Quantum Mechanics

SECTION 3

SECTION OBJECTIVES

- **Recognize the dual nature of light and matter.**
- **Calculate the de Broglie wavelength of matter waves.**
- **Distinguish between classical ideas of measurement and Heisenberg's uncertainty principle.**
- **Describe the quantum-mechanical picture of the atom, including the electron cloud and probability waves.**

THE DUAL NATURE OF LIGHT

As discussed in Section 1, there is considerable evidence for the photon theory of light. In this theory, all electromagnetic waves consist of photons, particle-like pulses that have energy and momentum. On the other hand, light and other electromagnetic waves exhibit interference and diffraction effects that are considered to be wave behaviors. So, which model is correct? We will see that each is correct and that a specific phenomenon often exhibits only one or the other of these natures of light.

Light is both a wave and a particle

Some experiments can be better explained or only explained by the photon concept, whereas others require a wave model. Most physicists accept both models and believe that the true nature of light is not describable in terms of a single classical picture.

For an example of how photons can be compatible with electromagnetic waves, consider radio waves at a frequency of 2.5 MHz. The energy of a photon having this frequency can be found using Planck's equation, as follows:

$$E = hf = (6.63 \times 10^{-34}\ \mathrm{J{\bullet}s})(2.5 \times 10^{6}\ \mathrm{Hz}) = 1.7 \times 10^{-27}\ \mathrm{J}$$

From a practical viewpoint, this energy is too small to be detected as a single photon. A sensitive radio receiver might need as many as 10^{10} of these photons to produce a detectable signal. With such a large number of photons reaching the detector every second, we would not be able to detect the individual photons striking the antenna. Thus, the signal would appear as a continuous wave.

Now consider what happens as we go to higher frequencies and hence shorter wavelengths. In the visible region, it is possible to observe both the photon and the wave characteristics of light. As we mentioned earlier, a light beam can show interference phenomena and produce photoelectrons. The interference phenomena are best explained by the wave model of light, while the photoelectrons are best explained by the particle theory of light.

At even higher frequencies and correspondingly shorter wavelengths, the momentum and energy of the photons increase. Consequently, the photon nature of light becomes very evident. In addition, as the wavelength decreases, wave effects, such as interference and diffraction, become more difficult to observe. Very indirect methods are required to detect the wave nature of very high frequency radiation, such as gamma rays.