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Abstract:

3/2 ω_L emission from various plane targets irradiated by a 2o J/5 ns Neodymium laser pulse has been investigated. A threshold as predicted for excitation of the 2 ω_{pe}-decay is observed.

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I. Introduction

Scattering of radiation in the plasma produced by laser irradiation of solid targets is a vital problem of laser fusion. It is well known that under typical experimental conditions harmonics and subharmonics of the laser radiation may be produced in the plasma. The study of these lines is of interest for the understanding of the light-plasma interaction.

In this report we present the results of an experimental study of 3/2 ω_L emission from the plasma produced by laser irradiation of plane solid targets. These results have been obtained in the Garching Neodymium laser experiment, under identical conditions and with similar methods as described previously in the context of studies of ω_L /1o/ and 2 ω_L /12/ emission from the plasma. For a comparison with the scattering properties of the plasma at other frequencies than 3/2 ω_L and also for a more detailed description of the experimental set-up we refer therefore to our previous work /1o,12/. 3/2 ω_L emission from laser-produced plasmas has also been investigated in /3 - 8/.

II. Experimental Set-up

The set-up used for the experiment is shown in Fig.1. The linearly polarized beam from the Neodymium laser (spectral width ∼ 3o Å, center wavelength 1o 571 Å) with a pulse duration of 5 ns and a variable (by attenuation with filters) pulse energy between o.1 and 2o Joule is focussed onto the target with an aspheric f/1 lens of 75 mm focal length. With a pulse energy of 2o Joule the maximum intensity in the focal plane is $4 \times 1o^{14}$ Wcm^{-2} /1o/.

Plane targets of four different materials were used for these experiments: solid deuterium, plexiglass ($C_5O_2H_8$), carbon and copper. The focussing lens, illuminated by the backscattered radiation from the plasma, was imaged on the entrance slit of a spectrograph (3-prism spectrograph, type Försterling I (Zeiss Jena)) or onto a photographic plate (Kodak IN). The latter technique, applied previously for the investigation of backscattered radiation at ω_L and 2 ω_L /1o, 12/ allows by appropriate filtering of the scattered radiation the angular distribution of 3/2 ω_L emission to be studied within the solid angle of the focussing lens.

III. Results

A typical spectrogram obtained with a copper target is shown in Fig.2. It shows scattered radiation at frequencies ω_L, 2 ω_L, 3/2 ω_L, and 5/4 ω_L. The latter line (not observed previously) consists of two broad (~ 2oo Å width) lines, about symmetric around the calculated 5/4 ω_L frequency and separated by ~ 4oo Å. It has not been investigated further during the course of these experiments.

The spectral profile of 3/2 ω_L radiation has been photographed for the targets mentioned above. We find that in general 3/2 ω_L radiation consists of two lines (see Fig.3) with the calculated wavelength of 3/2 ω_L radiation lying in the minimum between the two lines. The blue-shifted line is of lower intensity than the red-shifted one; its wavelength is not sensitive to the target material. The red-shift of the main line depends on the target material; its shift relative to the calculated wavelength of 3/2 ω_L radiation is highest for the heavy target materials and decreases with the atomic number (typical values are 4o Å for copper, 2o Å for carbon and 1o Å for Plexiglass). With solid deuterium the double-line character is no longer clearly resolved, probably the two lines merge together as their spacing becomes small.

The intensity of 3/2 ω_L radiation was different for different targets, when all other conditions were kept similar. It was strongest for a deuterium plasma, and decreased with an increase of the target's atomic number. But when the laser beam was allowed to fall in a crater made by a previous laser pulse, 3/2 ω_L intensity was found to be anomalously high. Sometimes a 5 fold increase over a plane target case was observed. Conversion efficiency of laser radiation into 3/2 ω_L radiation was of the order of 10^{-5} for solid deuterium.

An attempt was also made to record the emission aerea of 3/2 ω_L near the target surface side-on i.e. when viewed along the target surface but normal to the laser axis. Using appropriate filters, a magnified picture of the irradiated target aerea was formed on a photographic plate. Besides 3/2 ω_L, the emission aerea of 2 ω_L was also recorded for comparison under identical experimental conditions. Photographs taken with a carbon target are shown in Fig.5. In contrast to the spot-like source of 2 ω_L radiation (with a diameter of 3o μm, corresponding to the laser focal spot diameter), 3/2 ω_L is emitted from a region which has a half-moon like shape in the side-on photograph. No attempt has been made to measure a spatial separation between the emitting surfaces of 2 ω_L and 3/2 ω_L (supposed to correspond to n_c and $n_c/4$ respectively).

The distribution of the backscattered radiation across the focussing lens was also recorded. The incident beam was half masked (similar as described in /1o,12/). The back-scattered 3/2 ω_L radiation was found to illuminate the entire lens with uniform intensity. This gave an indication that 3/2 ω_L radiation is scattered isotropically, unlike collimated backscatter of ω_L /1o/ and also unlike 2 ω_L which is very strongly radiated at an specular angle /12/.

Polarization of the two lines of 3/2 ω_L radiation was also checked. Both of them were found to be strongly polarized in the same direction as the incident laser beam. To conduct this experiment both spectroscopic and spatial photographic methods were used. Spectra were recorded with an analyser in front of the spectrograph slit. In crossed position both lines disappeared. Also an analyser was kept in front of the camera when photographs of the focussing lens were taken with 3/2 ω_L radiation. Lens images were re-corded with the analyser parallel and crossed. Figure 5 shows a typical result. From the exposure of the photographic plates a polarization of better than 9o % is inferred.

Of particular interest is the dependence of the intensity of 3/2 ω_L radiation on the incident laser intensity. Measurements were performed by attenuating the incident laser beam with neutral density filters; the intensity of 3/2 ω_L radiation backscattered through the lens being monitored with a Valvo 56 TUVP photomultiplier with a S2o cathode. Figure 5 shows the result obtained with a carbon target. 3/2 ω_L intensity is found to increase (possibly from the level of plasma self-luminosity) by about four orders of magnitude in the range 1 - 3 Joules.

IV. Discussion

Recent computer simulations /9/ have shown that 3/2 ω_L emission as observed in this and other experiments /3 - 8/ should be attributed to the 2 ω_{pe}-decay rather than to stimulated Raman scattering. Besides the rather narrow line width observed, the main argument comes from the low threshold for the 2 ω_{pe}-decay as compared to stimulated Raman scattering.

The threshold intensity for the 2 ω_{pe}-decay has been calculated by Jackson /2/ and, for the inhomogeneous plasma, by Rosenbluth /1/. From /1/ one finds for typical parameters of our experiment ($L \simeq$ o.1 mm, $k\,T_e$ = o.5 keV) a threshold intensity of $\sim$ 10^{13} Wcm^{-2}. Experimentally we find an increase in 3/2 ω_L generation by more than four orders of magnitude at a laser energy around $\sim$ 1 Joule, corresponding /1o/ to an intensity of $\sim 2 \times 10^{13}$ Wcm^{-2}. Taking the uncertainties due to the focussing of the beam etc. into account the threshold observed in the experiment agrees surprisingly well with the predicted one. This supports the assumption that 3/2 ω_L generation is indeed connected with the excitation of the 2 ω_{pe}-decay.

As concerns the spatial origin of 3/2 ω_L radiation, previous experiments /3,4/ with targets consisting of light elements have already shown that it is produced at a position typically several ten microns away from the critical layer i.e. probably at a density of $n_c/4$. While the precise location of the conversion point in the density profile is not resolved in our experiment, the half-moon like shape of the region of 3/2 ω_L-emission in Fig. 4 seems consistent with the observation (by X-ray pinhole photography /11/ and interferometry /13/) that the expanding plasma in front of the target has a hollow structure. Hence the corresponding curvature of the diffusively scattering $n_c/4$ layer may give rise to the particular shape of the 3/2 ω_L emission aerea.

The double-line character of 3/2 ω_L emission observed with heavy target materials, the enhanced conversion rate in the case of a solid deuterium target and a cratered copper target (i.e. under conditions where the backscattered laser radiation is strongly collimated /1o/) and the angular (diffuse) distribution of 3/2 ω_L radiation are not jet understood. The existence of a reflection point for the ingoing plasmon, supersonic streaming of the plasma, excitation of the instability in the standing wave pattern formed by collimated backscatter from the denser part of the plasma and saturation effects (the measurements were made in the range above threshold where 3/2 ω_L intensity increases only slowly with the incident energy) are obvious possibilities which might have to be taken into account for their explanation.

Finally we may note that excitation of the 2 ω_{pe}-instability does not lead to a noticeable increase of absorption in our experiment. As measured previously /1o/ under identical experimental conditions, the reflection coefficient of the plasma increases steadily in the range of o.1 - 2o J incident laser energy whereas the measured reflection curve does not show any anomaly at the onset of 3/2 ω_L emission at a laser energy of ~ 1 Joule. Also in /7/ maximum 3/2 ω_L emission coincides with maximum reflection from the target.

Acknowledgement

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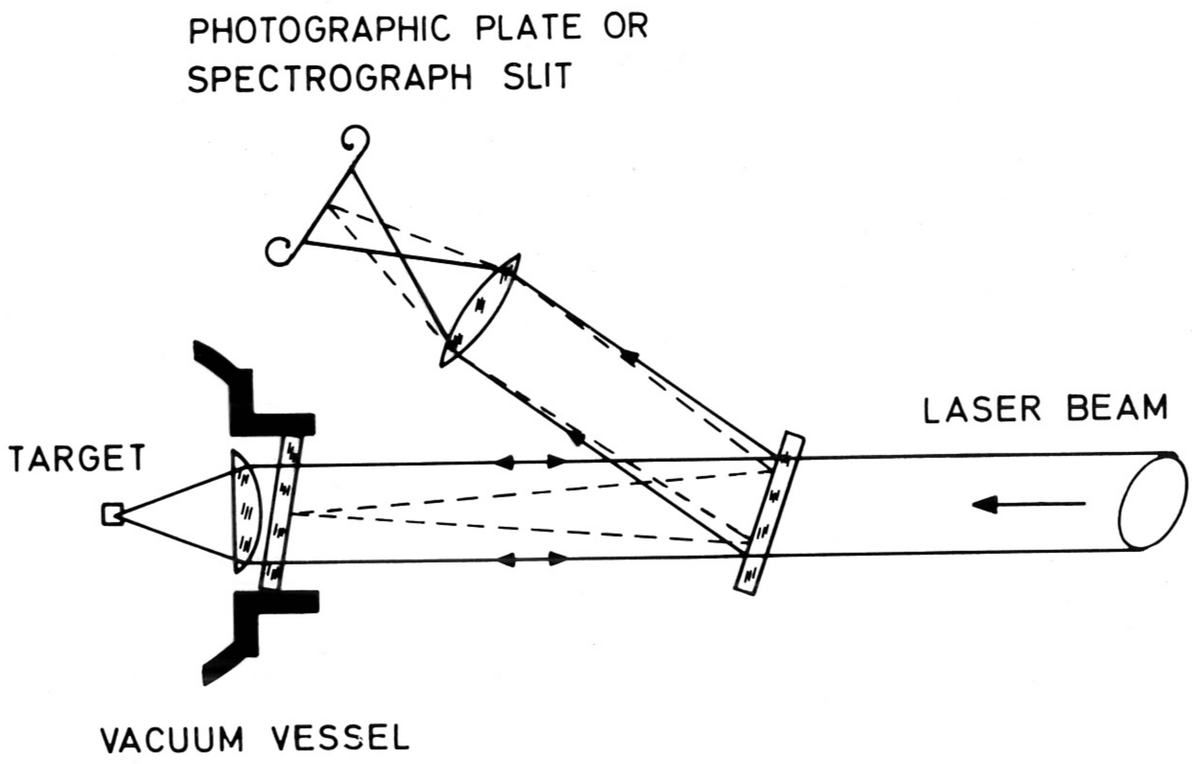


Fig. 1 Schematic diagram of the experimental setup

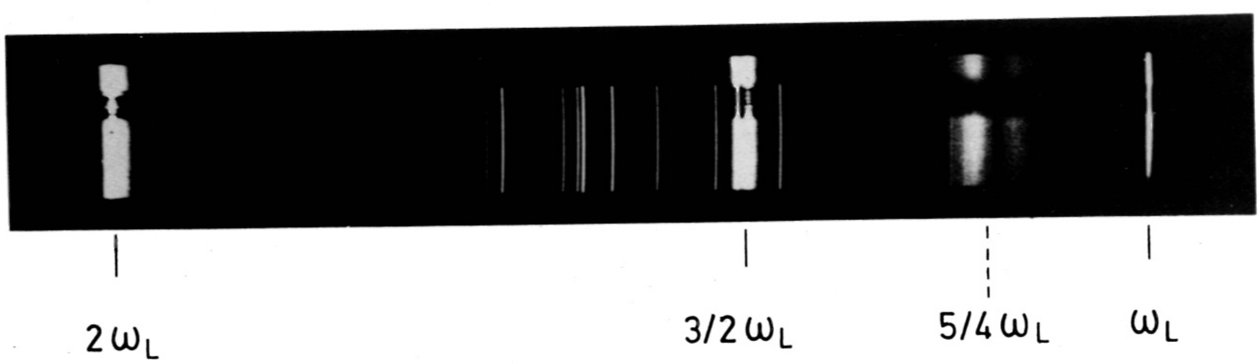


Fig. 2 Spectrogram from Copper plasma, showing ω_L, $2\omega_L$, $\frac{3}{2}\omega_L$ and a broad double line centered at approximately $\frac{5}{4}\omega_L$. The Ne-lines are used for calibration. Note the different height for calibration and plasma lines.

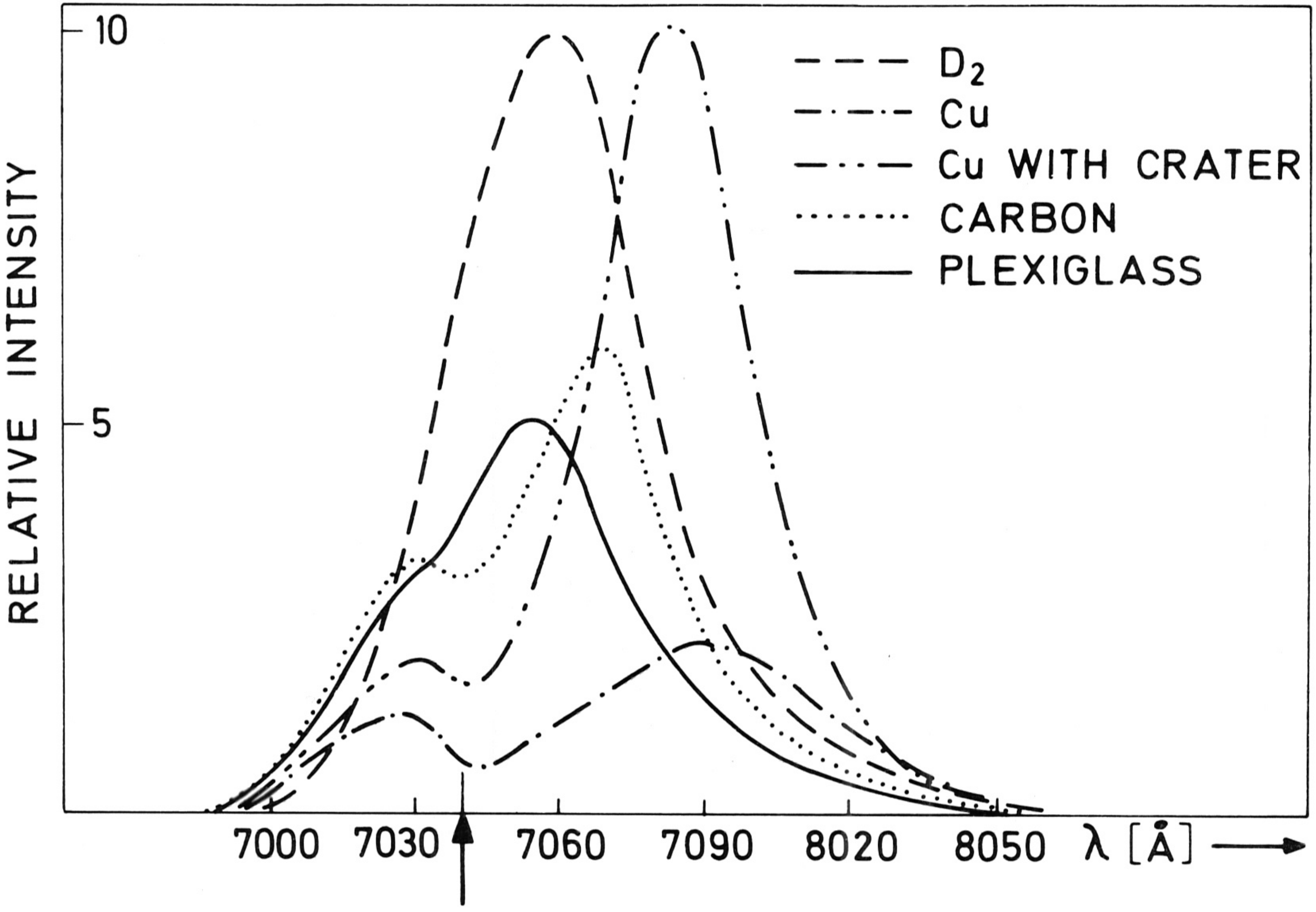


Fig. 3 $\frac{3}{2}\,\omega_L$ line shapes (densitometer traces) from various target plasmas. Peak intensities are normalized relative to the deuterium target (with the γ-curve of the plate).

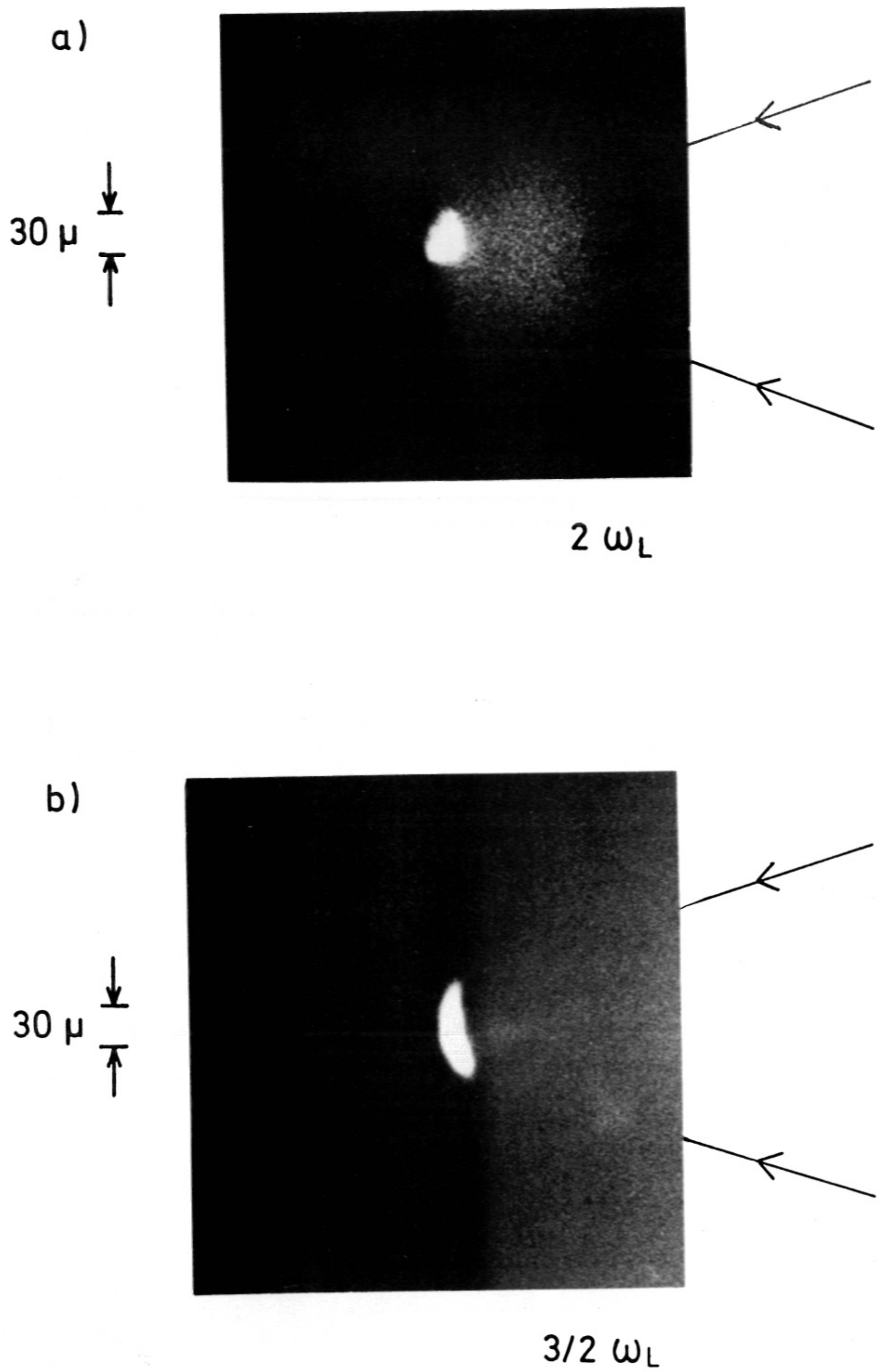
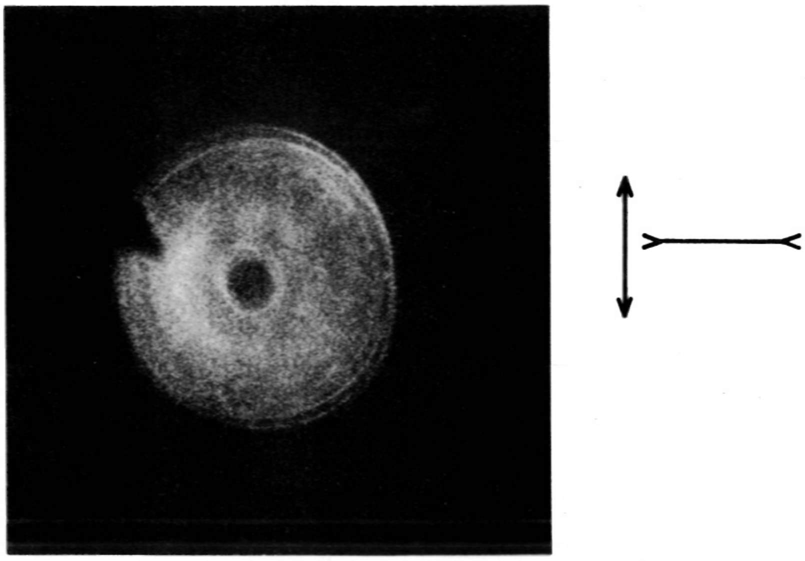


Fig. 4 2 ω_L (a) and 3/2 ω_L (b) emission area near the target surface (side-on). Carbon target a)



b)

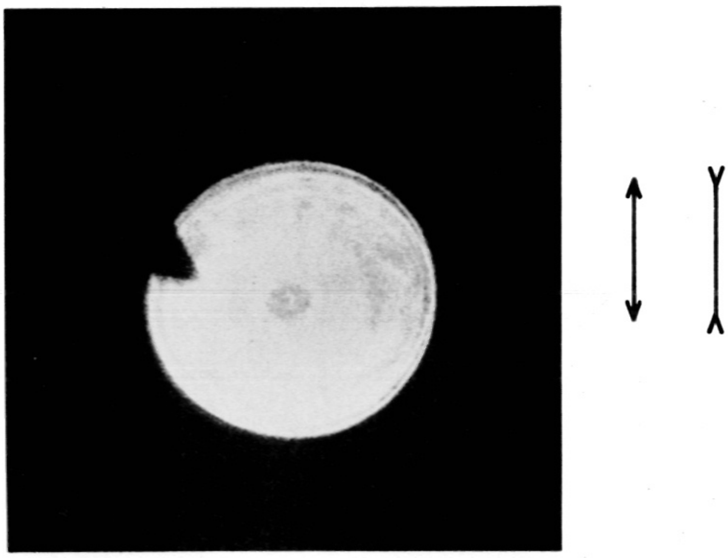


Fig. 5 Image of focussing lens formed with 3/2 ω_L radiation, with analyzer (>——<) normal (a) and parallel (Y-shaped vertical analyzer symbol) (b) to the polarization of incident laser radiation

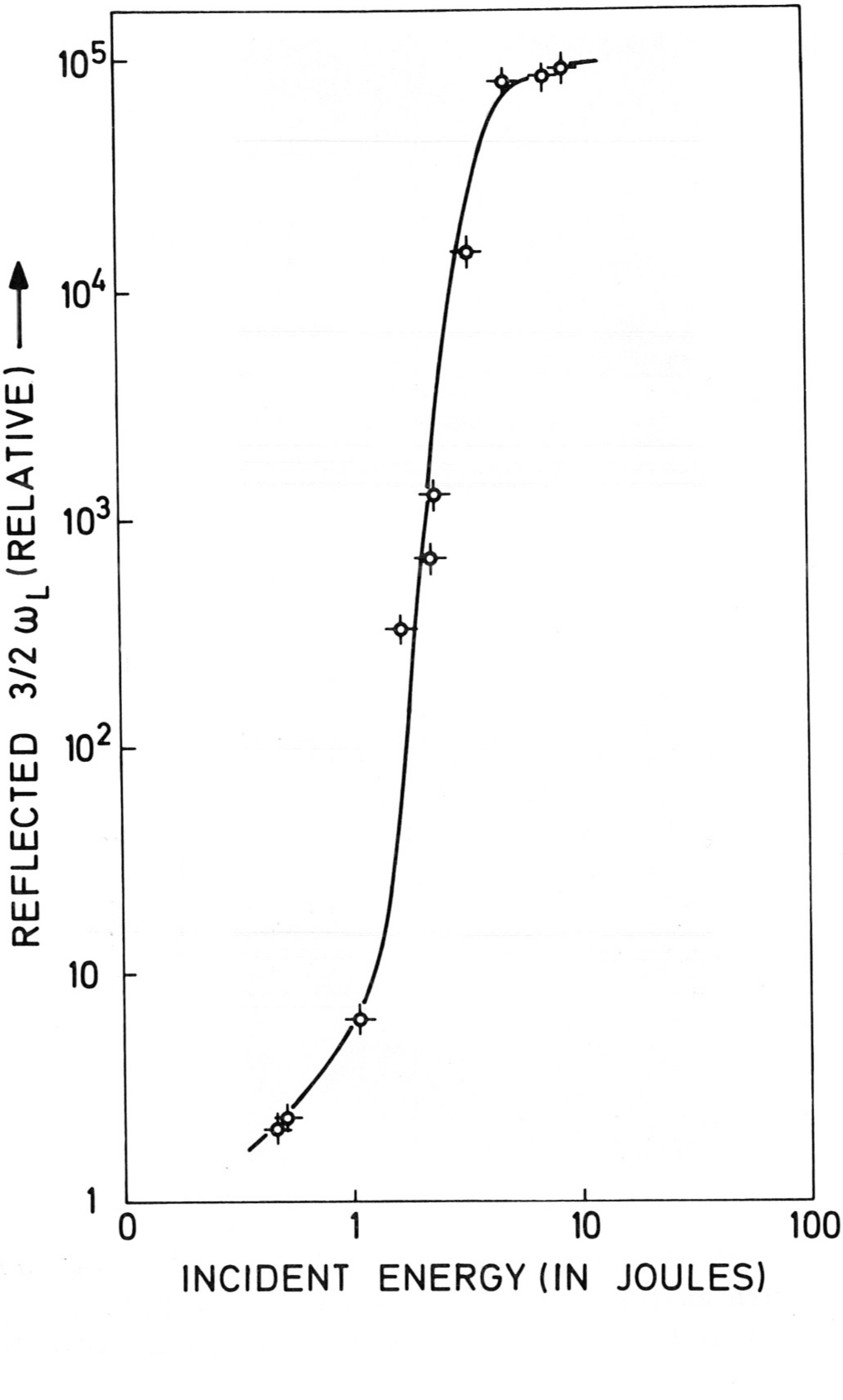


Fig. 6 Intensity dependence of 3/2 ω_L on the incident laser energy