Thermonuclear-neutron yield from a plasma compressed by a shell

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A polyethylene piston 10 μ thick, accelerated with the aid of a relativistic-electron beam to $(5–7)\times 10^6$ cm/sec, compressed a deuterium plasma in a lead cone by a factor 1000 to a density 10^{22} cm^{-3} and heated it to a temperature 1 keV. In accordance with the calculations, $(1–3)\times 10^6$ thermonuclear neutrons were registered per pulse.

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In view of the development of a technique of obtaining ultrahigh power light pulses from lasers and relativistic electron beams (REB), methods are being studied for inducing a thermonuclear reaction by compressing a DT mixture by a shell accelerated to high velocity. The plasma heat loss due to the electronic heat conduction and bremsstrahlung hinder the heating by compression. At a chosen temperature T, the losses are minimal at a definite value of the product of the plasma concentration by its dimension:

$$\sum_\alpha Z_\alpha^2 n_\alpha r(\text{cm}^{-2}) \approx 10^{21} T^{3/2}\ \text{keV} \tag{1}$$

Z_α is the effective charge of the ions with density n_α. When this condition is satisfied, the plasma can be heated to a chosen temperature by compressing it with a shell moving with velocity

$$v(\text{cm/sec}) \gtrsim 3\cdot 10^6 T\ \text{keV}. \tag{2}$$

We have reported in a preceding paper that in the diodes of large-current REB accelerator, due to the action of the magnetic and electric fields of the beam, it is possible to attain an energy input on the order of 1 keV per atom into thin anode foils. Experiments and calculations have shown that under these conditions the radiant heat conduction removes from a gold foil 5 μ thick, in the form of heat, 30 to 50% of the energy left by the beam in the foil. In experiments in which the cavity behind the anode foil was closed with a polyethylene film 10 μ thick, half the heat went to heating the internal surface to acceleration of this film. Calculations have shown that the registered velocities were $(5-7)\times 10^6$ cm/sec.

These results have induced us to experiment with compression of a deuterium plasma. At these "piston" velocities one could expect a temperature 1 – 2 keV and an appreciable neutron yield. The duration τ of the thermal pulse, according to calculations was 10 – 20 nsec. To make effective use of the heat, the shell radius must exceed $3v\tau$, or 2 mm under our conditions.

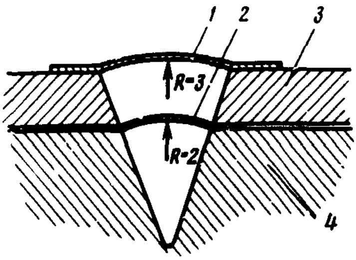


Fig. 1. 1—Au or Pt shell, 5 μ thick. 2—$(CH_2)_n$ shell, 10 thick. 3—Steel. 4—Lead.

According to the calculations and measurements, the energy of the REB from the "Triton" installation is 1.5 kJ in a pulse of 30 nsec, and is sufficient to accelerate a polyethylene foil (10 μ thick, 2 mm dia) to an energy 25 – 35 J. The foil, in the form of a part of a spherical surface of 2 mm radius, was accelerated into a cone with apex angle 60° impressed in lead. In our opinion, this simulates adequately spherical compression so long as the lead withstands the pressure of the compressed plasma. The experimental setup is shown in Fig. 1. To attain a temperature 1.5 – 2 keV the plasma compression must be by an approximate factor 1000. The piston energy suffices to heat 3×10^{16} deuterium atoms, corresponding to an initial density 10^{19} cm^{-3}. This is one-tenth the requirement according to (1) in the case of a thousand-fold compression. We therefore added 7 – 10% argon to the deuterium.

The neutrons were registered with activated-silver and proportional helium counters.

The neutron yield depended strongly on the initial deuterium pressure and on the mixture composition. The maximum yield was $(1-3)\times10^6$ neutrons per pulse and corresponded to a pressure 150 Torr at 7% argon. This agrees with the results of a one-dimensional numerical simulation. The cone walls were taken into account in the calculation by introducing a correction factor in the thermal-conductivity coefficient. The loss to the heating of the side walls in the space between the foils was taken into account by artificially lowering the adiabatic exponent for polyethylene ($\gamma = 1.2$). The stability of the measured neutron yield, despite the strong dependence of $\langle v\sigma\rangle$ on T, can be attributed to the bulging of the head of the cone. It was observed experimentally and corresponded to a thousand-fold compression and to a pressure $(3-5)\times10^7$ atm.

Figure 2 shows oscillograms of signals from two sintillation detectors located 1 and 1.6 m away from the target. The signal from a coaxial photocell that registered the bremsstrahlung x rays from the target (positive signal) was applied simultaneously to the oscilloscopes to serve as a reference. To suppress the x rays, the scintillation detectors for the neutrons were placed in lead containers 11 cm thick. The delay time of the signals to the second detector relative to the first was 25 nsec, corresponding to a thermonuclear-

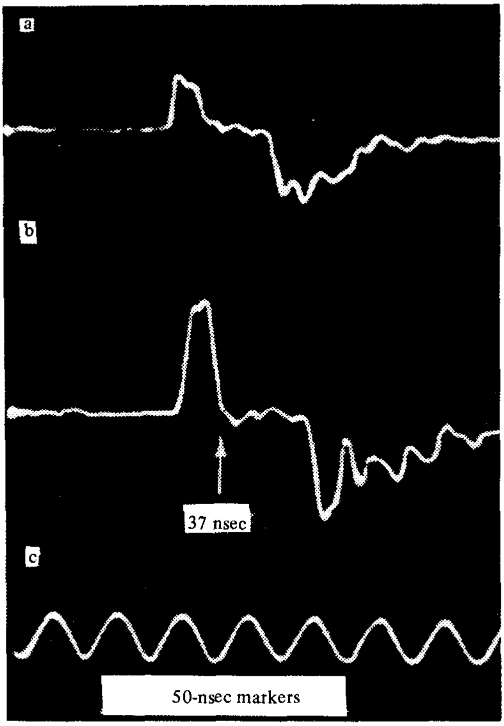

a
b
37 nsec
c
50-nsec markers

FIG. 2.

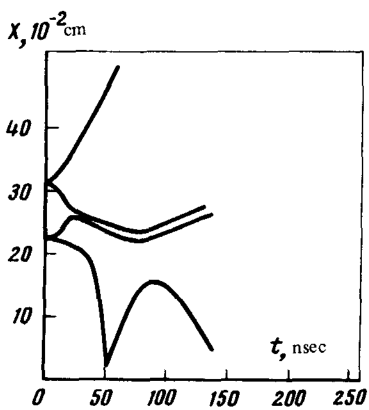
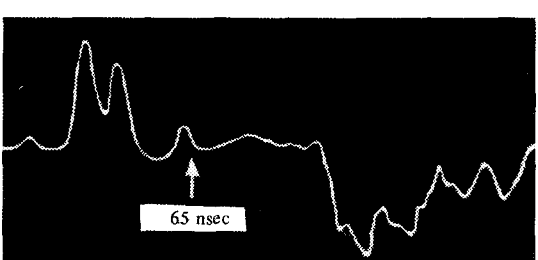

X, 10^-2 cm
40
30
20
10
t, nsec
0
50
100
150
200
250

FIG. 3.


65 nsec

neutron energy 2.4 ∓ 0.5 MeV. Knowing the neutron energy, we could determine the instant of their production. It is marked by an arrow on the oscillogram. In this experiment, the neutrons were produced 37 nsec after the appearance of the x rays, after the diode voltage had been substantially decreased. These oscillograms agree with a calculation with an energy input 1 kJ.

Figure 3 shows the calculated r–t diagram of the process at an energy input 600 J to the gold foil. This calculation corresponds to the lower signal from the distant neutron pickup. In this experiment the neutrons were produced 20 – 25 nsec after the end of the bremstrahlung x-ray pulse.

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