Calculations of the compression and heating of experimental targets of deuterized polyethylene

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(Submitted March 14, 1974)
ZhETF Pis. Red. 19, 520-524 (April 20, 1974)

Results are presented of the calculations of the heating and compression of spherical targets of deuterated polyethylene uniformly irradiated by a laser. The results pertaining to the evaporated part of the target agree with experiment.[1] It follows from the calculation that a 30-fold compression of the central part of the target could be attained in the experiment.

In[1] they published results of experiments on heating spherical targets of deuterated polyethylene by a 9-beam laser with pulse duration 6 nsec at the base. Such a laser ensured a nearly spherically-symmetrical irradiation of the target.

The initial data taken from[1] (radius and target material, lasing energy and duration) were used for numerical calculations of spherically-symmetrical heating of targets in accordance with the following procedure.

We solved the one-dimensional equations of single-temperature hydrodynamics with electronic thermal conductivity. Since the mass of the material in the radiation-absorption zone is much smaller than the mass heated by heat conduction, the radiation source need be taken into account only in the boundary conditions. The laser radiation was therefore specified in the calculations as the energy flux on the surface of the target (on the Lagrange boundary). In the region of matter heated by the thermal wave, the electron temperature greatly exceeds the ion temperature, and there is no time for electron-ion relaxation to occur during the time of heating and spreading. In the shock-wave region, the ion and electron temperatures are equal. In the single-temperature problem this circumstance can be taken into account by specifying the total heat capacity in the internal part of the target, and by specifying in the external part, in the evaporated matter, the heat capacity

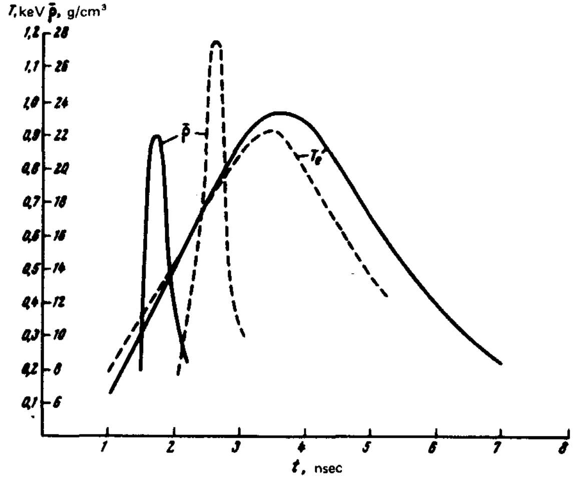

FIG. 1. Average density of matter in the compressed region ($0 < R_0 < 4.3 \times 10^{-3}$ cm) and average electron temperature in the evaporated region (4.3×10^{-3} cm $< R_0 < 5.5 \times 10^{-3}$ cm). Solid-line—radiation pulse of triangular shape; dashed line—pulse shape realized in the experiment.

regions is chosen by means of several successive calculations. As shown by the calculations, the final result depends little on the position of the boundary.

The parameters of the target material were the following: initial density $\rho_0 = 1.0$ g/cm^3, material—fully ionized CD_2, equation of state—ideal gas with $\gamma = 5/3$.

$$E = 1.22 \cdot 10^{15} \cdot T \,\mathrm{keV} \frac{\mathrm{erg}}{\mathrm{g}} \text{ in internal part,}$$

$$E = 0.888 \cdot 10^{15} \cdot T \,\mathrm{keV} \frac{\mathrm{erg}}{\mathrm{g}} \text{ in evaporated part of target.}$$

The coefficient of electronic thermal conductivity is

$$\kappa = 1.8 \cdot 10^{19} \cdot T_{\mathrm{keV}}^{5/2} \frac{\mathrm{erg}}{\mathrm{cm\,sec\,keV}^{7/2}}.$$

The dependence of the laser pulse on the time is that of an isosceles triangle with base 6 nsec. A comparison of the results of the calculations with pulses of triangular shape and of the shape realized in the experiment show that their difference is negligible.

The main data of[1] and their comparison with the results of the calculation are listed in the table.

N		Data of [1]			Calculation results	
	r, cm	E, J	T, eV	N exp	N	T^e_{max}, eV
1	$2.5 \cdot 10^{-2}$	600	40	–	–	700
2	$1.25 \cdot 10^{-2}$	202	120	–	–	800
3	$5.5 \cdot 10^{-3}$	214	840	$3 \cdot 10^6$	10^6	10^3
4	$3 \cdot 10^{-3}$	232	$4 \cdot 10^3$	–	–	$4.5 \cdot 10^3$

Here r is the initial target dimension, E is the laser energy, N is the neutron yield, and $T^e_{\max}$ is the maximum electron temperature in the evaporated region. Some results of calculations for target No. 3 are shown in diagrams 1 and 2. Let us comment on the results of the calculations.

In target No. 1, the largest of all, approximately 1/30-th of the entire mass is evaporated in the thermal regime. The maximum electron temperature in the central part of the target is negligible. The focusing of the shock wave in the center of the target occurs after the termination of the laser pulse.

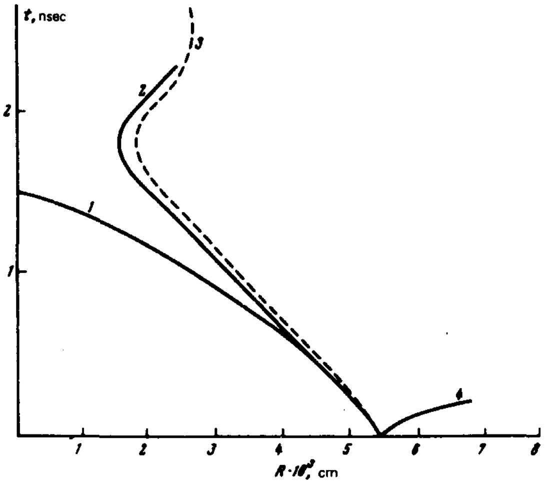

FIG. 2. R-t diagram: 1—shock wave, 2—trajectory of last Lagrangian particle moving towards the center ($R_0 = 4.3 \times 10^{-3}$ cm), 3—thermal wave, 4—outer target boundary.

In target No. 2, the thermal wave evaporates 16% of the mass, and the average density of the evaporated mass reaches 5 g/cm^3. A strong shock wave moves to the center. Near the instant of wave focusing in the region of the center of the target, the maximum densities and temperatures reach 45 g/cm^3 and 250 eV, respectively, while the pressure reaches 5×10^9 atm.

Greatest interest attaches to the calculation of the third target, from which neutrons were registered in the experiment. The shock wave arrives at the center after 1.54 nsec. Thus, during the time of action of the laser the material has time to become compressed and relieved. By the instant of maximum compression, approximately 15% of the total laser energy enters the target. The laser energy is ineffectively employed in this case for target compression, since most of the energy is fed to the already relieved polyethylene. The maximum densities, temperatures, and pressures at the center are of the same order as in target No. 2, but the average densities over the nonevaporated mass reach 22.8 g/cm^3. There are practically no thermonuclear reactions in the compressed region, since the average temperature of this region is low (several electron volts). The neutrons are produced only in the evaporated part of the target. Since we calculated only the electron temperature in the evaporated region, the ion temperature was obtained by numerically integrating the equation

$$\frac{dT_i}{dt} = \frac{(T_e - T_i)\rho}{a T_e^{3/2}},$$

where $T_e(m,t)$ and $\rho(m,t)$ are the electron temperature and density of the material as a function of the Lagrangian coordinate and of the time, obtained from the first part of the calculation. We then determined the neutron yield

$$N = 0.562 \cdot 10^{46} \iint \rho < \sigma v >_{DD} dm dt.$$

The Maxwellian average of the rate of the DD reaction, as a function of T_i, was taken in the form of the interpolation formula from.[2] The neutron yield was 10^6 neutrons.

In target No. 4, the shock wave was focused within 0.75 nsec. By the instant when half the laser energy is released, the target is fully heated by the thermal wave. The electron temperature reaches 4.5 keV. The neutron yield was not calculated for this case.

The calculated and experimental data on targets 3 and 4 are close to each other. The difference between the results for targets 1 and 2 is possibly due to the fact that the experimentally determined temperature (average energy per particle) was obtained by dividing the experimentally-determined energy absorbed in the target by the total number of particles in the target, whereas this energy should be attributed only to the particles in the evaporated part of the target. If this assumption is true, then the results of the calculations and experiments for targets 1 and 2 also become close to each other.

The second conclusion that can be drawn from the calculation result is that appreciable compressions of part of the target could be attained in the experiment. This conclusion is only indirectly confirmed by the agreement of the calculated data with the experimental part, and requires an experimental confirmation.

The calculations were performed with a program constructed using the implicit difference scheme described in[3].

In conclusion, I am deeply grateful to A. A. Burnatyan, V. A. Murashkina, V. E. Neuvazhaev, L. P. Feokistov, and L. I. Shibarshov for a discussion and support of the work, and to A. Pasyukova and T. Shtaleva for performing the calculations.

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