INVESTIGATION 1
Notes to the Instructor

PURPOSE

To allow students the opportunity to investigate further the use of diffraction patterns to elucidate the arrangement of atoms in materials. It is also intended that the "reciprocal lattice effect" will be discovered.

METHOD

This investigation assumes that students have completed the activity in the guide that accompanies the "Exploring the Nanoworld" kit and are therefore accustomed to using an optical transform slide and seeing the diffraction patterns made by them.
This investigation will elaborate on that activity by using the Discovery slide available from ICE (See supplier information in the Appendix), which includes 8 different arrays of lines and dots. Some development and explanation of Fraunhofer's equation, either qualitatively or quantitatively, will be necessary. **Note: Throughout this unit we will use "dots" and "arrays" to refer to features on the optical transform slides; and "spots" and "patterns" to refer to diffraction features.**

MATERIALS

Discovery slide and stereoscope or microscope

Materials needed to construct LED circuits*

Rohm super-bright red LEDs, Mouser **592-SLH56-VT3** (See supplier info.)

Molded black battery snaps, Mouser **1236005**

1000 ohm Transohm Carbon Film resistors, Mouser **29SJ250**

*With some precautionary instructions, students could probably assemble their own LED circuits.

Overhead transparencies of the two pages that follow the Answers to the Follow-Up Questions
Give page numbers for these.

PROCEDURE

a. Orient the slide provided by the instructor so that the ICE logo is on the right-hand side. Using a stereoscope or microscope, look carefully at the arrays on the slide and make a sketch in the space provided in Table 1 of the Data Sheet.

b. Connect the battery snap to the red LED and place it at least a meter away from you. View the LED through the different regions of the slide and sketch the diffraction patterns that you see in the appropriate spaces in Table 2.

ANSWERS TO FOLLOW-UP QUESTIONS

1. Consider your sketches of arrays *a* and *c*. How are they similar? How are they different?

   The arrays on the following page clearly show that *a* and *c* both consist of an array of horizontal lines, but the spacing of the lines in *c* is smaller.

2. Discuss how the difference between arrays *a* and *c* affect the diffraction patterns that are produced.

   First, note that each array yields a diffraction pattern that consists of a vertical column of spots. The number and intensity of the spots will depend upon the intensity of the LED and the darkness of the room, but the diffraction spots in pattern *c* are more widely separated than those in pattern *a.* Secondly, if a question arises as to why a horizontal array produces a vertical diffraction pattern, the following may help. In a horizontal array of lines, the distance between them represents the repeat distance, *d*. If the incident light is monochromatic, or reasonably so, constructive interference will occur when the product of the sine of the diffraction angle θ times *d* corresponds to a multiple (*n*) of the wavelength, according to the Fraunhofer equation developed in the Introduction. Because there is a finite repeat distance in the vertical direction, there will be constructive as well as destructive interference in this direction and therefore, a series of bright spots and dark spaces will be produced. In the horizontal direction the repeat distance is infinite. This, in turn, requires that θ be zero. The same arguments may be made for vertical arrays and the resulting horizontal row of diffraction spots that emerge. As the spacing of the array decreases, the distance between spots in the diffraction pattern increases. This result may be explained by looking at the Fraunhofer equation and noting that as the repeat distance, *d*, decreases, θ increases, and the regions where constructive interference occurs are further separated.

3. Consider your sketches of arrays *b* and *d*. How are they similar? How are they different? How do they both differ from the arrays *a* and *c*?

   The similarities are that they both consist of vertical lines. The arrays differ in that the spacing of the lines in array *d* is smaller. They both differ from *a* and *c* in that the arrays comprise vertical, not horizontal lines.

4. Discuss how the differences between arrays *a* and *c*, and between *b* and *d*, affect the shape of the diffraction patterns that are produced.

   The student response should note the obvious difference of the diffraction patterns for *a* and *c* being vertical columns of spots and those of *b* and *d* being horizontal rows of spots. See the explanation in question 2 above.

5. Discuss how the difference between arrays *b* and *d* affects the diffraction patterns that are produced.

   As the spacing of the arrays decreases, the distance between spots in the diffraction pattern increases. See the explanation in question 2.

6. Consider the remainder of your sketches in the order *e*, *g*, *h*, and *f*. What change in the arrays for this sequence do you note?

   As you progress through the sequence, the square array of dots becomes smaller. This, of course, is analogous to the arrays of parallel lines considered earlier, and these arrays could be viewed as a series of lines in which segments have been removed, creating an array of dots instead of lines.

7. Discuss how the sequential changes in the arrays *e*, *g*, *h*, and *f* affect the diffraction patterns that are produced.

   The diffraction patterns produced by the square arrays of dots are also squares. As the square formed by the array of dots becomes smaller, the squares formed by the diffraction spots become larger.

   Note: The extrapolation from horizontal and vertical lines to a square array of dots may be demonstrated by overlapping arrays c and d using two of the Discovery slides and shining a laser or laser pointer through them. A square diffraction pattern is observed.

8. If we were to call the arrays "lattices", what is the meaning of the phrase "reciprocal lattice effect" with respect to the diffraction patterns produced by them?

   The "reciprocal lattice effect" refers to the observations stated several times above: the spacing of spots in the diffraction pattern varies inversely with feature spacing in the array that produced it. A corollary that was not investigated but which is evident from the Fraunhofer equation is that the size of the diffraction pattern produced is also dependent upon the wavelength of the light used to produce it. This would be a good extension that could be conducted by looking at LEDs of different colors or a point source of white light like a mini-Maglite flashlight.

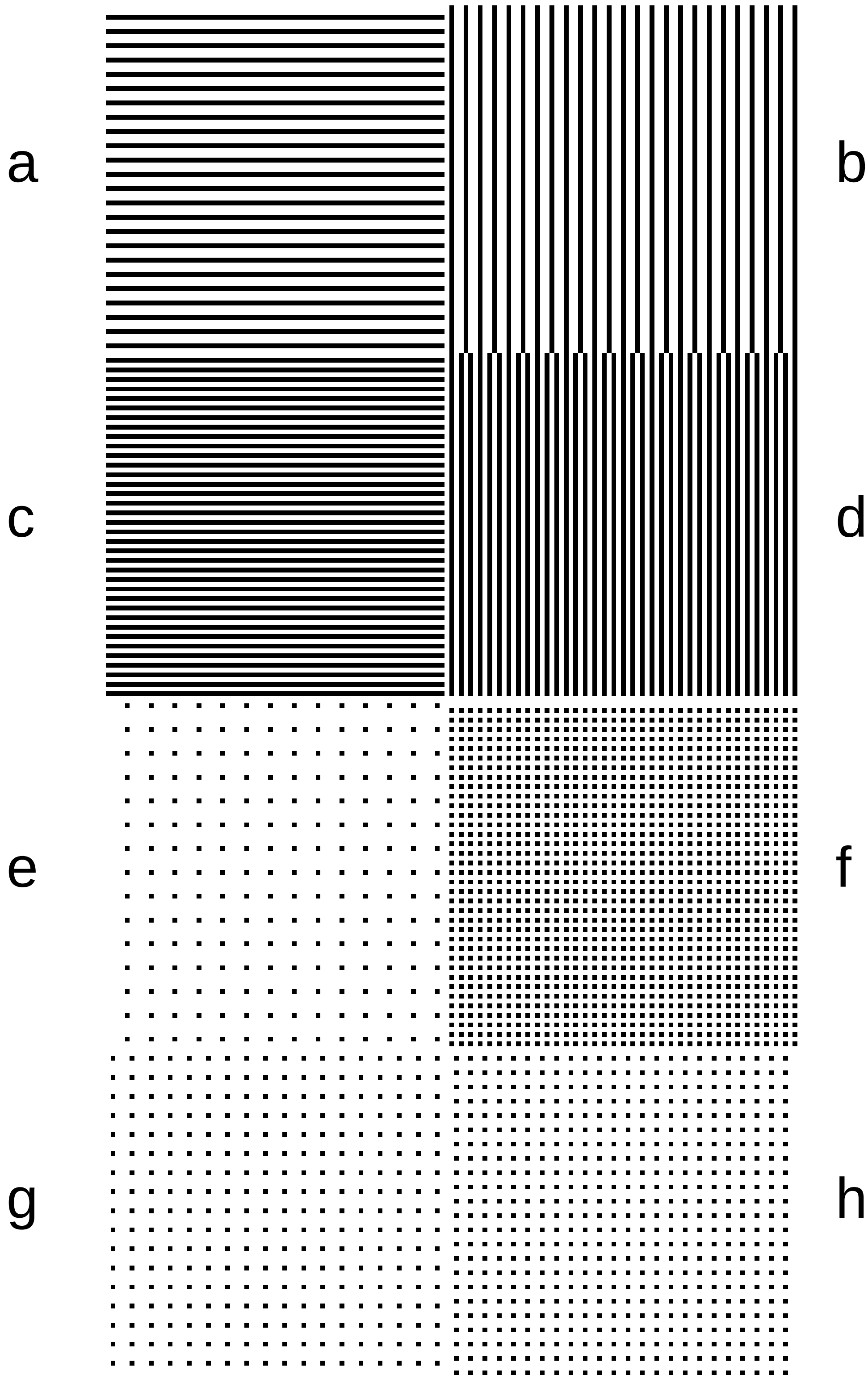

Figure 1. The arrays on the optical transform Discovery slide (Figure 4.4 from A Materials Science Companion), available from ICE, oriented so that the ICE logo is on the right side as you look through the slide.

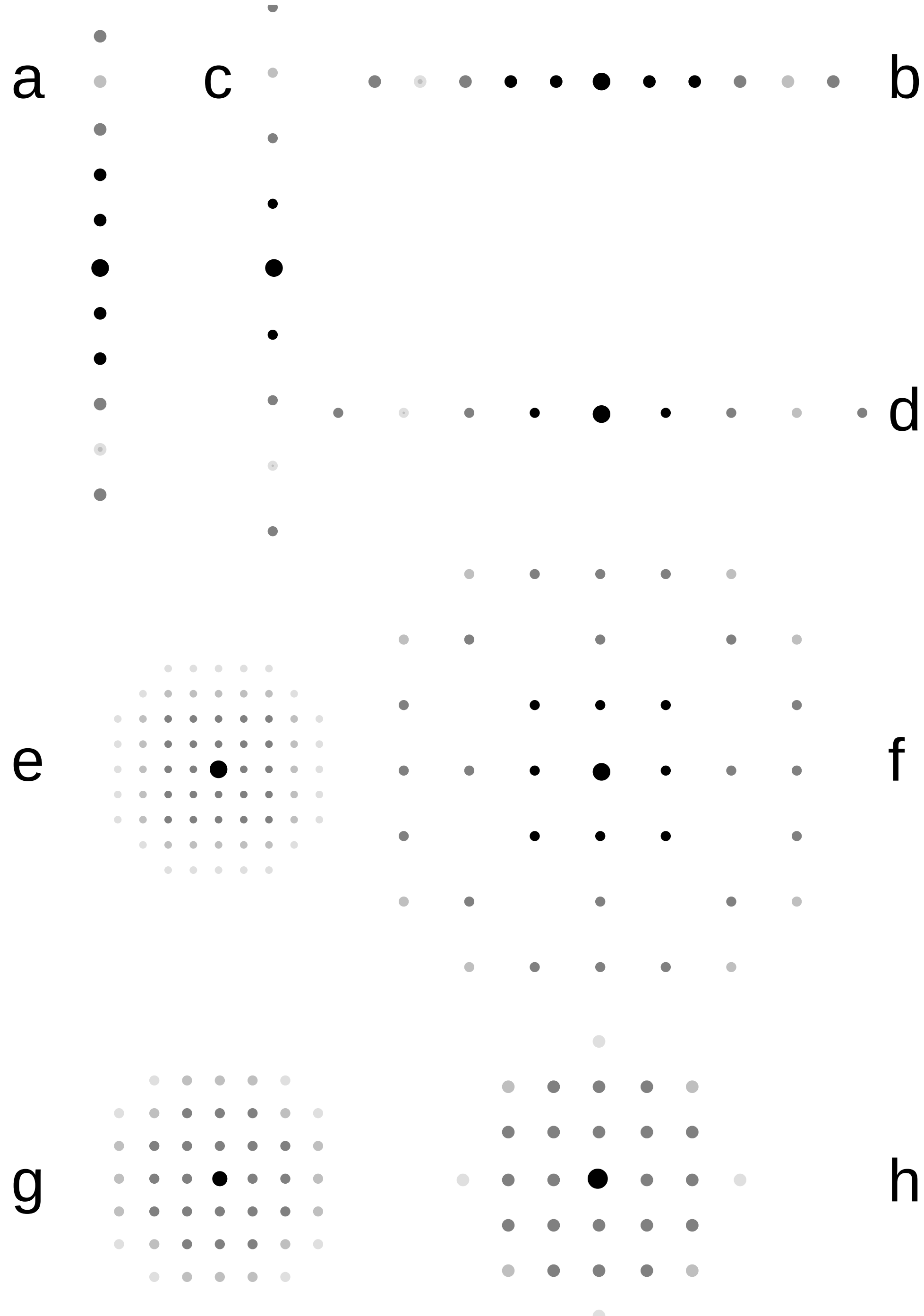

Figure 2. A simulation of the diffraction patterns obtained from the Discovery slide, with the indicated letter corresponding to the array (Figure 4.5 from A Materials Science Companion) from which the diffraction pattern is produced. (The number and intensity of spots observed will vary with the intensity of light used and the darkness of the room in which the patterns are observed.)