

X-Ray Diffraction and Scanning Probe Microscopy (SPM)

Overview

This module is designed to introduce students to two major tools that are used to determine the structure of matter and to reinforce concepts associated with electromagnetic radiation. Historically, X-ray and related diffraction methods have provided a great deal of information about crystalline materials ranging from gold to table salt to DNA, in which the atoms or molecules are arranged in a repeating pattern. Because the wavelength of X-rays and the spacing between atoms in a crystal are comparable, the phenomenon of diffraction occurs. From the pattern of diffraction spots, scientists work backward to identify what atoms are present in the crystal and how they are arranged relative to one another. This experiment is expensive and dangerous to demonstrate in a classroom, as X-rays are a highly energetic form of electromagnetic radiation.

To circumvent this problem, the experiment is scaled up in this module. Instead of using X-rays having wavelengths on the order of an angstrom, visible light with wavelengths of thousands of angstroms is employed. Similarly, instead of atoms spaced by angstroms, arrays of dots or lines on a 35-mm slide are spaced by many thousands of angstroms. Making these two modifications again leads to diffraction, as the wavelength and feature spacing are sufficiently close in scale to create observable effects. Thus, when these slides are used to view point sources of light like LEDs or flashlight bulbs, diffraction patterns (optical transforms) that mimic those that would be produced by shining X-rays on crystals can be observed. (It is also possible to shine pocket laser beams through these slides to create the same effect.) The trigonometric equations underlying both X-ray diffraction and the optical transforms (Fraunhofer diffraction) and their algebraic simplification (optical transforms) can be presented at the teacher's discretion.

Students have an opportunity to see how diffraction patterns are affected by the nature of the corresponding arrays and, in particular, to discover the “reciprocal lattice effect,” in which small spacings on the array become large diffraction spacings and vice versa. The experiment also provides an opportunity to explore the electromagnetic spectrum and spectral composition of various lighting sources, as different colors of light affect the size of the diffraction pattern.

A recent breakthrough has been the use of scanning probe microscopes to image individual atoms on the surfaces of solid materials. Students have an opportunity to “image” the magnetic fields of refrigerator magnets with a probe tip cut from the magnet; and to “image” an electrically conducting surface using the probe of a simple multi-meter. These experiments mimic scanning methods that use probe tips of atomic sharpness that are moved across a surface in atomic-scale increments. The variations in forces between tip and surface provide atomic-level topographic information. The cover of the “Exploring the Nanoworld” kit is an image of pairs of silicon atoms, obtained using a scanning tunneling microscope, representing one instrument of scanning probe microscopy.