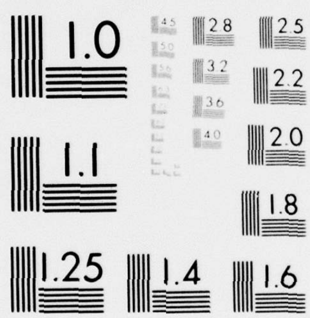
AD-A037 718 NAVAL RESEARCH LAB WASHINGTON D C F/G 20/5
BREAK-UP DYNAMICS OF POLYMER BEADS UNDER LASER BOMBARDMENT.(U)
FEB 77 J R GREIG, R E PECHACEK
UNCLASSIFIED NRL-MR-3448 NL

1 OF 1
ADA037718

END
DATE
FILMED
4-77



MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963 A

NRL Memorandum Report 3448

Break-up Dynamics of Polymer Beads Under Laser Bombardment

J. R. GREIG AND R. E. PECHACEK

Experimental Plasma Physics Branch
Plasma Physics Division

February 1977

NAVAL RESEARCH LABORATORY
Washington, D.C.

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: NRL Memorandum Report 3448	2. GOVT ACCESSION NO.
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): BREAK-UP DYNAMICS OF POLYMER BEADS UNDER LASER BOMBARDMENT.	5. TYPE OF REPORT & PERIOD COVERED: Interim report on a continuing NRL problem.
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): J. R. Greig and R. E. Pechacek	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Research Laboratory, Washington, D.C. 20375	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: NRL Problem H02-28C, Project RR 011-09-41
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE: February 1977
	13. NUMBER OF PAGES: 16
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): UNCLASSIFIED
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Presented at the Seventeenth Annual Meeting of the Division of Plasma Physics, St. Petersburg, Florida, 10-14 November 1975. Bull. Am. Phys. Soc. Ser. 11 20, 1266 (1975).

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Laser
Solid target
Heating
Gas injection
Plasma heating

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Spherical polymer beads approximately 1 mm diameter, have been irradiated with a 100 J, 40 nsec Q-switched Nd/glass laser. This is not enough energy to dissociate and ionize all the atoms contained in the polymer bead. Instead a small fraction ($\sim$1%) of the material is ablated from the irradiated side of the bead accounting for $\sim$60% of the laser pulse energy. The remainder of the polymer bead subsequently disintegrates in a symmetric, reproducible manner. Approximately 15% of the laser pulse energy is used in this disintegration to dissociate $\sim$ 30% of the molecules in the

(Continues)

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (Continued)

cont

polymer bead. The balance of the laser pulse energy (~25%) is lost in reflection at glass surfaces and at the target itself.

If the laser pulse is preceded by a prepulse containing ~ 15% of the total pulse energy, the gas released by molecular dissociation is mostly released within 1 μsec of the peak laser power. Also the disintegration and gas release are both approximately spherically symmetric about the initial target point. However with no prepulse approximately the same amount of gas is released over a longer time period and this gas and the debris of the target are ejected away from the laser.

CONTENTS

BREAK-UP DYNAMICS OF POLYMER BEADS UNDER LASER BOMBARDMENT

1. INTRODUCTION:

We are interested in the interaction of an energetic laser pulse (100 J in 40 nsec) with a small solid target as a means of liberating a substantial number ($> 2 \times 10^{19}$) of gas atoms at some chosen point in an evacuated chamber. We are not attempting to ionize and heat these atoms as they come off the solid target. Indeed we expect that most of these atoms may exist as molecules or as finely divided ($\sim 20\ \mu m$) superheated solid or liquid particles.

The reason for our interest in this sort of gas release is that such a gas cloud could be heated by a second very high energy laser pulse (1 kJ in 200 nsec). The plasma produced in this way should be ideal for fast compression experiments such as the Linus program at NRL and for investigating plasma losses from cusps or other magnetic bottles.

By this time last year we had already shown that our 50 - 100 J, $\sim$ 60 nsec Nd/glass laser pulse would release $(1 \rightarrow 3) \times 10^{19}$ atoms from polyethylene targets[1]. These targets were sheet material 0.5 mm thick or small pieces of this sheet suspended on fibers.

Since then we have rebuilt the Nd/glass laser using Pockels cells instead of the rotating prism as the Q-spoiling mechanism. One advantage of using Pockels cells was that we were able to remove the prepulse in Figure 2 of Reference 1. Surprisingly we soon found that the prepulse plays a dominant role in the laser/target interaction. Now we have a controlled prepulse and can deliver 100 J in 40 nsec with

Note: Manuscript submitted January 19, 1977.

beam divergence of ~ 0.3 mradians, which is approximately 10^{12} watts/ cm^2 on a target spot of 0.3 mm radius.[2] Such a spot size is well matched to the size particles we need to irradiate; for polystyrene (CH) a 1 mm diameter sphere contains ~ 4.6×10^{19} atoms; and for polyethylene (CH_2) the same sphere contains ~ 6.7×10^{19} atoms.

In this brief report, we discuss the difference between results obtained with a prepulse and those obtained without a prepulse. We discuss mostly the dynamics of the target debris in these two situations. From this we deduce an approximate energy balance between the incoming laser energy and that accounted for in the target.

A more complete discussion of our results concerning the disintegration and vaporization of plastic targets irradiated by high power lasers will be published in the near future[3].

II. RESULTS AND DISCUSSION:

A typical output pulse from the modified Nd/glass laser is shown in figure 1. The delay between the prepulse and the mainpulse is variable from ~ 300 nsec to ~ 5 μsec. However for these experiments it was held at approximately 600 nsec except when the prepulse was removed altogether.

The vacuum chamber used for these experiments was described in Reference 1. And the same 100 cm focal length lens was used to focus the laser beam on to targets suspended in this vacuum chamber. We have used a number of different diagnostic techniques from simply measuring the pressure increase in the vacuum chamber; time integrated spectroscopy for wavelength identification; framing camera photography with an STL camera; shadowgraphy using a 20 nsec ruby laser; Mach-Zehnder interferometry using 3472 Å and 6943 Å from a 20 nsec ruby laser and doubler;

holographic interferometry using a 20 nsec ruby laser; and examination of target damage on sheet targets. The techniques for double exposure interferometric holography were taken from Jahoda and Siemon[4].

If we use spherical polystyrene beads as targets and a laser pulse with no prepulse, the breakup of the target is very symmetric and reproducible (Figure 2). To obtain such symmetry we must, of course, score a direct hit on the target. From these shadowgrams we can determine the momentum and kinetic energy given to the debris of the target. The momentum was ~ 30dyn. sec and the total kinetic energy was ~ 0.35 J.

By requiring momentum balance and knowing the ion velocity we can estimate the number of ions and the minimum energy given to the hot plasma plume which comes off the irradiated side of the target. If the ion velocity[1] was ~ 10^7 cm/sec, the plasma plume must have contained ~ 3×10^{17} ions. The directed kinetic energy of these ions is then ~ 15 J. Some plasma envelopes the target so the total energy will always be larger than this amount (Figure 3).

At very early times before they have cooled down we may expect the electrons to have roughly the same energy as the ions i.e. the same temperature, so that with an average of two electrons per ion there would be ~ 30 J in electron kinetic energy. But since the ion velocities were measured ~ 100 nsec after peak power it is most likely that the electrons had already cooled by that time.

As well as the kinetic energy we must consider the energy required to dissociate the polymer molecules in the cold gas cloud (~ 13 J) and the energy required to ionize the atoms in the plasma plume (~ 5 J).

Thus out of a 95 J Nd/glass laser pulse, some 75 J reaches the target through the turning prism and focusing lens. Of this energy only about 13 J goes into the cold gas cloud in which we are primarily interested. About 15 J goes into the directed kinetic energy of the hot ions in the plasma plume and another 5 J into ionization energy. The rest of the energy is either reflected from the target or after initial absorption as electron kinetic energy is then radiated away.

As described earlier those polystyrene beads shown in figure 2 were hit by a single laser pulse with no prepulse. And we had already checked that the cold gas released by polyethylene sheet targets (measured by the pressure rise in the chamber) was the same now without a prepulse as it was last year with a prepulse. However as we progressed with the shadowgraphy and holographic interferometry we found that the detailed dynamics of the two cases with and without the prepulse are quite different.

First we found that the plasma plume produced in either case was as shown in figure 3, similar though more ions were produced with a prepulse and the plasma enveloped the polystyrene bead more completely. There the similarity ends!

In figure 4, the shadowgram of the hit with no prepulse is not quite as symmetric as those shown in figure 2. This may be because these smaller polystyrene beads are solid, whereas those shown in figure 2 were macro-porous. But there is a characteristic difference between this sort of disintegration and that caused with a prepulse (figure 4b).

Using holographic interferometry (Figure 5), we found that with no prepulse it seemed to take longer for the cold gas to be emitted. Therefore by the time it was released, the density was so low that there was no measurable fringe shift. Whereas with a prepulse an approximately sperical gas cloud was formed within 1 μsec and already contained $\sim 10^{19}$ atoms.

Another difference is much more apparent with polyethylene sheet material. This is shown in figure 6. With no prepulse the debris of the hit goes cleanly away from the laser (compare the conical shapes of the debris clouds with polystyrene bead targets). But with a prepulse the debris fans out both toward and away from the laser. With the polyethylene sheet we were able to observe the damage done by the prepulse alone by using an attenuated no-prepulse laser shot. We found that the prepulse which is after all 10 $\rightarrow$ 15 J makes a crater in the target $\sim$ ·5 mm diamter and $\sim$ ·3 mm deep - with some spalling through the back of the target. The fanning out of the debris as seen in prepulsed shots also occurs if a non-prepulse shot is put on to a previously formed pre-pulse crater. Thus this fanning out of the debris is caused by the surface properties of the target, i.e. whether it is flat or broken. We say broken because we know that when the prepulse is only 600 nsec before the main pulse the crater cannot have formed before the main pulse arrives at the target because the velocity of the solid debris is only $\sim 10^5$ cm/sec and very little gas is released by the prepulse ($\sim$ 10% of the final amount).

III. CONCLUSION:

Combining the results described here with those described previously in Reference 1, it is clear that these small plastic targets can be used to produce a cloud of cold gas in an evacuated chamber. For laser pulse energies between 50 and 100 J, and pulse durations of about 50 nsec, targets containing up to $\sim 5 \times 10^{19}$ atoms have been disintegrated. Of these atoms, more than 20% are dissociated to atoms or diatomic molecules. Thus when a small plastic target is irradiated by a high energy laser pulse a cloud is produced which contains finely divided target debris and gas molecules. The ratio of gas molecules to solid debris, and the symmetry of the explosion are strongly influenced by the presence of a laser prepulse. With a prepulse there are more gas molecules and the expansion of the cloud is more spherical.

With or without a prepulse, such clouds should be ideal targets for heating with a very high energy CO_2 laser. We intend to continue now with such heating experiments.

ACKNOWLEDGEMENT

We note again the regular discussions we have had on this work with Drs. Alan W. DeSilva and David W. Koopman, both of the University of Maryland.

This work was performed in the Experimental Plasma Physics Branch led by Dr. A. E. Robson.

REFERENCES

1. J. R. Greig and R. E. Pechacek NRL Memorandum Report 2994 (1975).

2. J. R. Greig and R. E. Pechacek NRL Memorandum Report (1977).

3. J. R. Greig and R. E. Pechacek to be published J. Appl. Phys. (1977).

4. F. C. Jahoda and R. E. Siemon Los Alamos Scientific Laboratory Report, LA - 5058 -MS (1972).

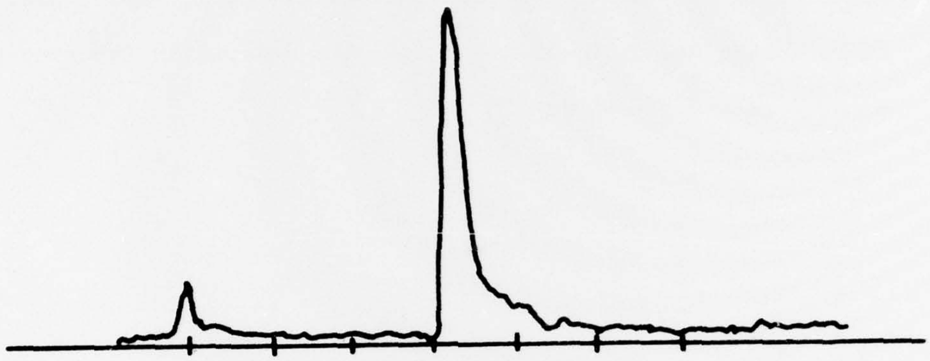


Fig. 1 — The Nd/glass laser pulse produced using Pockels cells to achieve Q-switching. The total pulse energy is ~ 100 J and the width at half maximum power is ~ 40 nsec. The prepulse contains ~ 15% of the total energy and occurs ~ 600 nsec before the mainpulse. The beam divergence was ~ 0.3×10^{-3} rad.

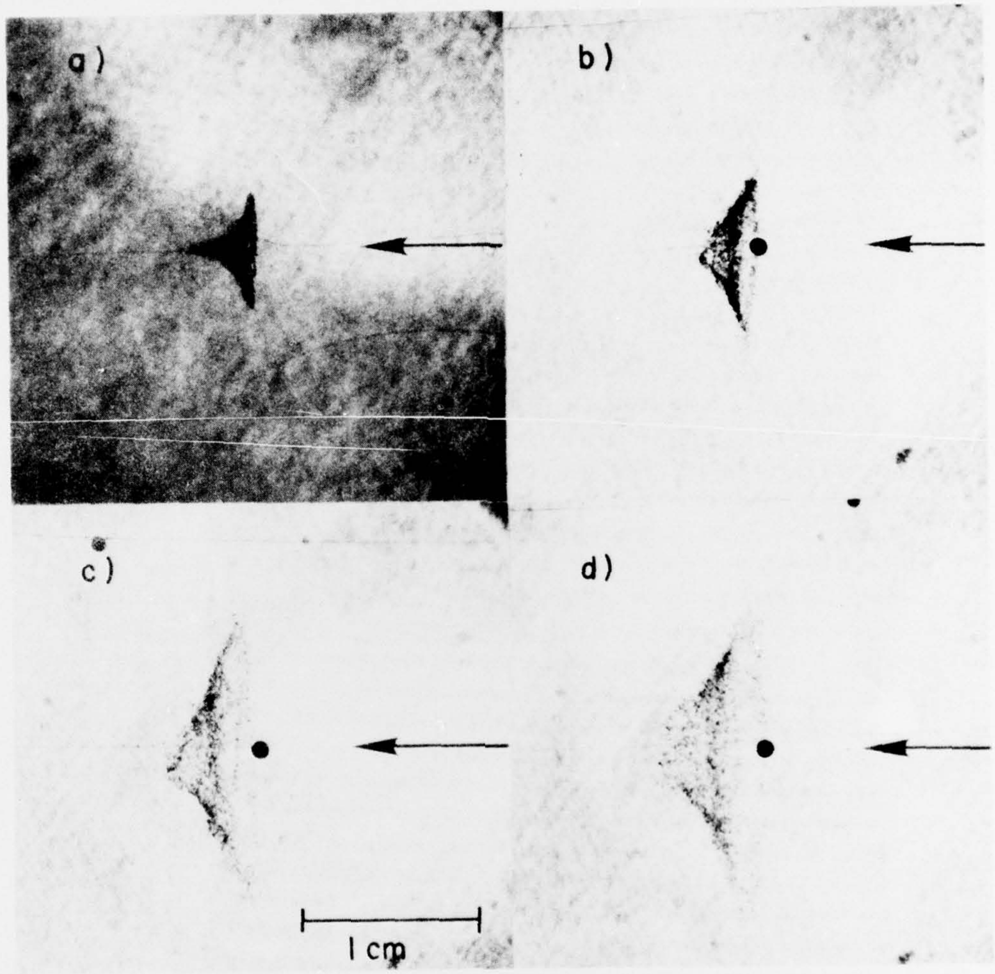


Fig. 2 — Shadowgrams showing the disintegration of 1 mm diameter polystyrene resin beads after irradiation with ~ 95 J Nd/glass laser pulses with no prepulses. (a) 2 μsec after peak laser power; (b) 4 μsec; (c) 6 μsec; and (d) 8 μsec. Exposure time ~ 16 nsec. Nd/glass laser incident from the right. The spot in (b), (c), and (d) marks the initial position of the target.

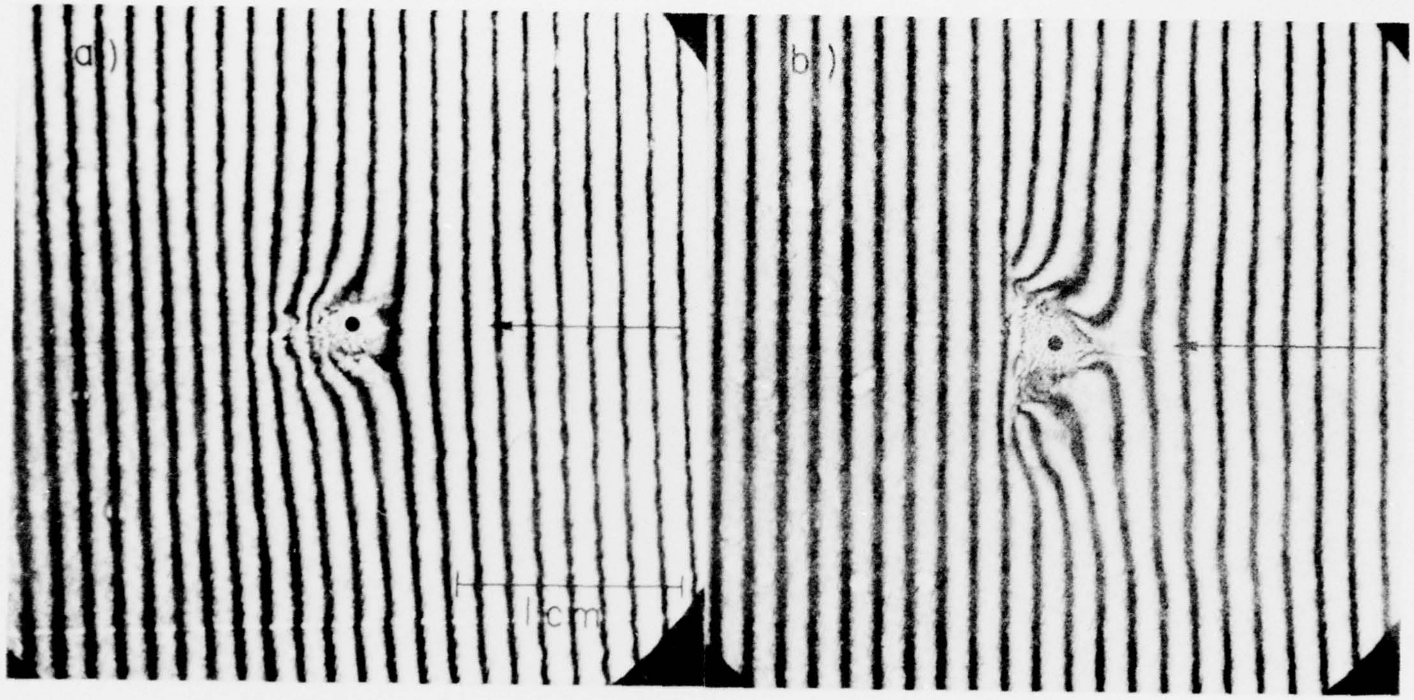


Fig. 3 — Holographic interferograms showing the plasma produced by laser irradiation of 0.7 mm diameter polystyrene beads. (a) 130 nsec after peak laser power, energy 90 J with no prepulse; (b) 100 nsec after peak laser power, 80 J with prepulse at ~ 600 nsec. Exposure time ~ 16 nsec. Nd/glass laser incident from the right.

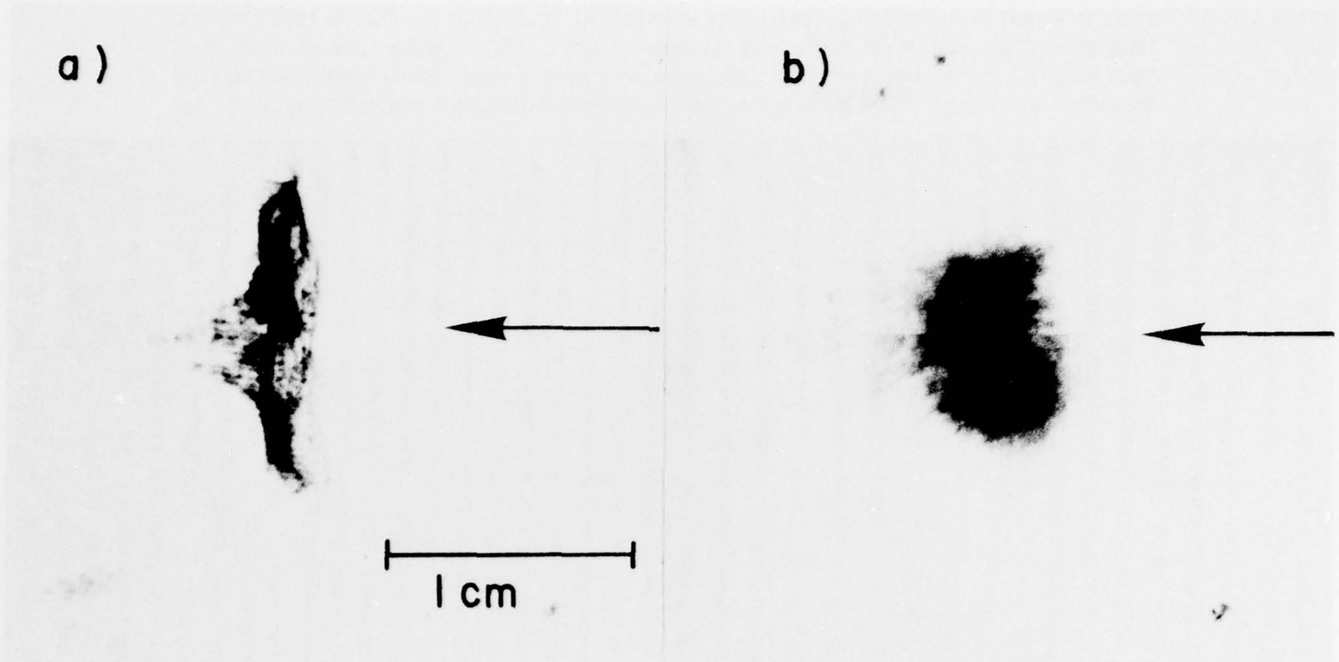


Fig. 4 — Shadowgrams showing the disintegration of 0.7-0.8 mm diameter polystyrene resin beads after irradiation with ~ 80 J Nd/glass laser pulses. (a) 3.7 μsec after peak laser power, with no prepulse; (b) 1.8 μsec after peak laser power, with prepulse at 600 nsec. Nd/glass laser incident from the right. Exposure time ~ 16 nsec.

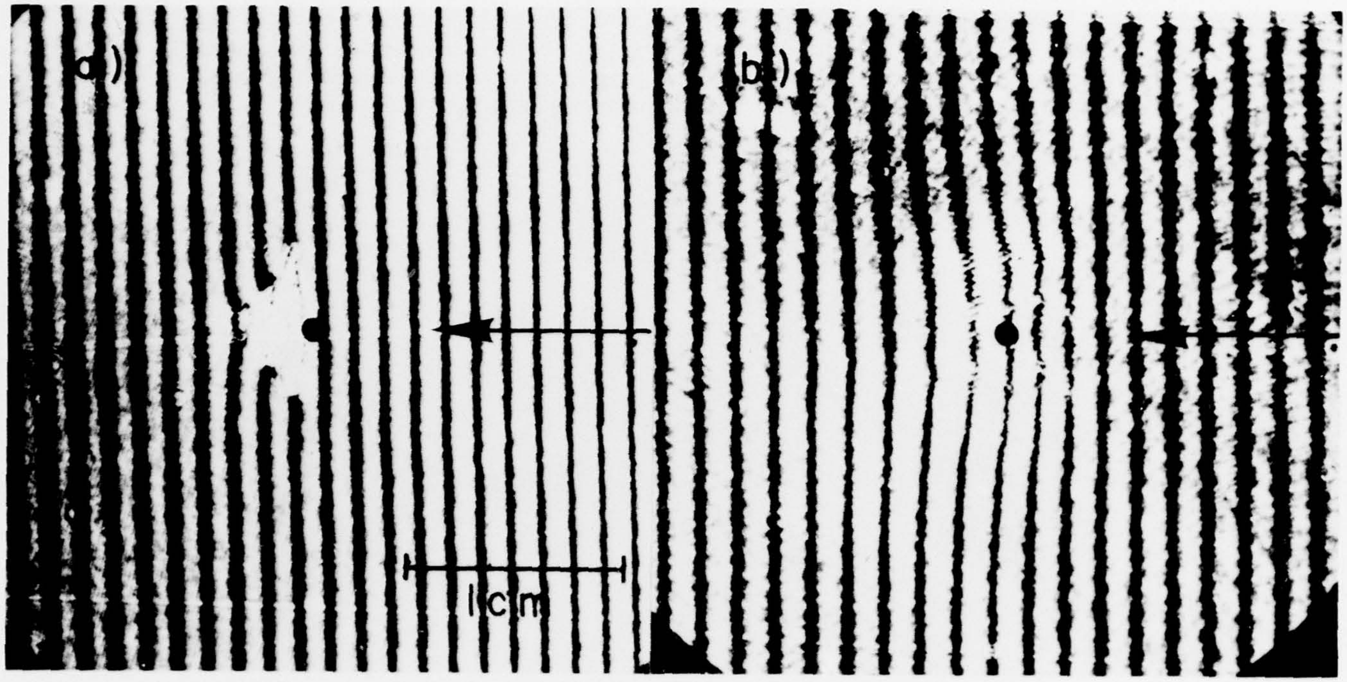


Fig. 5 — Holographic interferograms showing the disintegration of 0.7 mm diameter polystyrene resin beads after irradiation with Nd/glass laser pulses. (a) 2 μsec after peak laser power, total energy ~ 90 J with no prepulse; (b) 2 μsec after peak laser power, total energy ~ 80 J with prepulse at 600 nsec. Nd/glass laser incident from the right. Exposure time ~ 16 nsec.

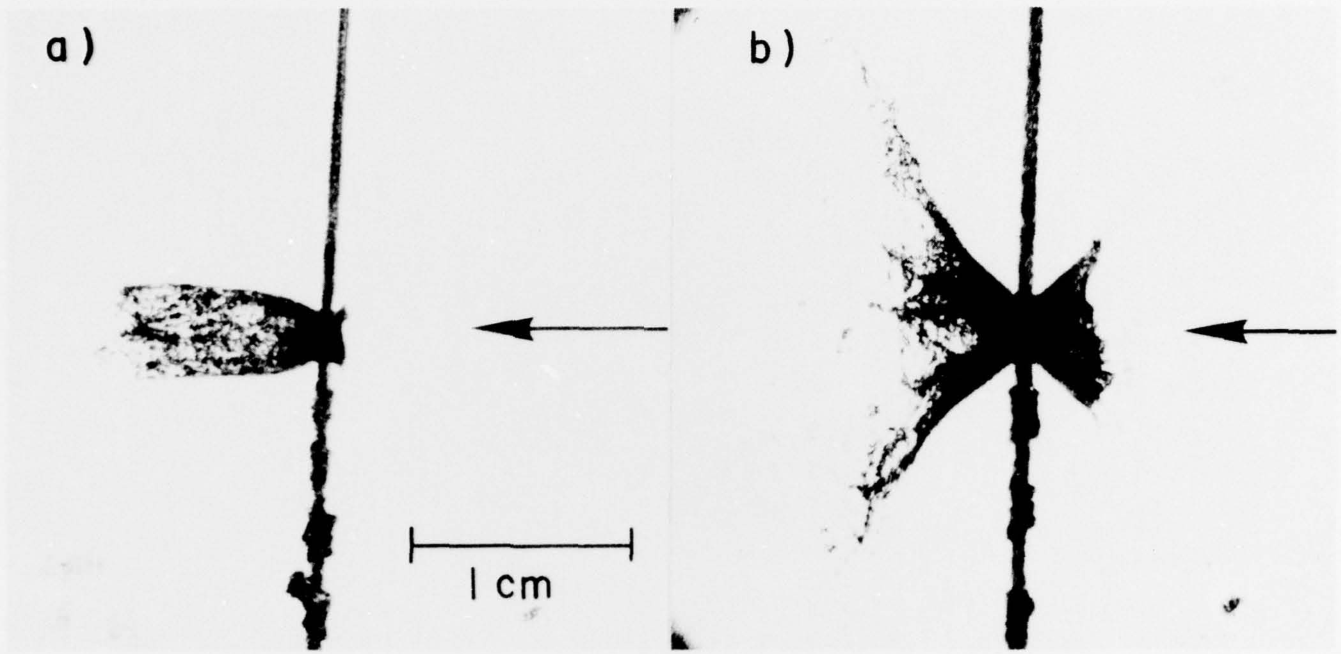


Fig. 6 — Shadowgrams showing the disintegration of polyethylene sheet targets 0.5 mm thick after irradiation with Nd/glass laser pulses. (a) 4 μsec after peak laser power, energy ~ 80 J with no prepulse; (b) 4 μsec after peak laser power, energy ~ 80 J with prepulse at 600 nsec. Nd/glass laser incident from the right. Exposure time ~ 16 nsec.