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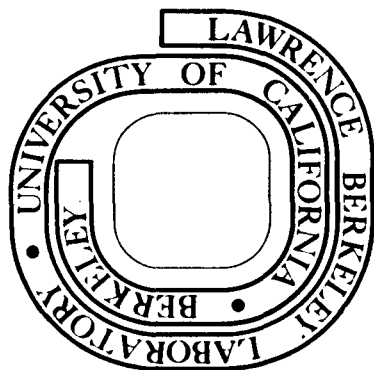
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APPARATUS FOR PRODUCING LASER TARGETS OF
50- μ DEUTERIUM PELLETS*

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ABSTRACT

Apparatus is described which produces 50- μ deuterium pellets that are being used in a laser-produced plasma facility. The pellets are sliced from a continuously spun solid deuterium thread at a rate of up to 10 pellets/sec. The methods of thread production and slicing, and pellet collimation are discussed. A unique feature of the apparatus is that it uses no liquid helium.

INTRODUCTION

There is considerable interest in studying plasmas produced by laser irradiation of solid pellets. Such plasmas formed from solid LiH pellets have been studied.¹⁻³ However, there are advantages in using pure hydrogen (or its isotopes): Hydrogen isotopes take the least amount of energy to ionize fully, and they lose less energy through bremsstrahlung and line radiation than any other element. Therefore hydrogen plasmas can be kept hot more easily than any other. A further advantage is that analysis of the plasma is simplest when only one type of ion is present.

Deuterium pellets of 100- to 400- μ size have been produced and irradiated.⁴⁻⁶ However, in order to get a fully ionized plasma of > 100 eV ions using a 10 J laser, it is desirable to use smaller pellets. Small spherical pellets produced by freezing liquid droplets have also been irradiated.⁷ The disadvantage here is that the droplets must be produced at pressures higher than the triple point pressure of deuterium (131 Torr).

In the apparatus to be described, the pellets are produced by slicing a 50- μ diam thread into 50- μ length cylinders with a thin tungsten wire. The solid thread is made by allowing liquid deuterium of the proper temperature and pressure to flow through an aperture into a vacuum. The temperature is controlled through the vapor pressure of continuously produced liquid hydrogen coolant. After being produced, the pellets are collected by a funnel and collimated by falling through a quartz capillary tube. This method of pellet production uses no

liquid helium and only a few drops of liquid hydrogen, which renders the process both safe and inexpensive (approximately 10^{-5} dollar per pellet).

DISCUSSION

The apparatus for producing 50- μ deuterium pellets consists of the following components (Fig. 1): (1) a hydrogen liquifier, (2) a thread spinner, (3) a thread slicer, and (4) a pellet collimator.

1. Hydrogen Liquifier

Bottled high-pressure hydrogen is used to produce the liquid hydrogen coolant. Hydrogen of ≈ 70 atm is cooled to 65 K (pumped liquid nitrogen) and is then allowed to expand out a counter-current heat-exchanged capillary which has no constriction at the output. Although such a construction is generally used because it increases the effectiveness of the counter-current heat exchanging, it also increases the chance of the tube becoming plugged from the impurities in the H_2 that condense out. Here, plugging is virtually eliminated by using this straight-walled capillary and by filtering the incoming H_2 with Zeolite (Linde, 13x and 5a at 65 K). The capillary is 150- μ id and is approximately 40 cm long. Approximately 0.15 liter/sec STP of H_2 is used in the liquifier.

At first, attempts were made to spin a hydrogen thread by extruding it through a small hole in the hydrogen liquifying cavity. Hydrogen threads were actually produced by this method, but only on a transient basis.

The present system uses two separate thermally connected cavities: one containing the coolant, the other the thread material. Thus, we can independently vary the pressure, temperature, and thread material of the extrusion cavity. The temperature can be regulated to within 0.1 K by adjusting the pressure in the liquifying cavity to the nearest 20 Torr.⁸ Note that the only equipment needed for temperature regulation is a needle valve on the H₂ exhaust and a pressure gauge.

2. Thread Spinner

One of the most interesting parts of the device we call the "thread spinner." This is the tapered extrusion orifice in a 300- μ -thick zone-refined copper plate. The large 100- μ opening of the orifice faces the liquid, and the smaller 70- μ opening is toward the vacuum chamber. Such a hole in any good thermal conducting material will work. For example, we have used a 6/90 ruby watch jewel. It was found experimentally that a stable thread is produced when the temperature of the copper plate and deuterium cavity is between 19 and 22 K and the cavity pressure is between 400 and 1200 Torr. The rate at which the thread is formed is about 4 mm/sec. Changing the temperature or pressure seems to have little effect on the rate of the thread formation or its diameter except near the extremes of the operating range. During normal operation the pressure is set at 500 Torr and the temperature at 21 K. A qualitative explanation of the thread spinning is shown in Fig. 2. Lines of heat flow are indicated on the left and the directions of solid, liquid, and gas movements are shown on the right. When liquid deuterium is introduced into the cavity, a plug of solid deuterium

forms at the hole from the liquid that is cooled and frozen through evaporation when it is exposed to the vacuum. Liquid deuterium flows into the plug from above and solid and gaseous deuterium flow out the bottom. As the tapered plug moves downward, the deuterium melts near the copper and is removed by pressure in the liquid layer next to the copper. Steady flow occurs when the downward force from the pressure above the plug is balanced by the upward force on the plug from the pressure in the liquid layer. This balance can be achieved by keeping the copper temperature near triple point temperature of deuterium (18.69 K) which maintains the desirable controlled distance between the solid deuterium and the copper.

The total amount of deuterium that flows into the vacuum chamber due to the thread and its production is ≈ 50 micron-liters per sec. This low pumping load is important since it allows one to easily maintain a pressure as low as $< 10^{-4}$ Torr, which is necessary because forces develop on the pellets due to gas moving between surfaces of different temperatures. These forces arise because more momentum flux is incident on the pellet from the hot surface than from the cold surface and because the pellets ablate at a greater rate on the side facing the hot surface. Both of these phenomena force the pellets toward the cold surfaces. It is conceivable that these forces could be used to collimate and/or transport the pellets, or they can be reduced by decreasing the pressure in the vacuum chamber. These forces were observed to dominate the motion of the pellets during early experiments but were made small compared to gravitational forces, by decreasing the pressure. They will be small, compared to gravitational forces, if

$p \ll \rho g l$, where p is the chamber pressure, ρ = the pellet density, g = gravitational acceleration, and l = the characteristic size of the pellet. For a 50- μ deuterium pellet, $\rho g l = 7 \times 10^{-4}$ Torr.

For the sake of completeness, Fig. 3 shows other modes of operation that have been observed. In the freeze-off mode (Fig. 3a) a dome of solid deuterium forms over the hole and only gas enters the vacuum chamber. This mode of operation puts out about 2000 micron-liters of gas per sec. By raising the temperature to the normal operating range, the stable thread used to make pellets forms. This dome has been observed through a transparent ruby thread spinner.

If the extrusion orifice is inverted (Fig. 3b), a thread will form, but it will move very fast. Liquid surface tension holds the thread to the copper plate. Attempts to slice the thread break this weak bond and disrupt the formation of the thread. Increase of pressure on mode (b) results in an unstable thread which is larger than the spinner hole (Fig. 3c).

The amount of deuterium flowing into the vacuum chamber while operating in any of modes, a, b, or c, is more than an order of magnitude larger than the amount of deuterium introduced while making pellets. Finally, there is a mode of operation not illustrated, which is caused by too high a temperature and/or pressure. A large amount of liquid flows through the hole, forming random-sized globs of frozen deuterium. This mode of operation is called "blow-out" and generally overloads the vacuum system.

3. Thread Slicer

As a stable thread is being produced, it is sliced into pellets by a 25- μ tungsten wire which is driven past the hole perpendicular to the thread and cuts it about 25 microns from the spinner hole. The wire is attached to a speaker coil which is driven with a 250-Hz, gated square wave. While the 250-Hz oscillation is on, the thread is vaporized at the plane of oscillation of the relatively hot wire. Pellets of desired length are extruded while the wire is stopped. Thus by adjusting the on and off time of the 250-Hz oscillation one can control the length of the pellet and the rate of pellet production.

It was found experimentally that when a 25- μ wire was passed through the thread only once, the thread remained intact. One can speculate that the wire, which is held at liquid deuterium temperature, passes through the thread causing it to liquify near the wire. This liquid flows around the wire and fuses the thread together again on the other side, much of the deuterium in the thread being evaporated at each pass. Several passes are needed to slice the thread which indicates the smoothness of the slicing method.

The slicing action is so gentle, in fact, that it can be adjusted so as not to traverse the thread completely. This causes the thread to be notched in such a way that the pellets produced are connected by a small filament of deuterium. By observing the notched thread with a microscope while operating in this manner, the length of these connected pellets can be made approximately equal to the diameter of the thread. Then the amplitude of the oscillation can be increased until

the thread is completely severed, thus producing cylinders of 50- μ length and diameter. Preliminary measurement of the amount of deuterium in the pellets indicates that the length of the pellet can be adjusted to give about 3×10^{15} molecules per pellet.

4. Pellet Collimator

As one might expect, the pellets leave the slicing region with some horizontal velocity. Most of them are caught by an 8-cm-diam copper funnel, which has a 2-mm hole in the center and is liquid-nitrogen cooled. A relatively flat funnel with a slope of about 20° is used because less horizontal and vertical velocity is given to the pellets in bringing them to the center. This slope is just steep enough to prevent the pellets from sticking to impurities and imperfections in the funnel surface. A low vertical velocity is desirable because the pellets will then have a longer time in the collimating tube to lose its horizontal velocity.

After leaving the funnel, the pellets fall through a 3-mm-id quartz capillary tube, also held at LN temperature. (Quartz is used because it is essential that the interior wall of the tube be clean and smooth.) This tube is broken into 10-, 15-, and 20-cm segments to allow for the escape of gas from the pellets. The length and diameter of the segments allows sufficient gas conductivity to prevent gas build-up in the tube.

The following conditions must be satisfied so that pressure does not build up in the tube: $C \gg NRAv_g$, where C is the conductivity of the tube. N is the maximum number of pellets in the tube, R is the

number of molecules liberated by the collision of a gas molecule with pellets, A is the total area of the pellet, and v_s is the thermal velocity of gas in the tube. If this inequality is not satisfied, gas will evaporate from the pellet in the tube at a greater rate than can be exhausted by the tube. Thus, there will be an exponential increase of the gas pressure in the tube that will blow pellets out of either end of the tube, usually with considerable horizontal velocity, and the pellets will not be collimated.

This inequality is satisfied for the capillary tubes used to collimate the pellets. The pellets seem to fall parallel to the tube and are distributed over the cross-sectional area of the tube. If the pellets are produced at the rate of 10/sec, then the incident rate of pellets in the focal region of the ruby pulse laser is $\approx 1/\text{min}$. The last segment of the collimating tube also provides vacuum isolation of the pellet production chamber. The pellets are detected and irradiated 10 cm below the collimating tube.

Experiments with the plasma produced by irradiating these pellets are now in progress.

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FOOTNOTE AND REFERENCES

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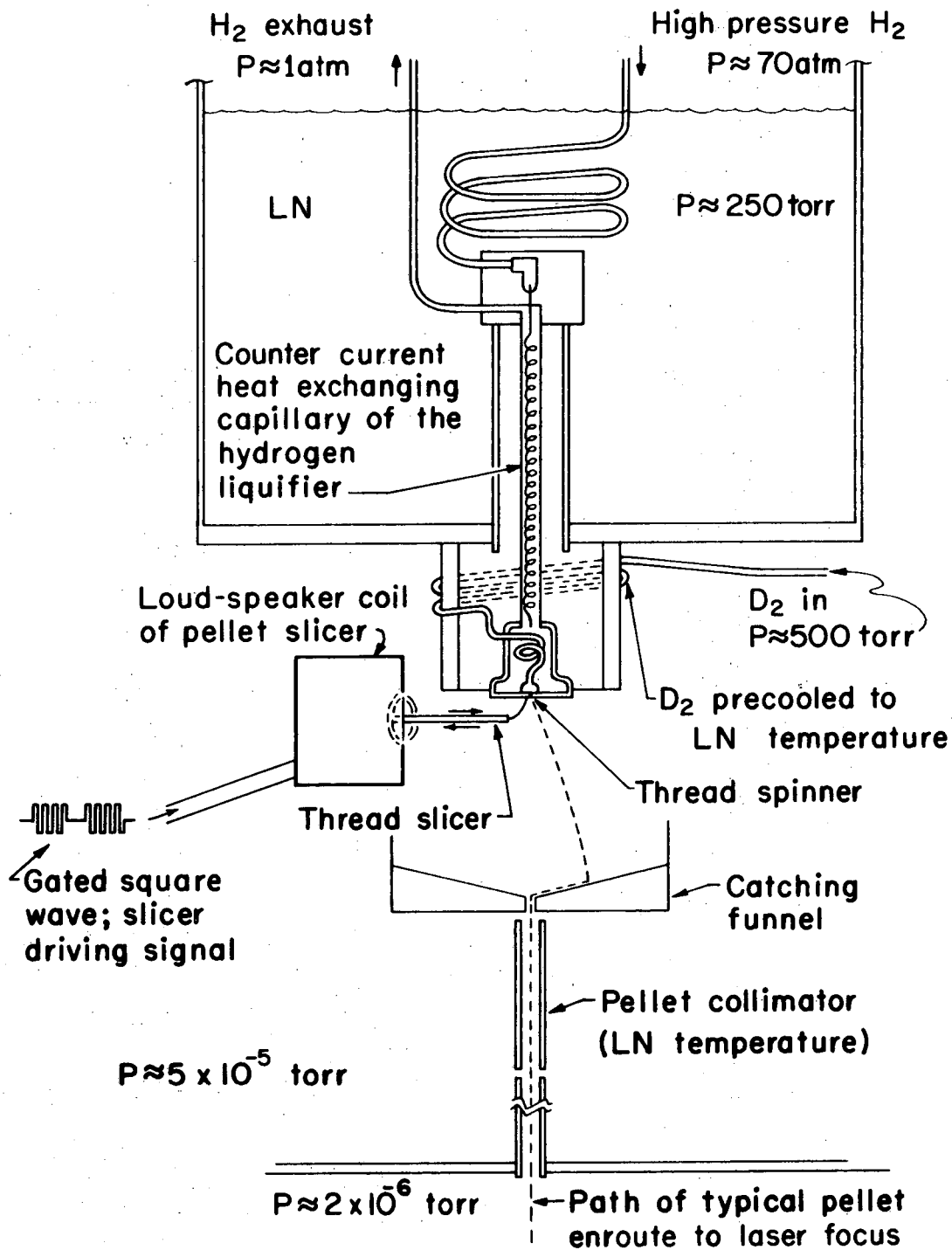
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FIGURE CAPTIONS

Fig. 1. Apparatus for producing laser targets of 50- μ diam deuterium pellets.

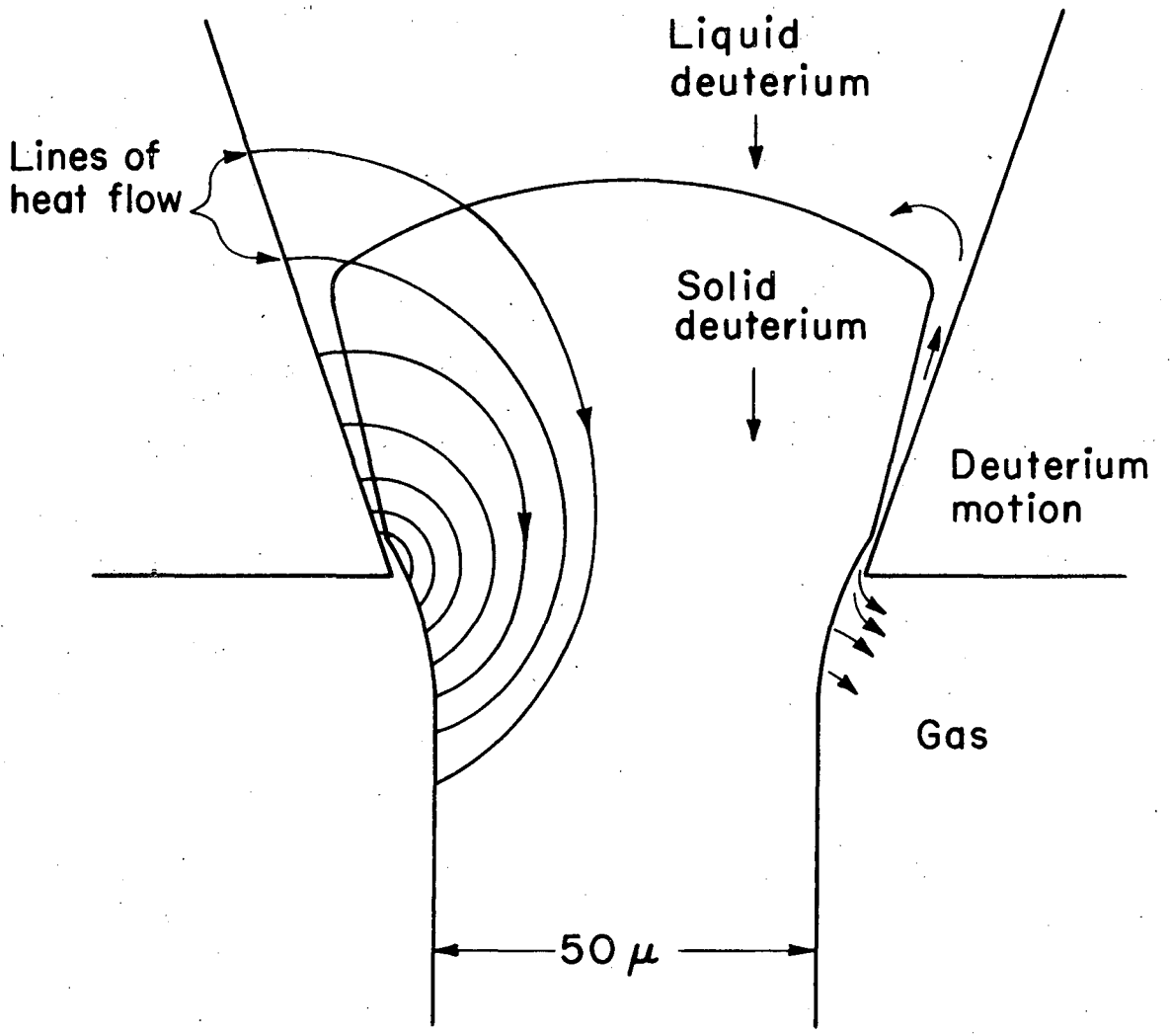
Fig. 2. Model of the thread "spinning".

Fig. 3. Other modes of spinner operation.



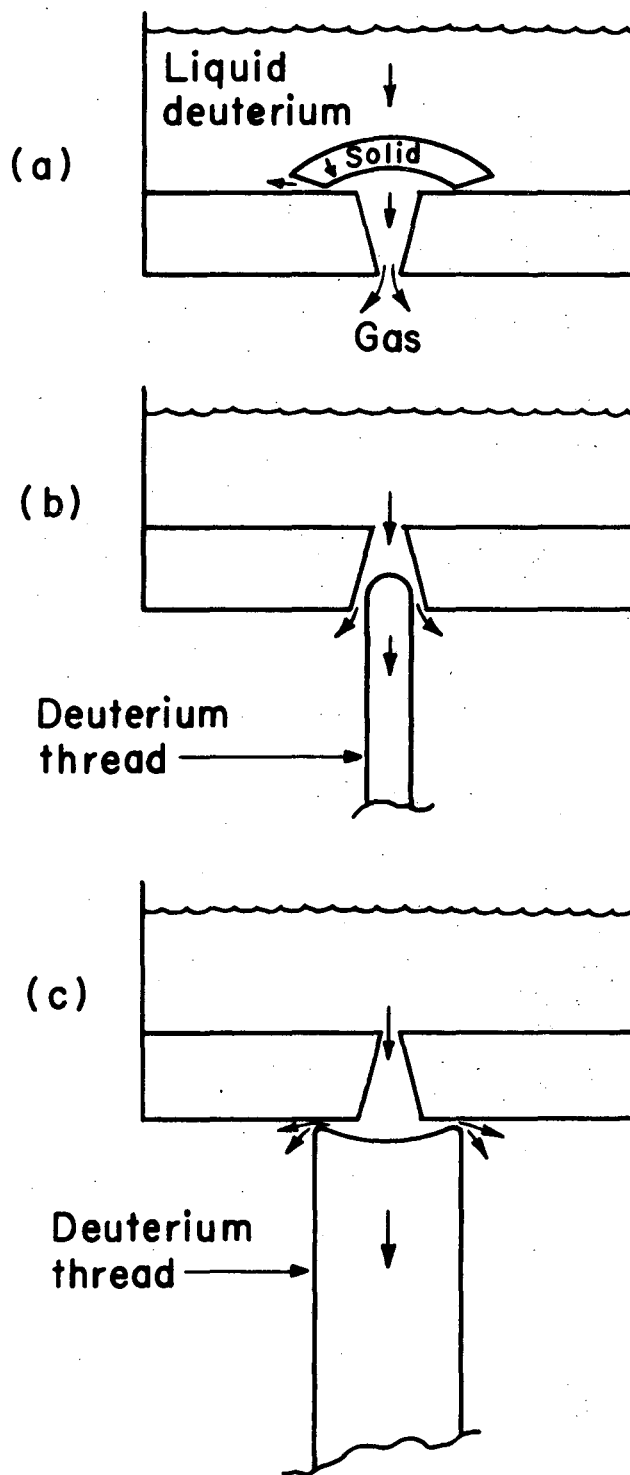
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Fig. 1



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Fig. 2



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Fig. 3

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