Demonstration of light diffraction by a two-dimensional ultrasound structure in a liquid

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To demonstrate the diffraction of light by a two-dimensional ultrasound structure in liquid, one uses a setup consisting of a cell with a piezoelectric quartz radiator and a special ultrasound reflector serving to produce a two-dimensional ultrasound structure (Fig. 1a) as well as a radio-frequency oscillator (Fig. 1b). The light source is a gas laser, preferably with a beam of round cross section.

The oscillator operates in the cw mode at one of two fixed frequencies, 12 or 20 Mz. The choice of relatively high ultrasonic frequencies is governed by the need for obtaining maximum linear dimensions of the diffraction patterns displayed on the screen.

The ultrasound radiator is a round X-cut quartz plate of 40 mm diameter with metallized surfaces. Its natural frequency is at 4 MHz and it is excited at the third or fifth harmonic. As shown in Fig. 1a, one of the metallized surfaces of the quartz plate presses against the edges of a round opening in the metallic wall of a cell joining the housing of the instrument. This quartz surface is in contact with the liquid and radiates ultrasound into it. A high-frequency voltage from the oscillator is applied to the metallized surface of the opposite and acoustically unloaded surface, via a coaxial cable. Mounting the radiator (2) in this manner results in the best conditions for radiating ultrasound into the liquid and ensures screening of the liquid from the high-frequency field of the oscillator. The choice of the liquid is determined by its elasto-optical constant and does not depend at all on its electrical properties. Distilled water was used in the experiments described below.

A reflector consisting of a 45° glass prism (1) and glass plates (2 and 3) is placed in the cell ahead of the quartz. The reflector is coupled to an adjustment device that permits smooth variation of the distance between the reflector and the quartz, and rotation of the reflector through small angles about the vertical axis. When the reflector is properly set, two mutually perpendicular standing-wave systems are produced in the water, one between the upper half of the quartz, the prism, and the horizontal plate of the reflector (3), and the other between the lower half of the quartz and the vertical plate of the reflector (2). This produces between the prism and the reflector plates a two-dimensional periodic ultrasonic structure of compression and rarefaction in the water. The laser beam passes to the screen through the glass walls of the cell in a direction parallel to the surfaces of the prism and the plates. On passing through the ultrasonic structure, which serves as a two-dimensional grating, the light is diffracted and a diffraction pattern in the form of a rectangular grid of diffraction maxima, corresponding to the symmetry of the ultrasonic structure, is seen on the screen of the large auditorium (Figs. 2 and 3). Under laboratory conditions, this phenomenon was first observed by Bär and Meyer[1,2].

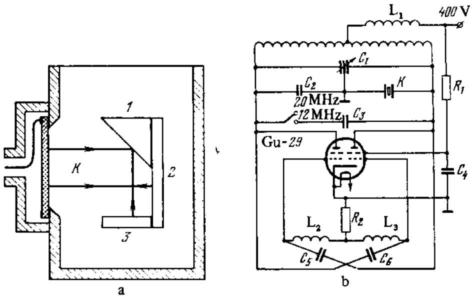

FIG. 1.

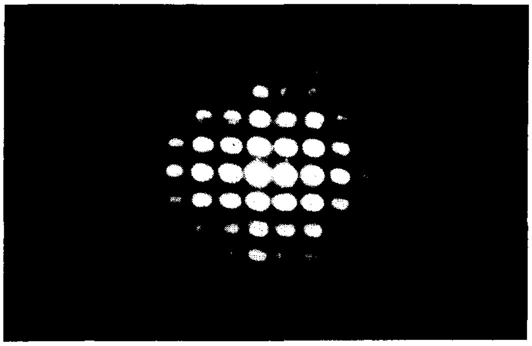

FIG. 2.

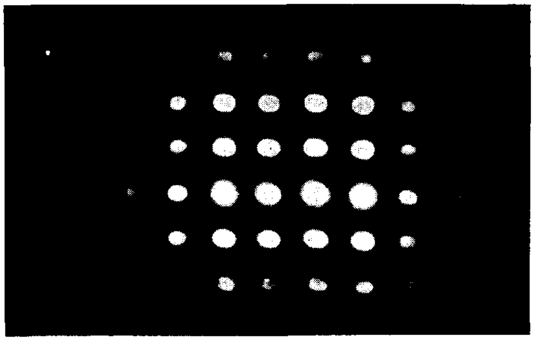

FIG. 3.

The setup makes it possible to display on the screen also the image of the ultrasonic structure itself, which is projected with an "Orion" lens (F = 20 mm) placed directly at the cell. Figures 4 and 5 show fragments of photographs of the ultrasonic field on the screen. When the oscillator frequency is increased from 12 to 20 MHz, the length of the ultrasonic waves in the water decreases from 0.12 to 0.07 mm: Figure 5 shows the corresponding decrease of the period of the ultrasonic structure as compared with Fig. 4. The decrease of the period of the structure causes a corresponding increase of the diffraction pattern shown in Fig. 3, in comparison with the pattern in Fig. 2. If the distance from the cell to the screen is 10 m, then the diameter of the diffraction pattern is 40 cm and 70 cm at 12 or 20 MHz, respectively. This is sufficient for a large auditorium.

It is also possible to show during the course of the demonstration how the two-dimensional ultrasonic struc-

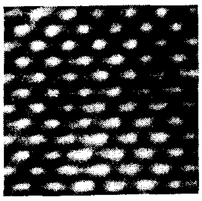

FIG. 4.

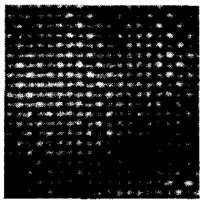

FIG. 5.

ture is produced. To this end, a shutter, in the form of a rubber sheet stretched on a wire frame, is placed in front of the quartz. By covering the upper or lower half of the quartz plate, we can eliminate in turn one of two systems of standing waves. This demonstrates the diffraction patterns from plane standing waves produced upon reflection from the horizontal plate of the reflector (Fig. 6) or from the vertical plate (in this case a similar picture is observed, but turned 90°).

Thus, this setup can also be easily used to demonstrate diffraction of light by a one-dimensional ultrasonic grating, using an ordinary white-light source[3]. In this case, a spectral decomposition of the white light will be observed. To demonstrate visually plane waves by this method, however, a gas laser must be used.

In addition to diffraction of light by periodic structures, one can demonstrate diffraction by a two-dimensional disordered interaction of ultrasonic waves. To this end, a second reflector is placed in front of the quartz. It is an accordion-folded strip of copper-foil but the widths and orientations of the folds are random. The laser beam is directed parallel to the folds and edges of the reflector through the region of intersection of the ultrasonic waves. The screen shows in this case a diffraction pattern in the form of dark and light concentric rings (Fig. 7). This proves that a random stationary distribution of the liquid-density oscillation amplitudes is produced in the case of disordered intersection of the ultrasound beams.

By varying the construction of the reflector, this setup can be used to demonstrate the diffraction of light by ultrasound structures having different symmetries[2].

The diagram of a push-pull oscillator using a high-frequency double tetrode (GU-29) is shown in Fig. 1b (its specifications are: $C_1 = 5 - 20$ pF, $C_2 = 70$ pF (equal to the capacitance of the quartz K), $C_3 = 60$ pF, $C_4 = 10{,}000$ pF, $C_5 = C_6 \approx 50$ pF, $R_1 = 7$ k, 10W, and $R_2 = 12$k, 25 W. The frequency is changed with a tumbler switch that adds the capacitor C_3 to make the generation frequency 12 kHz).

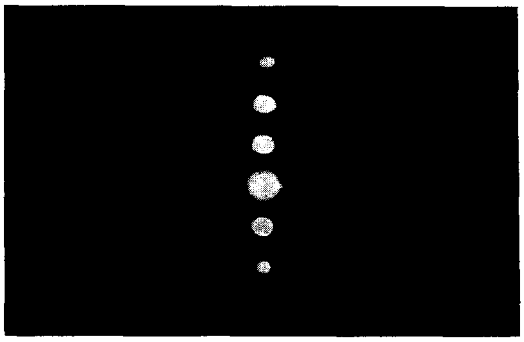

FIG. 6.

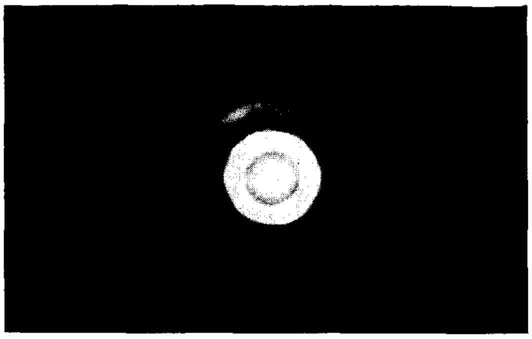

FIG. 7.

It should be noted that the reflectors described above can be used to demonstrate the diffraction of light from a two dimensional structure, by using the already existing installations with which to demonstrate the diffraction of light by plane ultrasonic waves[2,3]. It is desirable, however, to use a quartz crystal with a large radiating surface, and to increase the frequency and power of the oscillator to a maximum.

The authors thank V. S. Buklanov and M. S. Tikhomirov for taking part in the work.

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[3] Lektsionnye demonstratsii po fizike (Lecture Demonstrations in Physics), ed. by V. I. Ivernova, Nauka, 1965.

Translated by J. G. Adashko