Invited Paper

Schlieren photography in physics

M. A. Breazeale
University of Mississippi
National Center for Physical Acoustics
University, MS 38677
U. S. A.

ABSTRACT

Schlieren photography has been used many years in physics; however it has proved to be exceptionally valuable in the study of ultrasonic waves in liquids. Part of the reason for its value is that many of the ultrasonic phenomena studied have their optical analogues. Thus, when one studies ultrasonic images he actually is studying a general wave phenomenon from a perspective that is impossible with light alone. Examples are given of ultrasonic schlieren photographs as are conclusions possible from their study.

Keywords: Schlieren image, reflection of an ultrasonic beam.

1. SCHLIEREN OPTICAL SYSTEM

The schlieren system is diagrammed in Fig. 1. Although many schlieren systems contain mirrors as the imaging system, we prefer to use lenses because there is no distortion of the image to correct for. In our system lenses L_2 and L_3 are large (focal length, 120 cm, f/6.3). This gives us a large field of view : diameter, 20 cm. Although the alignment of the system is obvious, it is worthwhile to mention that the location of L_3 is important. It is possible to obtain shadows of the ultrasonic waves to be studied at many positions, but a true image only at the one indicated, or its conjugate. At the position indicated in Fig. 1, a black spot is inserted to block the central diffraction order. The remainder of the diffraction pattern in this plane is used to form the image. This makes the system a dark-field illumination system. This system has been used for a number of studies. The following discussion gives an impression of the types of studies possible.

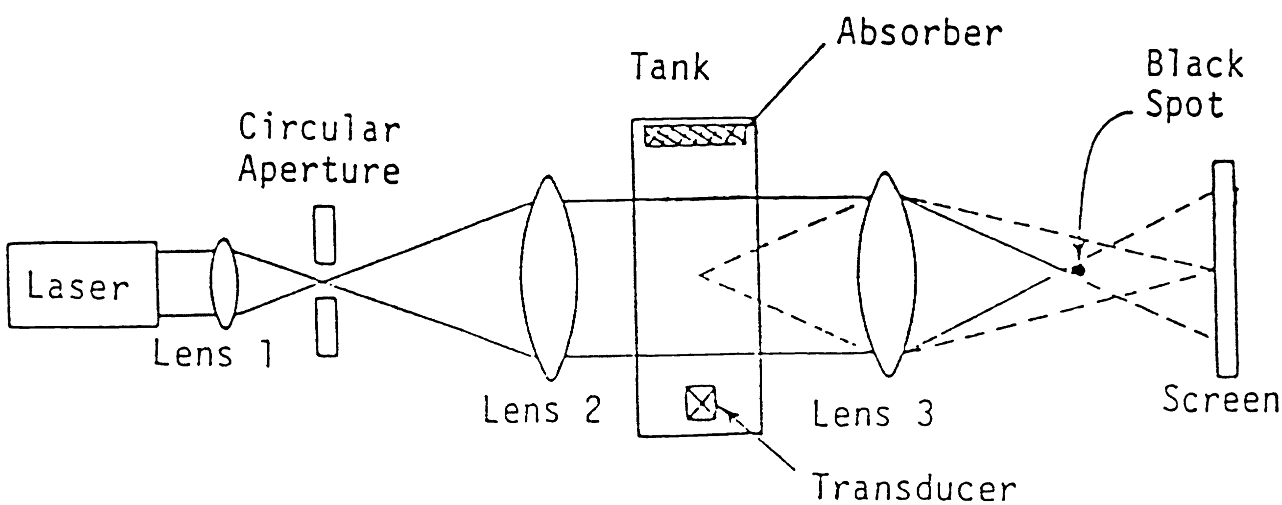


Figure 1. Diagram of a Schlieren System.

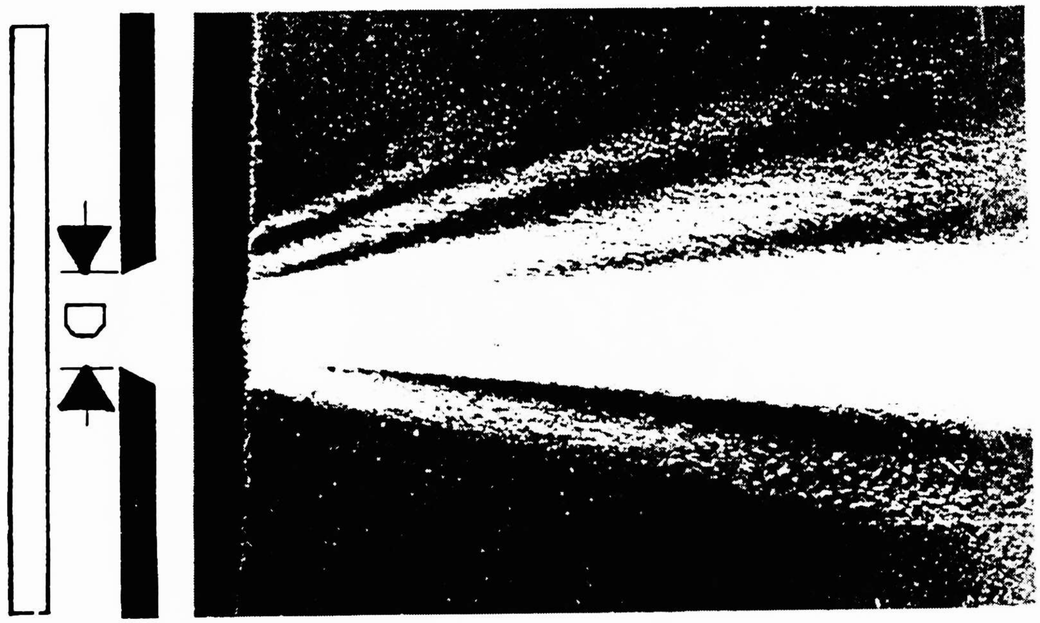
*This paper is dedicated to the memory of Professor B. D. Cook.

2. SCHLIEREN PHOTOGRAPHS OF ULTRASONIC WAVES

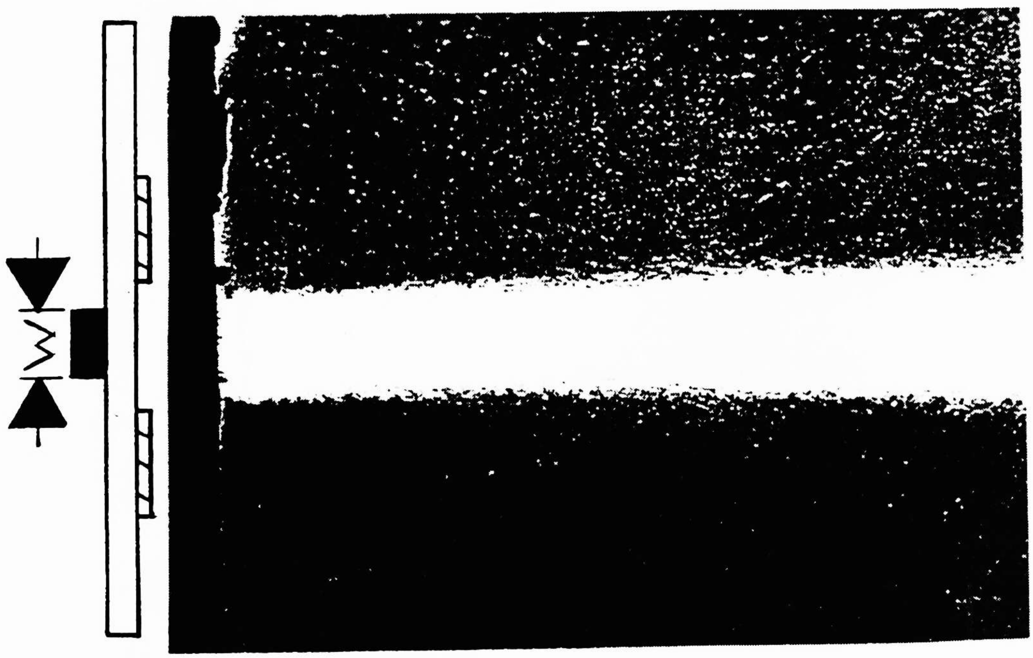
A schlieren photograph of an ultrasonic wave reflected from a water-solid interface is given in Fig. 2. The reflection is clear enough, but details of the reflection are not[1]. Theory and experiment indicate that at an angle of incidence of 30.5^{0} one should observe a displacement of the reflected beam along the interface[2]. A second examination of Fig. 2 reveals that the displacement appears to be confirmed, but interference from other beams originating at the transducer make absolute confirmation impossible.

At this point it is necessary to redesign the transducer. The sidelobes coming from the transducer are interfering with the physical interpretation of the schlieren photographs. We did this[3]. The results are shown in Fig. 3. When a sound wave (or light) passes through a slit of width D, diffraction causes the sidelobes shown in Fig. 3a. We were able to cause the sidelobes to vanish, as shown in Fig. 3b by obtaining a Gaussian amplitude distribution through the use of an appropriate transducer of width W (This is called apodization in optics). The apodization of the ultrasonic transducer enabled us to take the photograph shown in Fig. 4, where it is clear that reflection at this angle actually results in two beams: a displaced one and an undisplaced one. The situation actually is as shown in Fig. 5, at an angle at which surface waves are generated on the interface the reflected beam is split into at least two components. At smaller or larger angles the reflection results in a single beam[4].

Figure 2. The effect of transducer sidelobes on a photograph of the reflection of an ultrasonic wave at an interface.



(a)



(b)

Figure 3. Schlieren photographs showing a) sidelobes produced by diffraction at a slit of width D, and b) single beam appearing at an apodized transducer.

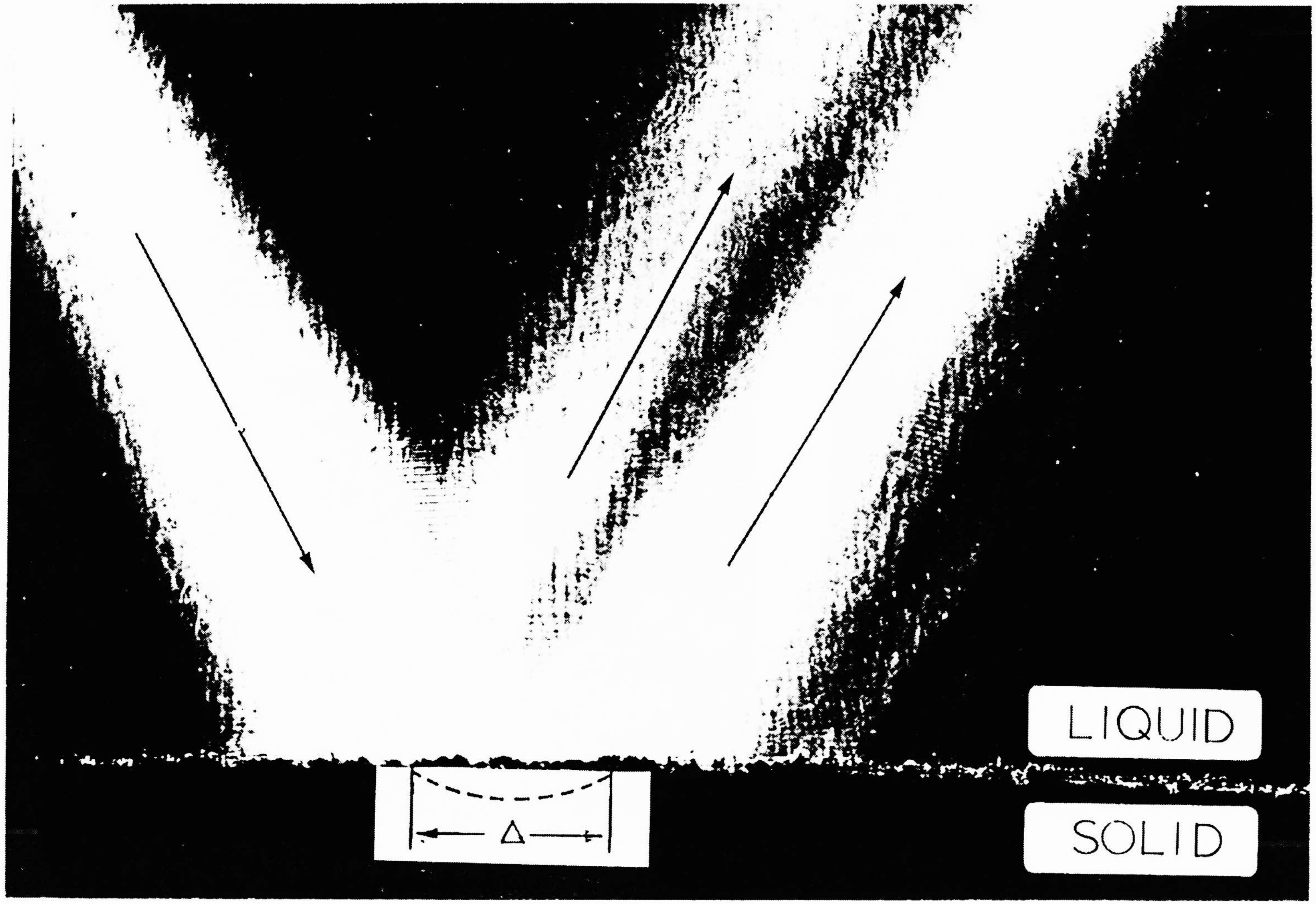


Figure 4. Schlieren photograph showing reflection of an ultrasonic beam at a water-solid interface

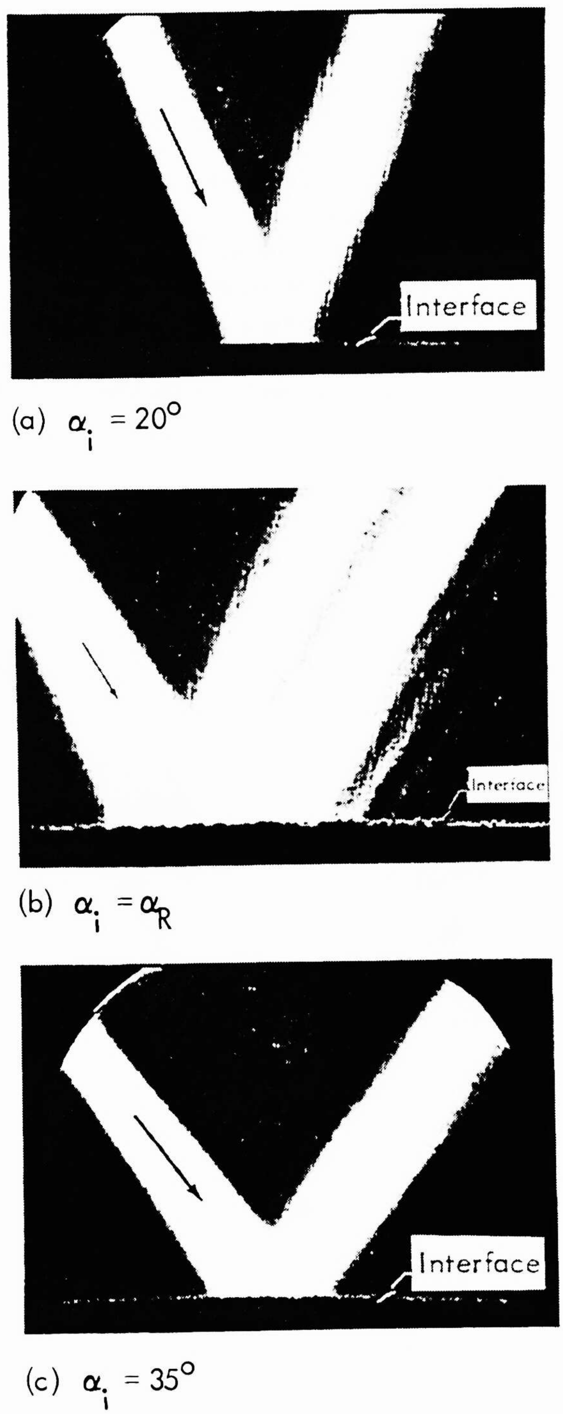


Figure 5. Reflection of an ultrasonic beam at three incident angles: a) small angles; b) the angle of excitation of an interfacial wave; c) large angles.

Finally, we have been able to observe at least one phenomenon that could be predicted from optical theory, but must be observed ultrasonically. When the interface is corrugated in such a manner that the reflected wave is shifted in phase by 180°, then the surface wave actually is propagating in a direction opposite to that shown in Fig. 4. This means that the reflected beam should be displaced in a direction opposite to that shown in Fig. 4. At this angle, the angle of incidence θ_i satisfies

$$\sin \theta_i = V_{liq}\left(\frac{1}{fd} - \frac{1}{V_R}\right), \tag{5}$$

where V_{liq} is the sound velocity in the liquid, f is the frequency, d is the grating spacing, and V_R is the velocity of the Rayleigh wave on the interface. The situation is diagrammed in Fig. 6. The schlieren photograph confirming that such a situation is possible is given in Fig. 7. This photograph was made[5] with a 6MHz ultrasonic beam in water reflected from a brass grating with a period d= 0.178 mm. If one uses θ_i measured from Fig. 7, θ_i = 22.5°, then one can calculate V_R, because everything else is measurable. The resulting value $V_R = 1.47 \times 10^5$ cm/sec is only approximately the velocity of a Rayleigh surface wave on brass, 2.015×10^5 cm/sec; however, the Rayleigh surface wave is defined only for a free surface. This probably means that the liquid (water) in contact with the brass loads the surface and changes the surface wave velocity by more than 25%.

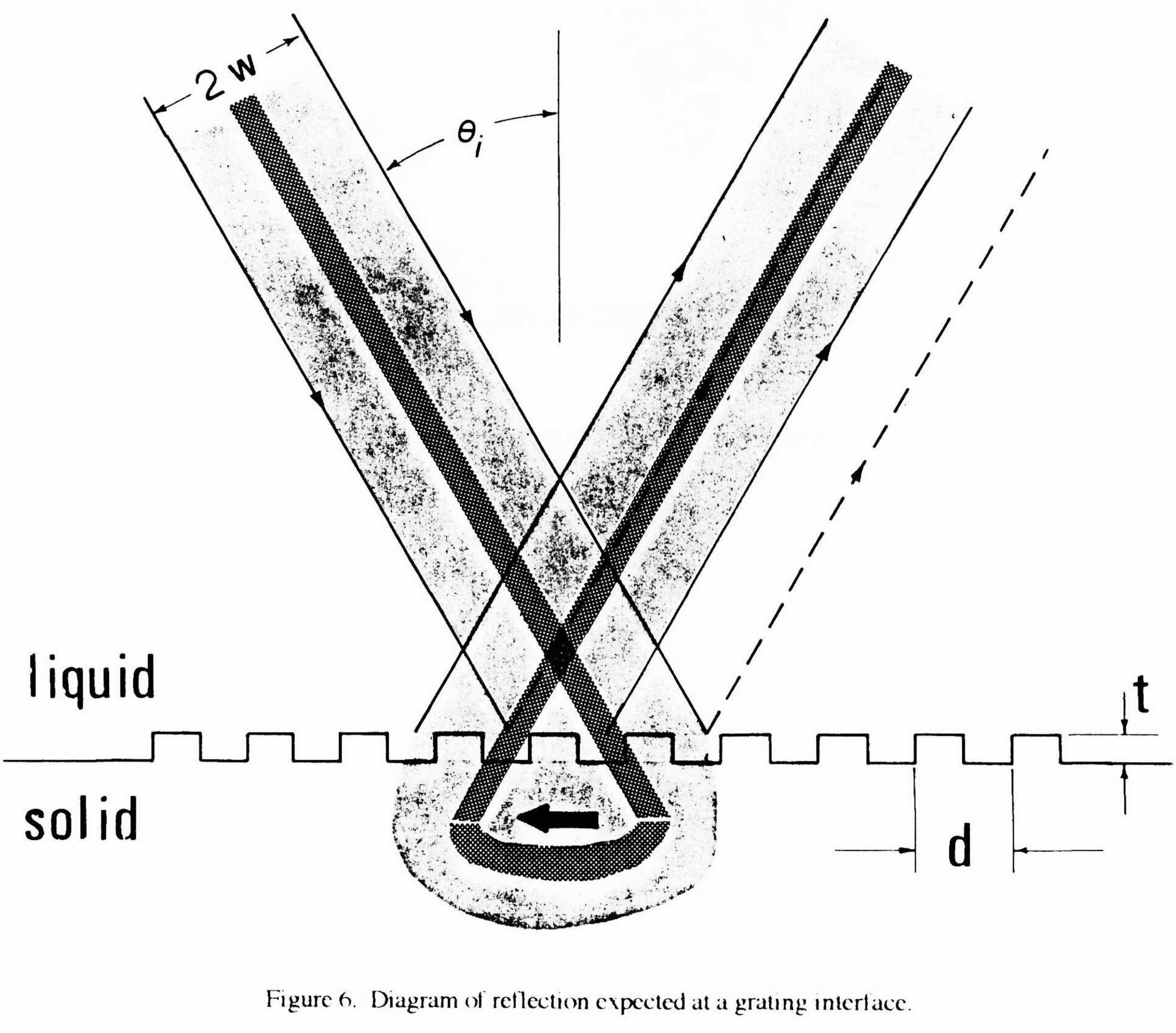


Figure 6. Diagram of reflection expected at a grating interface.

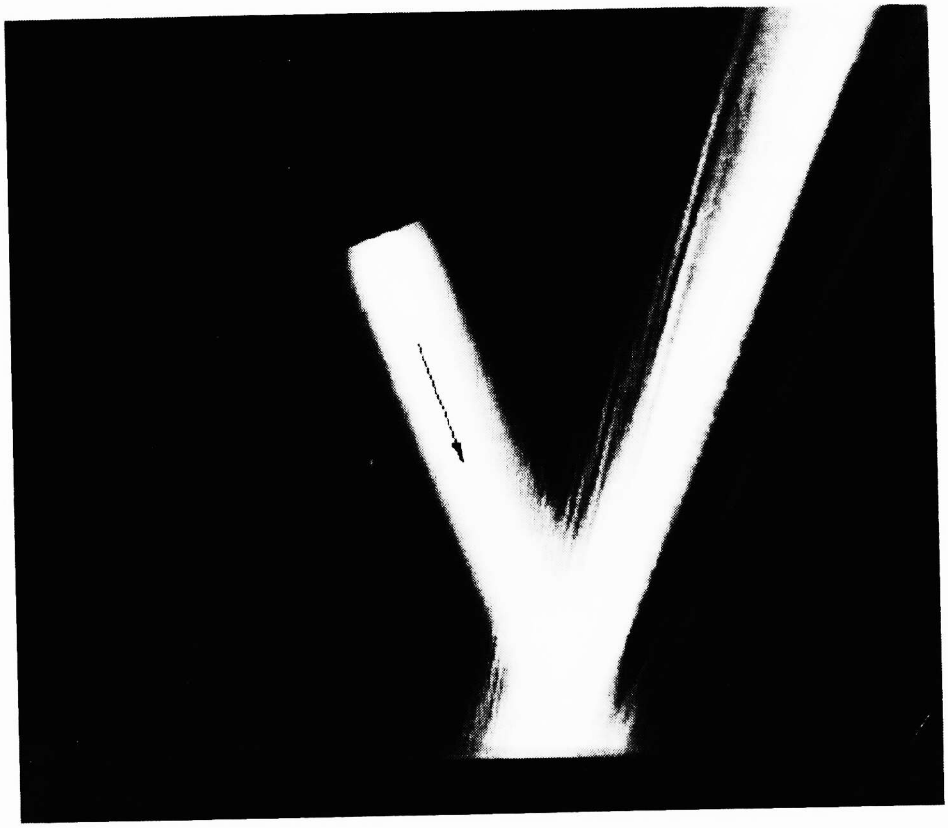


Figure 7. Schlieren photograph showing "backward displacement" of an ultrasonic beam at a grating interface.

3. CONCLUSION

The Schlieren system in optics is a powerful tool. When combined with ultrasonic waves in water it is able to visualize details of wave interaction that are impossible to visualize with light alone. In the examples given the ultrasonic phenomena shown occur in optics when light is internally reflected at a plane interface.

4. REFERENCES

1. L. Adler, M. A. Breazeale, and J. H. Smith, Akusticheskii Zhurnal **21**, 1-10 (1975).
2. M. A. Breazeale, L. Adler, and G. W. Scott, J. Appl. Phys. **48**, 530-537 (1977).
3. F. D. Martin and M. A. Breazeale, J. Acoust. Soc. Am. **49**, 1668-1669 (1971).
4. M. A. Breazeale and L. Adler, J. Acoust. Soc. Am. **56**, 866-872 (1974).
5. M. A. Breazeale and M. A. Torbett, Appl. Phys. Lett. **29**, 456-458 (1976).