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Experiment 4

Optical Diffraction Experiments

George C. Lisensky

Notes for Instructors

Purpose

To discover how a diffraction pattern is related to a repeating dot array; to use the diffraction pattern to measure the dimensions of the repeating dot array.

Method

A visible laser beam is directed through a 35-mm slide containing repeating arrays to give a diffraction pattern. *See* Chapter 4.

Materials

Point source of white light, such as a Mini Maglite with the lens removed

Visible laser, such as a solid-state laser pointer with a wavelength of 670 nm

White card (such as an index card)

Rulers

35-mm slides with repeating patterns, available from the Institute for Chemical Education. Alternatively, the patterns in Figure 4 can be drawn on a Macintosh computer with a paint program (HyperCard,

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MacPaint, SuperPaint, etc.), either by using the rectangle tool with a fill pattern, or by using zoom or fat bits to draw the pattern pixel by pixel. A 10.5 × 16.5-inch set of patterns is printed on 11 × 17-inch paper using a laser printer; this set of patterns is illuminated by two 300-W reflector floodlights, and photographed with a 1-second, f-8 exposure onto Kodak Precision Line LPD4 black-and-white, 35-mm slide film. The film is developed using Kodak D11 or D19 developer for 3 minutes, Kodak stop bath for 30 seconds, and Kodak rapid fixer for 5 minutes. The photographic procedure reduces the original 1/72-inch pixels on the paper to (30 mm) /(16.5 inch × 72 $inch^{-1}$) = 0.025-mm pixels on the slide. The smallest pattern (Figure 4F or 4b with alternating black and white pixels) has a repeat distance of approximately 0.05 mm.

Hand lens (the Radio Shack pocket microscope is convenient.)

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Optical Diffraction Experiments

Purpose

To discover how a diffraction pattern is related to a repeating dot array; to use the diffraction pattern to measure the dimensions of the repeating dot array.

Introduction

Diffraction of a wave by a periodic array is due to phase differences that result in constructive and destructive interference (illustrated in Figure 1). Diffraction can occur when waves pass through a periodic array if the repeat distance of the array is similar to the wavelength of the waves. Observation of diffraction patterns when beams of electrons, neutrons, or X-rays pass through crystalline solids thus serves as evidence both for the wave nature of those beams and for the periodic nature of the crystalline solids. However, X-rays are hazardous and they require special detectors.

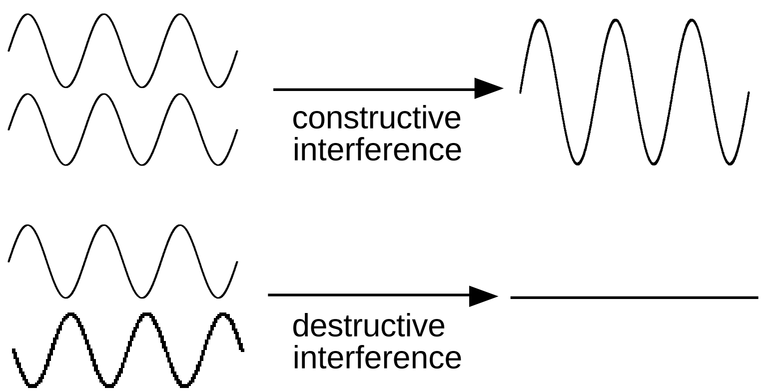

Figure 1. When waves line up (the oscillations are in phase), they add to give a bigger wave. When the peak of one wave is aligned with the trough of another, the waves annihilate each other.

Atoms, with spacings of about 10^{-10} m, require X-rays to create diffraction patterns. In this experiment, you make a change of scale. By using dots with spacings of about 10^{-4} m, visible light can be used instead of X-rays to create diffraction patterns. You will shine red laser light (670 nm wavelength) through a slide containing repeating arrays of dots, and observe Fraunhofer diffraction (see Figure 2).

NOTE: This experiment was written by George C. Lisensky, Department of Chemistry, Beloit College, Beloit, WI 53511.

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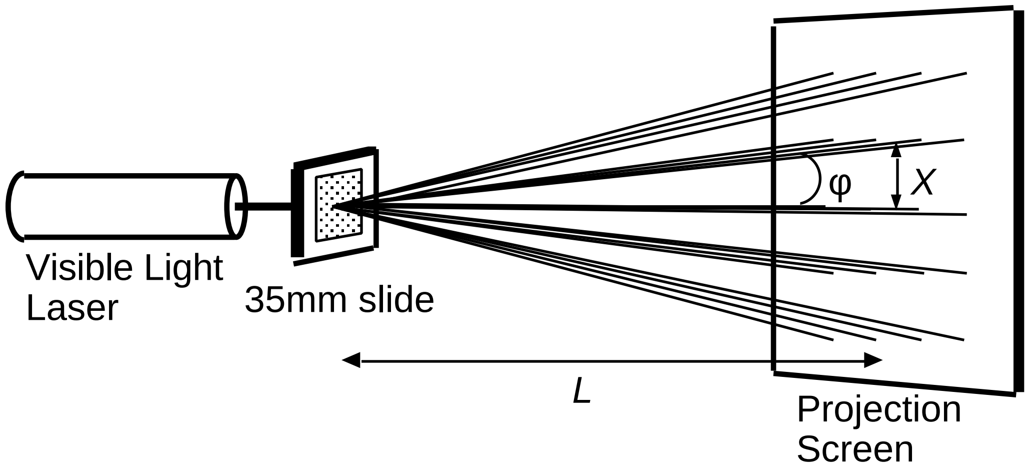

Figure 2. The Fraunhofer diffraction experiment.

Mathematically, the equations for Fraunhofer and Bragg diffraction (the basis of X-ray diffraction) are similar and embody the same functional dependence on the dot spacing (*d*), wavelength (λ), and scattering angle (φ or θ), (*see* Figure 3).

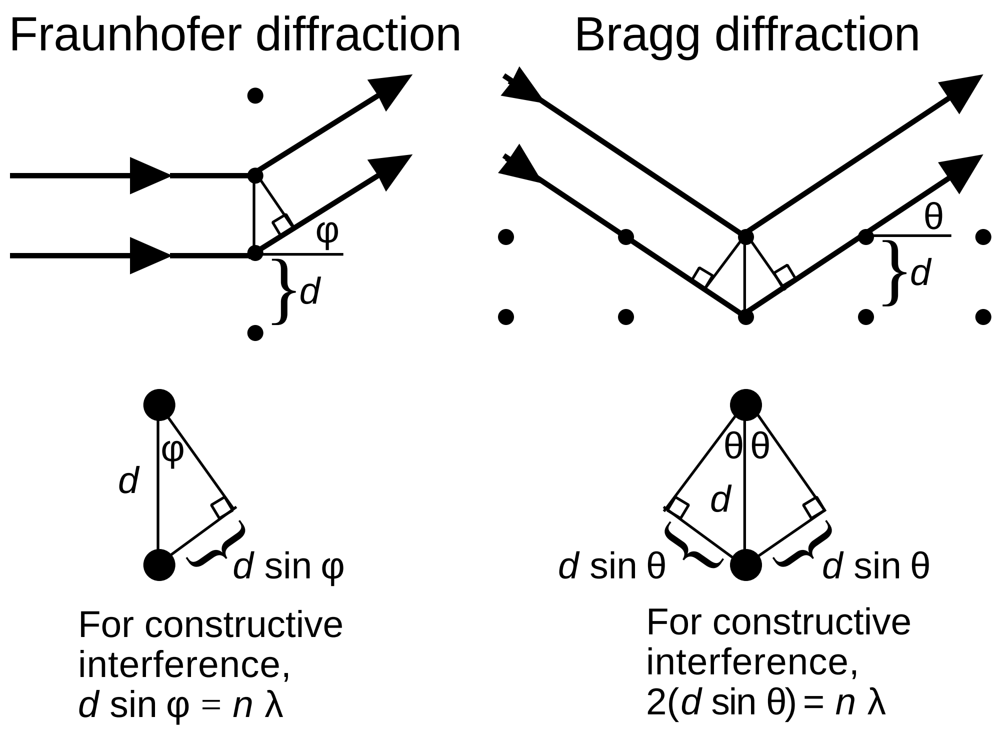

Figure 3. A comparison of Fraunhofer diffraction with Bragg diffraction. When waves are scattered by a periodic array, the path difference between any two waves must be a whole number of wavelengths, *n*, if the waves are to remain in phase and give constructive interference.

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In this experiment, you will first check how the size and orientation of the diffraction pattern is related to the periodic array that produced it, and then you will measure distances in diffraction pattern spacings in order to calculate the repeat distance for the array in the slide. By measuring the distances X and L, shown in Figure 2, and using the trigonometry definition that $\tan \varphi = X/L$, you can solve for φ. Use of the Fraunhofer equation, $d \sin \varphi = n\lambda$, then gives d when λ is known.

General Procedure

Obtain slides containing greatly reduced versions of arrays like those in Figure 4. Each photographic slide contains eight patches. Each patch has a different periodic array.

Look through a slide at a point source of white light. What do you see? Is the slide a diffraction grating? Why?

Shine a diode laser (670-nm wavelength) at a white piece of paper several meters away. Fasten the laser in place. **CAUTION: The laser is potentially dangerous. Do not look directly into a laser beam or shine a laser toward other people, as damage to the eye can occur.** Look through a slide at the laser dot on the paper. What do you see? Why?

Put the slide in the laser beam and watch the paper. What happens? Light travels from the laser to the paper and then to your eye. Are the same results obtained if the beam goes through the slide before it hits the paper as after it hits the paper?

Pretend that you want to sketch the shape of the diffraction pattern from an array. What light source should you use (the white bulb or the laser)? Should you shine the beam through the slide or look at the spot through the slide? Pretend that you want to measure the spacing between the spots. What method is easiest?

Use a hand lens to examine the arrays on the slide. For ease of interpretation, you may prefer to keep a consistent orientation for the slide.

Questions

Answer the following questions, devising and conducting experiments to obtain data where appropriate. "Data" for this experiment will sometimes consist of a sketch of an array and a sketch of the resulting diffraction pattern, and may include measurements of distances.

1. What is the diffraction pattern of a horizontal array of lines? Of a vertical array of lines?
2. What is the diffraction pattern of a square array of dots? Of a rectangular array of dots? Of a parallelogram array of dots where the angle is not 90°? Of a hexagonal array of dots? How do the orientations of the diffraction patterns relate to the orientation of the array of dots?

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3. Find two similar arrays that differ only in size. Does an array with a smaller repeat distance give a diffraction pattern with a smaller repeat distance? Does an array with a larger repeat distance give a diffraction pattern with a larger repeat distance?

4. Choose two arrays, carefully measure some distances in the diffraction pattern, and calculate the size of the unit cell for that array. What is the size in millimeters of the spacing between dots in the array on the slides?

5. What happens if you put an additional dot in the array in the center of the unit cell? Does it matter if the dot placed in the center is the same size as those in the original array?

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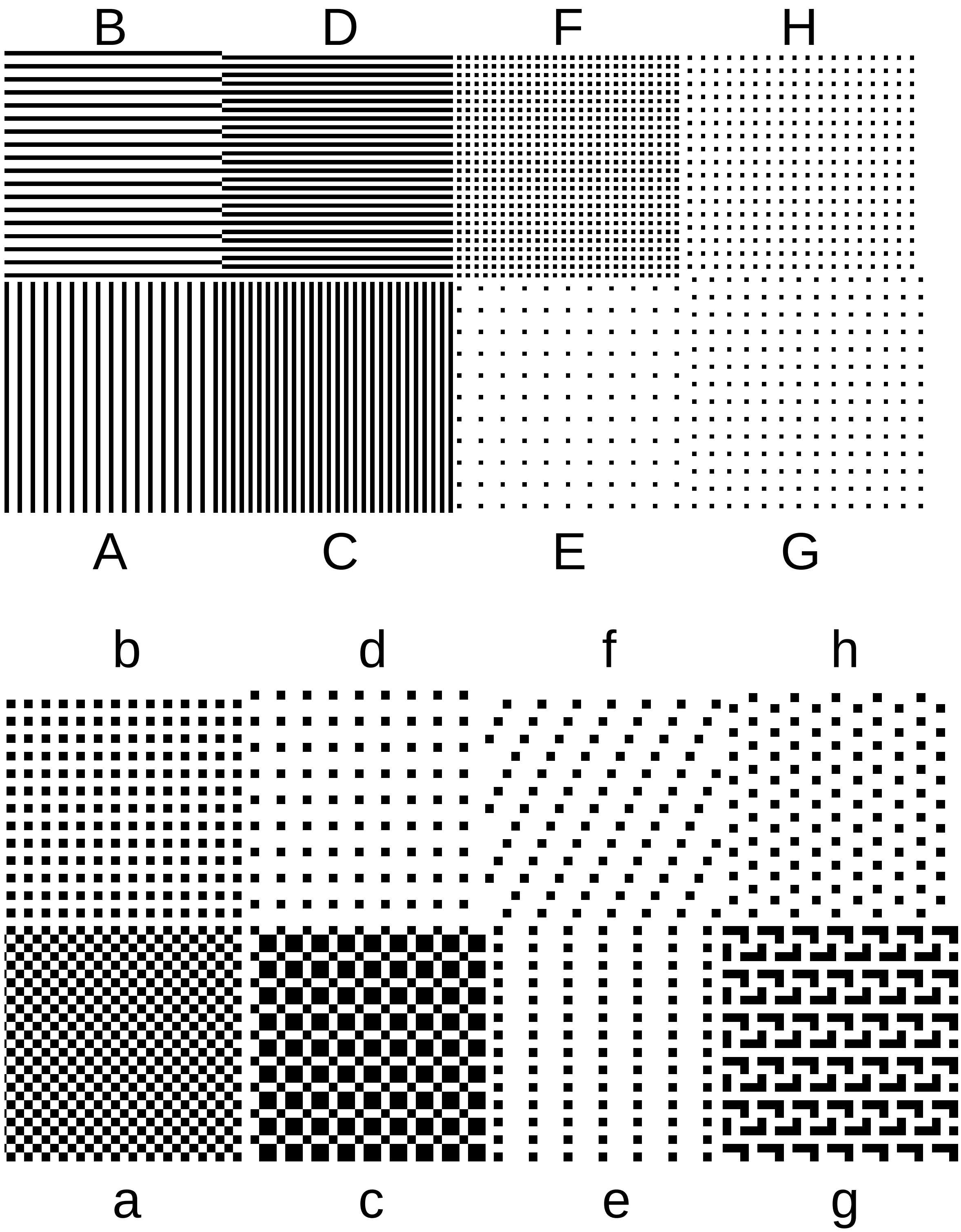

Figure 4. Arrays of dots that can be used to generate diffraction patterns with a laser. The actual patterns on the slide are much smaller.

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