NEUTRON GENERATION IN SPHERICAL IRRADIATION OF A TARGET BY HIGH-POWER LASER RADIATION

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One of the essential problems in the use of lasers for thermonuclear purposes is the determination of the dependence of the temperature and of the neutron yield on the laser radiation energy and on the heating conditions. A yield of not less than 10^4 neutrons from a CD_2 target heated by a sharply-focused nanosecond laser beam, at 50 J energy, was registered in [1]. In [2], where a solid D_2 target was used, the maximum neutron yield was $\sim 5 \times 10^4$ at a laser energy up to 100 J and a duration 3.5 nsec at half-altitude.

At large values of the light-pulse energy, sharp focusing of the radiation on the target surface is not the decisive factor, owing to the smearing of the high-temperature zone by the heat-conduction and gasdynamic mechanism of energy redistribution.

The development of a multiple-beam laser has made it possible to experiment with heating a spherical target by spherically symmetrical irradiation [3]. In this case the neutron yield from a heated solid deuterated-polyethylene target greatly exceeded the results obtained with sharp focusing. In contrast to the known experiments, the dimension of the heated target was approximately equal to the diameter of the focal spot, and the heated mass was determined by the mass of the particle.

The scheme used to focus nine laser beams on the target was analogous to that used in [3]. The focusing was with two-element lenses of f = 6 cm producing a focal-spot diameter of 20 μ. Thus, taking into account the divergence of the laser radiation, the latter was focused into a spot of 50 μ diameter. Unlike in [3], a divergent beam with angle 10^{-2} rad was used in the preamplifier system. Before reaching the splitting system, this beam was made parallel, with simultaneous compensation of the astigmatism in the laser system. The energy of all nine beams, for a duration of 6 nsec at the base, was 214 J, and the average temperature was 840 eV. To reduce reflection and for more uniform target irradiation, the focal plane of the objective was located a distance of 200 μ away from the target surface. The target diameter was 110 μ.

The neutrons were registered by three scintillation detectors located at different distances from the target [1]. To measure the time of flight, a time marker from a laser beam was aimed on each detector scintillator with the aid of a light pipe. The neutron pulses were thus identified by the delay time of the neutron signal relative to the laser signal, which was proportional to the time of flight of the neutrons from the target to the detector.

The quantitative measurements were performed with nuclear emulsions, using the recoil protons. A type NIKFI-R emulsion 300 μ thick was placed 6 cm from the target. A control emulsion from the same batch was located in a different room. After three experiments in which neutrons were recorded by the scintillation counters, both emulsions were developed simultaneously under the same conditions. The irradiated emulsion had 87 tracks per cm^2, corresponding to the recoil protons from the neutrons of the D-D reaction, while the control emulsion had 48 tracks. To verify that the photographic properties of both emulsions were identical, the number of stars in the same square centimeter was measured and turned out to be 45 and 49 respectively. It follows therefore that if the neutrons are assumed to be isotropically emitted from the plasma, the number of neutrons per flash is 3×10^6. The table lists the results of the temperature measurements for spherical targets with different radii. At a radius of 30 μ, the temperature reached 4 keV.

Target radius cm	Laser energy J	Average temp., eV	Neutron yield per pulse	
			exper.	calc.
$2.50 \cdot 10^{-2}$	600	40	–	–
$1.25 \cdot 10^{-2}$	202	120	–	10^2
$5.50 \cdot 10^{-3}$	214	840	$3 \cdot 10^6$	$8 \cdot 10^7$
$3.00 \cdot 10^{-3}$	232	$4 \cdot 10^3$	–	$1 \cdot 10^{10}$

It is interesting to estimate the plasma temperature and the parameter nτ under the conditions of our experiment. Since the laser-pulse parameters correspond to an intermediate heating regime (between the thermal-conductivity and gasdynamic stages), we present here two independent estimates. According to [5] we have for CD_2

$$T_{\text{ther}} \approx 6.5 \cdot 10^9 \frac{Q^{4/9} r^{2/9}}{r^{8/9} n^{2/9}} \text{eV} \approx 3.6 \cdot 10^3 \text{ eV},$$

$$T_{\text{gas}} \approx 3.8 \cdot 10^2 \frac{Q^{4/9}}{r^{2/3}} \text{eV} \approx 2.15 \cdot 10^3 \text{ eV},$$

$$nr_{\text{ther}} \approx 9.2 \cdot 10^6 \, T_{\text{eV}}^{3/2} \approx 2.4 \cdot 10^{12},$$

$$nr_{\text{gas}} \approx 0.6 \cdot 10^{11} \left(\frac{10^4}{T_{\text{eV}}} \right)^{1/2} Q^{1/9} \approx 2 \cdot 10^{11},$$

where Q is the radiation power in GW, r is the target radius in 10^{-2} cm, and n is the total ion density. The numerical values are given for Q = 8 GW, r = 30 μ, $n = 10^{23}$, and $\tau = 10^{-9}$ sec.

One cannot exclude the possibility that a certain role is played in our experiments by the cumulation effect. Estimates of the pressure, using the results of [4], give a value not less than 10^8 bar. It should be noted, however, that the laser-pulse duration used in the present study was much longer than the optimal value determined by the gasdynamic lifetime of the heated target, which was ∿0.5 nsec in our case.

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NEW TYPE OF RESISTANCE OSCILLATIONS IN A MAGNETIC FIELD

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While investigating the dependence of the resistivity ρ of filamentary bismuth crystals (whiskers) on the magnetic field ($H < 3$ kOe at $T = 4.2°K$), we observed a new type of oscillatory behavior of $\rho(H)$.

The objects of the investigation were bismuth whiskers in the form of filaments and ribbons, of thickness on the order of 1 μ and length up to 0.5 mm, grown from the gas phase [1]. The purity of the initial bismuth was characterized by a ratio $\rho(330°K)/\rho(4.2°K) \approx 500$, corresponding to a mean free path $\lambda(4.2°K) \approx 1$ mm.

The samples were mounted by the clamped-contact method [2]. The plots of $\rho(H)$ and of the derivatives $\partial\rho/\partial J = f(H)$, obtained by a modulation technique, were produced with an automatic x-wire recorder.

The measurements were performed on 27 samples, of which 17 were in forms of small ribbons (the width exceeded the thickness by several times). The orientation of the sample axes could be deduced from the anisotropy of the resistance in the magnetic field and from the periods of the Shubnikov-de Haas oscillations. The axes of the ribbons and of several filamentary whiskers were in the basal plane.

The new type of oscillations was observed in 14 ribbon whiskers but in none of the filamentary whiskers.

Figure 1 shows one of the most striking $\rho(H)$ dependences for a sample with dimensions $\ell = 155$ μ, $\Delta \approx 8.5$ μ, and $d = 1.4$ μ (ℓ is the distance between the potential contacts, Δ the width, and d the thickness); the measuring current $\vec{I}$ was parallel to the magnetic field $\vec{H}$. The oscillation amplitude was usually of the order of several per cent of the monotonic part of the resistance, making the oscillations difficult to observe. The use of the modulation procedure greatly facilitated the registration of the oscillating part of the resistance. Figure 2 shows one of the simplest plots of $\partial\rho/\partial H = f(H)$ for a ribbon measuring 140 × 2 × 1 μ and for $\vec{I} \parallel \vec{H}$.

In the general case the oscillatory $\partial\rho/\partial H = f(H)$ dependence is more complicated, as can be seen from Fig. 3, which shows the results for a ribbon with dimensions 133 × 2 × 0.5 μ, $\vec{I} \perp \vec{H}$, and $\vec{H} \perp \vec{n}$ (where $\vec{n}$ is the normal to the plane of the ribbon).

The investigation of the influence of the number of factors on the unusual behavior of the resistance in the magnetic field has revealed the following distinguishing features: