable deviation of the system from the equilibrium distribution of energy levels [10], so that to obtain temperature values from measurement of spectral intensities a certain amount of caution must be exercised. A quantitative evaluation of the given effects is difficult because of the lack of data on local values of the plasma parameters and by the essentially recombination nature of the observed spectrum at temperatures of $\leqslant 30$ eV [11].

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