Laser compression of glass shells

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Results are presented of numerical calculations on heat and compression of microscopic glass spheres by laser radiation. A comparison of the calculated picture with an x-ray photograph of the target [Pis'ma Zh. Eksp. Teor. Fiz. **23**, 474 (1976)] points to a volume compression $\sim 2\times 10^2$.

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1. Experimental results on spherial heating of microscopic spheres made of glass and organic material by laser radiation are reported in[1]. It is of intere to compare the experimental data with results of theoretical calculations.

The physical model describing the processes of heating and compression of a target by laser radiation[2] include the equations of two-temperature hydrodynamics with electronic conductivity and ionic viscosity, the absorption of laser radiation within the framework of the transport equation with absorption coefficient $k(q, n, T)$, which is a function of the incident radiation flux q, of the electron density n, of the temperature T[3], and of the heat transfer via electronic thermal conductivity.[4] The ionization kinetics includes electronic processes and photorecombination.[5] The equation of state of the material include the effect of degeneracy and elastic pressure connected with the deformation of the electron shells of the atoms.[6] Account was taken of volume losses of energy due to the bremsstrahlung and recombination radiation.

2. We present the calculated characteristics of the plasma of a target constituting a glass sphere with initial diameter 140 μ and wall thickness 4 μ, containing an insignificant amount of residual gas at a pressure <0.5 atm. The duration of the laser pulse at the base was 2.5 nsec, and the total plasma energy was determined from the shock wave in the residual gas.[1] The unevaporated part of the target moves towards the center with an average velocity $\sim 3\times 10^6$ cm/sec. The maximum density and temperature in the center of the target is reached within ~ 1 nsec after the end of the pulse, when the temperature in the "corona" has dropped to 15 eV. Therefore the target-center glow due to heating by spherical cumulation occurs at a different time than the glow of the "corona."

The maximum electron temperature 300 eV in the "corona" and at the center ~ 600 eV. During the final stage of compression the target is a granule with strongly compressed ($\rho_{max} = 110$ g/cm^3) but relatively cold ($T_e = T_i = 10$ eV) periphery, and a hot $T_{max} = 600$ eV) but less dense center ($\rho \approx 3$–5 g/cm^3). The time evolutions of the density and the electron temperature in different parts of the target are shown in Figs. 1 and 2. The radiation flux averaged over the time of action of the pulse was $\bar{q} = 3\times 10^{12}$ W/cm^2. According to theoretical and experimental data[3], no fast electrons are generated in the corona at the indicated value of the flux.

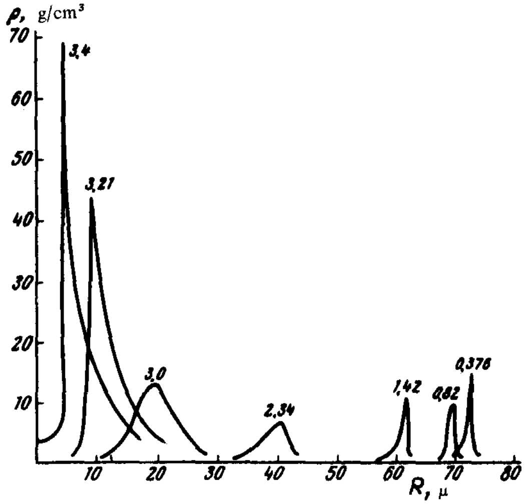

Fig. 1. Radial distribution of the target density at different instants of time the times in nsec are marked on the curves).

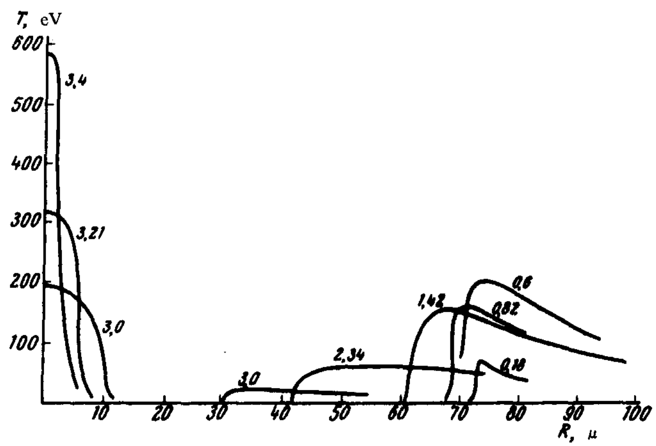

Fig. 2. Radial distribution of the electron temperature of the target at different instants of time.

The motion of the points with $\rho = \rho_{cr}(R_{cr})$ and $\rho = (1/4)\rho_{cr}$ is shown in Fig. 3. A comparison of the experimental[1] integral picture of the "corona" glow with calculation, in which it is assumed that the laser radiation is absorbed near the critical point, shows that the experimental and calculated midpoints of the luminescence band are located ~110 μ and ~90 μ from the center, respectively.

Knowing $R_{cr}(t)$, the beam-focus diameter, and the total energy of the beam, we can calculate the energy for a plasma sphere of radius $R_{cr}(t)$ without allowance for refraction. Comparing this quantity with the total plasma density determined in experiment ($E_{abs} = E_{s.w.} + E_{rad} \approx E_{s.w.}$, since $E_{s.w.} \gg E_{rad}$), we can estimate the effective coefficient of the plasma absorption, which amounts to 70—50%, depending on the assumtion made concerning the location of the radiation absorption.

We note that the ionization process in the "corona" is not stationary. The characteristic ionization times are $\sim 10^{-9}$ sec, and the maximum ion charge is 7. The total radiation with quantum energy larger than 3 keV amounts to $\sim 10^{-4}$ J. The glow of the central zone of the target is due to the heating of the gas in the cavity and the adjacent layer of glass, and the diameter of the glowing region is $\sim 20\ \mu$. The pressure reaches a value 10^9 atm. When describing the compressed glass it is necessary to use the real equation of state[6], while the use of the ideal-gas formulas overestimates the density by a factor of 2. Quanta with energy larger than 4 keV can pass through the solid glass shell.

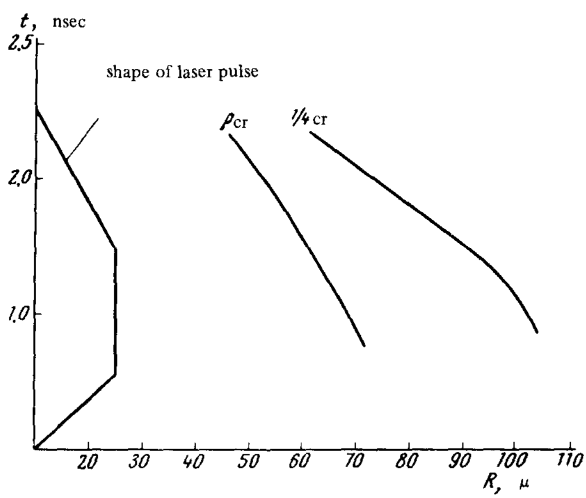

FIG. 3. Trajectory of point with $\rho = \rho_{cr}$ and $\rho = \rho_{cr}/\eta$ and shape of laser pulse.

3. An estimate of the degree of growth of the perturbation amplitude, based on a one-dimensional calculation in accordance with[7], shows that the perturbations can increase by 2—3 times during the acceleration stage. This means that no significant deviation from the one-dimensional picture will take place at an initial asymmetry corresponding to deviations not exceeding $\pm 10\%$ of the shell thickness. The pinpoint photograph shown in Fig. 2 of[1] is close to that obtained from calculation. In the target shown in Fig. 1a of[1], the initial perturbations are so large ($\pm 60\%$), that the motion soon becomes turbulent and the internal structure becomes smeared out. The pinpoint picture in Fig. 1b[1] (initial asymmetry $\pm 15\%$) offers evidence of the presence of local inhomogeneity of the shell. An inhomogeneity with dimension 0.5 to 0.7 μ suffices to upset the cumulation and to cause the internal part of the target to vanish.

4. Comparison of the experimental and calculated values of the electron temperature of the luminescence regions, of the total amount of x radiation, and of the plasma energy shows that they agree satisfactorily. From a comparison of the calculated experimental pinpoint picture it is seen that the unevaporated

art of the shell has traversed a path equal to ~20 shell thicknesses. This cor- esponds to a volume compression of the residual gas by a factor $(140/25)^3$ 175 (the corresponding calculated value is 343).

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