Neutron Production in Exploding-Wire Discharges

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(Received 13 July 1972)

High-power pulse generators have been used to produce dense plasmas by the explosion of thin polymer fibers. Sufficiently high ion energies have been achieved to produce large neutron yields. Neutron production is attributed mainly to the reaction $d(d,n)^3$He and neutrons are observed when either fibers containing the natural abundance of deuterium or nearly fully deuterated fibers are used. Results are given which show the variation of the neutron yield with initial fiber diameter and with deuterium content.

Recent studies[1,2] of exploded-wire plasmas have indicated that values of $n\tau$ in excess of 10^{12} sec/cm^3 have been achieved in the high-power discharges (10^{12} W) generated by the Gamble I and II devices.[3] Electron temperatures deduced from an analysis of the plasma radiation were in the range of 1 to 10 keV. A calculation of the electron-ion energy equipartition time for these discharges suggests that the ions and the electrons were equally energetic. Here we report on an experiment which shows that the ions are indeed sufficiently energetic to induce the d-d fusion reaction when the plasma contains deuterium.

Deuterium-bearing plasmas were produced by exploding polyethylene fibers in a vacuum using the Gamble II generator. The electrical properties of these plasmas are similar to those produced by the explosion of fine metal wires.[1,2] The dependence of neutron yield from the plasma on the initial fiber diameter and isotopic abundance of deuterium was studied.

Fibers about 3.5 cm long were mounted between the discharge electrodes in a vacuum chamber. Typical discharge currents driven by the generator were 1.2 MA with peak voltages of about 0.6 MV across the plasma. The duration of the discharges was approximately 5×10^{-8} sec. The efficiency of energy coupling from the generator to the load exceeded 25%. Discharge channels were determined to be 1 to 2 mm in diameter by x-ray pinhole-camera photographs. Such diameters are consistent with average ion densities greater than 10^{19} cm^{-3} for all fibers employed in the experiment.

The fibers used ranged in diameter from 10 to 190 μm. Polyethlene and polpropylene were used as fiber materials to minimize the ratio of carbon density to hydrogen and deuterium density in the plasma. Nylon was used to provide neutron yield data at fiber diameters not available in polyethylene. These three materials produced plasmas with the natural isotopic abundance of deuterium (0.015%). Polyethylene 99% enriched in deuterium was used to produce plasmas with a deterium density exceeding 10^{19} cm^{-3}.

Neutrons may be produced in the plasma by a number of reactions.[4] Neutrons with 2.5-MeV energy arise from the D$(d,n)^3$He branch of the d-d fusion reaction. Since the D(d,p)T branch occurs with about equal probability at low deutron energy, 14-MeV neutrons may be produced in the subsequent D$(\mathrm{T},n)\alpha$ reaction. If high-energy deuterons (> 200 keV) are present, lower-energy neutrons (< 0.5 MeV) may be produced in the reaction ^{12}C$(d,n)^{13}$N.

Two detection schemes were employed to measure neutron yield from the plasma. A silver activation counter was used to measure β activity induced by neutrons thermalized in polyethylene.[5] Lead activation by fast neutrons[6] provided a cross-check on the Ag detector and helped to determine the neutron energy spectrum. The Pb detector is insensitive to neutrons produced in the C-d reaction since Pb activation by fast neutrons has a 1.6-MeV threshold. In addition, comparison of the strengths of the activities produced in Ag and Pb allows one to determine the relative yield of 2.5- and 14-MeV neutrons through a knowledge of the dependence of induced activity on neutron energy.

Measurements with the Pb system shielded by cadmium indicated that Pb activation due to slow-neutron capture was insignificant. Plasmas created from metallic wires produced no measurable activity in either type of detector.

The results of the activation measurements are consistent with at least 95% of the neutron yield having been in the form of 2.5-MeV neutrons. Figure 1 summarizes the yield as a function of fiber diameter for the natural and highly deuterated materials. Neutron production deduced from Pb and Ag activation was determined by assuming

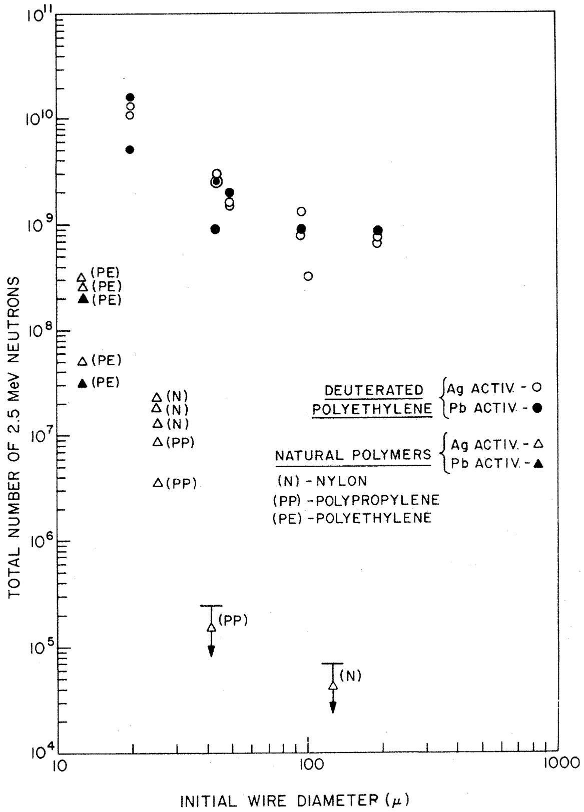

FIG. 1. Variation of neutron yield with initial fiber diameter.

all neutrons had 2.5-MeV energy.

The shape of the curves of yield versus diameter can be explained by simple pressure and energy balance considerations,[7] but it is difficult to understand the high neutron yield of the natural material. Also, the yields for the natural and deuterated material at the same diameter should be different by a factor of about 5×10^7 since the fusion reaction rate is proportional to the square of the deuteron density.

Extrapolation of the data for the deuterated material to small diameters using the scaling shown for the natural material indicates that neutron yields in excess of 10^{13} are attainable with deuterated fibers of about 10 μm diameter.

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Reasons for the Collisionless Nature of Interactions in a Laser-Produced Plasma Experiment*

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(Received 10 March 1972; revised manuscript received 17 July 1972)

Experimental and theoretical evidence is presented to substantiate the collisionless nature of the interaction reported previously. We refute arguments claiming that the observed phenomena were collisional.

In a previous paper[1] we reported the observation of a collisionless momentum-transfer interaction between the ions of interstreaming plasmas in a laser-produced plasma experiment. The phenomenon is produced when a Q-switched laser is focused onto a small solid target and the resulting plasma expands radially outward through a low-density ambient plasma. Recently, Wright[2] has given arguments that collisional processes could explain our experimental results, claiming that the laser-produced plasma density at distances less than 2 cm from the target is high enough to collisionally snowplow the ambient.

The assumption was made in our original paper[1] that collisions were not important in the primary region of study (5–10 mm). The present paper deals with the reasons for that assumption and shows that all the available experimental evidence supports this assumption. We present in this paper (1) the key arguments, including energy conservation, which rule out the proposed collisional mechanism[2]; (2) a discussion of momentum-transfer mean free paths; (3) a discussion of how our experimental data are fitted by a collisionless, but not a collision-dominated, model; (4) additional experimental data confirming our