PHYSICAL REVIEW LETTERS

VOLUME 12 | 6 APRIL 1964 | NUMBER 14

SOME PROPERTIES OF PLASMA PRODUCED BY LASER GIANT PULSE

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(Received 4 December 1963; revised manuscript received 19 February 1964)

Production of plasma by the action of a laser giant pulse on solid targets is described in this Letter. Absorption of the laser energy by the plasma was measured. With magnetic fields present, diamagnetic signals from the trapped plasma were measured, and time exposure photographs of the light emitted from the plasma region were taken.

The laser delivered about 0.2 J in a pulse having full width at half-maximum of 40 nsec and peak power of 5.4 MW. Variation in pulse magnitudes was less than 10% as monitored by a 1P42 detector. As shown in Fig. 1, the beam was focused by lens 1 into an area of about 10^{-3} cm^2 on a target within a vacuum system at 10^{-6} Torr. The target plane was 1.3 cm away from the median plane of a magnetic field (either mirror or cusp) produced by two coils having inside diameter of 15.2 cm, coaxial with the beam axis.

To measure transmission of laser light, the solid target shown in Fig. 1 was replaced by an aluminum or gold foil (1.6×10^{-4} and 1.8×10^{-4} g/cm^2, respectively) at the focal plane of lens 1. Because this was the focal plane also of lens 2, the light emerging from the vacuum system was essentially a continuation of the original laser beam; it passed through a red glass filter to a MgO reflector, employed for power measurements with a Korad photodiode PDS-20-1C.

For a target consisting of a single gold foil,

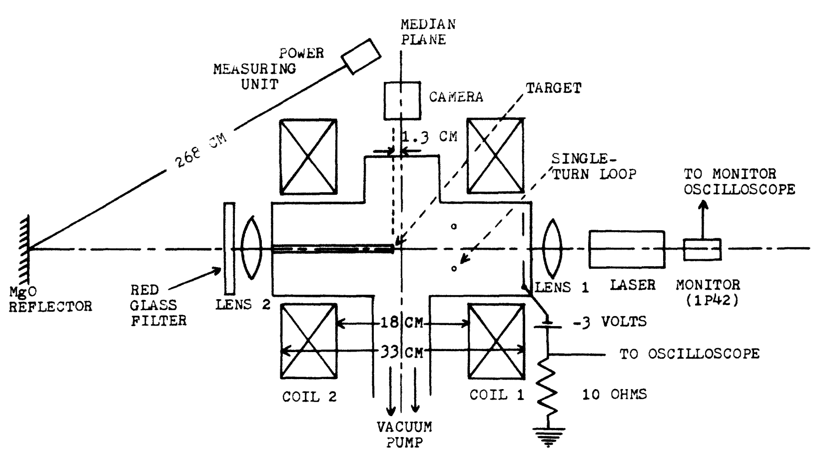

FIG. 1. Experimental system. Laser beam was focused on target. System pressure before burst was 10^{-6} Torr.

the peak power transmitted was 0.2 MW. A subsequent pulse through the hole in the gold foil, all optical elements remaining unchanged, yielded a peak power transmitted of 5.4 MW. Both of the transmitted pulses had the same duration, and were synchronous with the monitor pulses (within 50 nsec). Hence about 5×10^{14} gold atoms initially present in the focal spot absorbed 94% of the incident laser light. (The amount of reflected light will be discussed in connection with color photographs below.) For a single aluminum foil, the 4×10^{15} atoms initially present absorbed 99% of the incident laser light.

These absorption measurements involve plasma interactions with the laser beam, because ion energies in the range of 1000 eV have been produced for these conditions.[1] Magnetic fields of about 1000 gauss did not affect the percentage absorption.

For a thick target of aluminum at the focal plane, time-exposure photographs were taken of the light emitted from the plasma. Figures 2(a)-(c) show the light when the coils were not energized, coils aiding (1200 gauss at median plane), and coils bucking (the current magnitude being equal to that for the aiding case); Fig. 2(d) shows the target in room light.

The sharpness of the boundary suggests that the plasma is not significantly expanding during the time of light emission. No indications of "flute instability" were observed [approximately 100 pictures were taken of mirror arrangements similar to Fig. 2(b)]. Variation with magnetic field strength (measured at the mirror median plane) of the radius of the light-emitting region is plotted in Fig. 3, which suggest that the region is limited to a tube of flux; i.e., $AB=\text{const}$, where A is the area of the tube and B is the magnetic field strength. The boundary was quite sharp in each case, like that of Fig. 2(b).

Color photographs were taken, showing blue luminous regions similar to the black and white ones. No red light was evident. For each case, a nearly circular white spot, about 0.2 cm in diameter, was tangent to the target plane at the focal spot. The absence of red (laser) light indicates that the incident energy was absorbed by the plasma with very little scattering or reflection.

Targets of carbon and of wolfram exhibited light-producing regions similar to the aluminum case, but the boundaries of the plasmas were more diffuse.

Diamagnetic signals were produced in a loop of 5.6 cm in diameter surrounding the plasma. The voltage depended on the magnetic flux intensity, disappearing when the initial (vacuum) magnetic field was zero. As a further check, when the applied magnetic field was reversed in direction, the diamagnetic signals reversed in sign, but otherwise showed the same time behavior.

For a mirror field of 85 gauss at the median plane, and a spacing of 4 cm between the aluminum target and the loop, the volt-impulse induced by the production of the plasma was 400 maxwells. From this one obtains the ratio, β, of plasma energy density to magnetic field energy density, of 4%. For 1260 gauss and a spacing of 0.4 cm, the volt-impulse was 120 maxwells, yielding a β value of 0.1%. It should be noted that these data represent lower limit values, inasmuch as the solid target causes loss of plasma after its production.

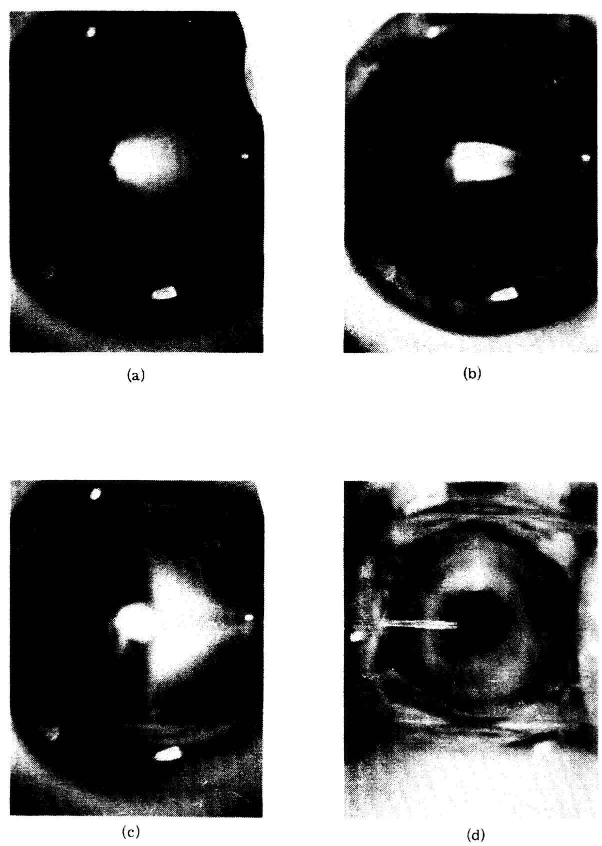

FIG. 2. Effect of magnetic field. (a) No field applied; (b) mirror field, 1200 gauss at central plane; (c) cusp field, same coil current as (b); (d) room-light photograph showing target.

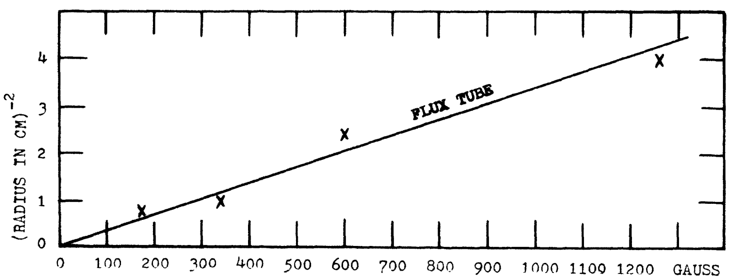

FIG. 3. Variation with magnetic field strength of radius of light-emitting region.

Diagmagnetic signals were also obtained for plasma in cusp magnetic fields. For 32 amperes in each coil in bucking connection (which would produce 1200 gauss at the median plane for aiding connection), the diamagnetic signal corresponding to production of plasma was about one microsecond long, with a volt-impulse of 800 maxwells, for a spacing of 8 cm between the aluminum target and the loop. The 5.6-cm diameter loop did not intercept plasma contained in the cusp magnetic field. The diamagnetic signal corresponding to plasma loss showed that about one half of the volt-impulse decayed in about 2 microseconds, and the remainder decayed exponentially in about one millisecond.

For the cusp case, the injection and trapping of plasma in the right-hand portion of the magnetic field is the result of cooperative processes, because the magnet coil currents did not change during the measurements.

It should be emphasized that the experimental configuration employed was determined by practical considerations. An obviously much more desirable arrangement, having fundamental interest, would consist of a tiny particle of solid or liquid material that is dropped into the central portion of a magnetic field, and irradiated by a powerful burst of laser light when it reaches the focal spot of the beam. The absorption measurements reported in this Letter indicate that practically all of the laser energy can be transferred to the particle. Also, the photographs and diamagnetic signals suggest that the ensuing plasma should be trapped in the magnetic field.

Since completion of the experimental portion of this work, two theoretical abstracts[2,3] have appeared on the subject of absorption of laser energy by plasmas.

The author wishes to thank the directors of the Hughes Research Laboratories for support of this work. Discussions of this material with Dr. A. Wayne Ehler were of considerable help. Also, the assistance of Mr. Larry Allum is appreciated.

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[2]A. G. Engelhardt, Bull. Am. Phys. Soc. 9, 305 (1964).

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STEEPENING OF LARGE-AMPLITUDE ALFVÉN WAVES*

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In this Letter we report the experimental observation of the steepening of large-amplitude Alfvén waves in a highly ionized plasma. Calculations concerning the expected steepening time for these waves have been previously reported by Montgomery[1] and Parker.[2,3]

The plasma device in which the waves are propagated has been described elsewhere[4,5]; only the salient features are given here. Hydrogen gas at 0.1 Torr is contained in a 14.6-cm-diam, 86.4-cm-long copper cylinder, the ends of which are closed by quartz plates. A coaxial electrode is located in one of these end plates and a copper screen covers the other. Figure 1 shows the manner in which the ionizing voltage and the wave-inducing signal are applied between the center

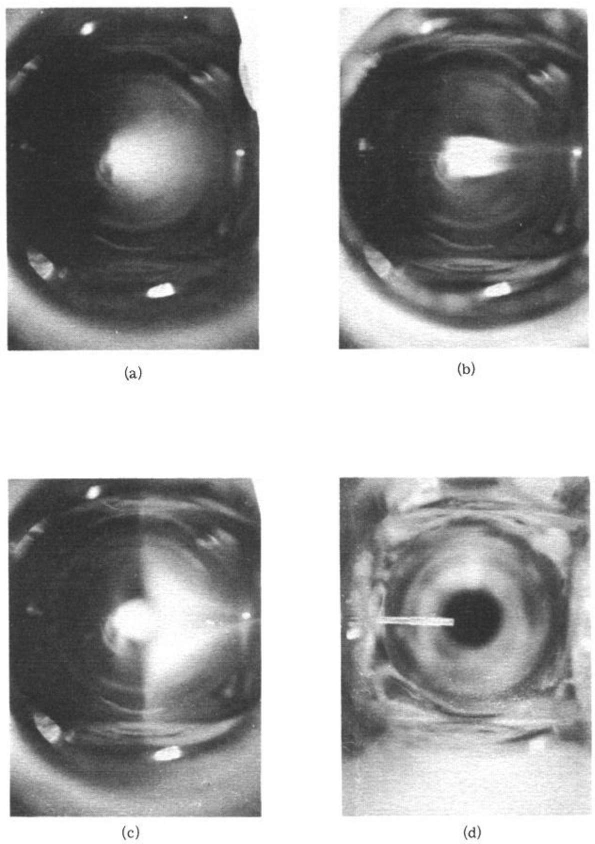

FIG. 2. Effect of magnetic field. (a) No field applied; (b) mirror field, 1200 gauss at central plane; (c) cusp field, same coil current as (b); (d) room-light photograph showing target.