Frequency and wavelength are mathematically related to each other. For electromagnetic radiation, this relationship is written as follows.

$$c = \lambda\nu$$

In the equation, $c$ is the speed of light (in m/s), $\lambda$ is the wavelength of the electromagnetic wave (in m), and $\nu$ is the frequency of the electromagnetic wave (in $s^{-1}$). Because $c$ is the same for all electromagnetic radiation, the product $\lambda\nu$ is a constant. Consequently, we know that $\lambda$ is inversely proportional to $\nu$. In other words, as the wavelength of light decreases, its frequency increases, and vice versa.

## The Photoelectric Effect

In the early 1900s, scientists conducted two experiments involving interactions of light and matter that could not be explained by the wave theory of light. One experiment involved a phenomenon known as the photoelectric effect. *The* **photoelectric effect** *refers to the emission of electrons from a metal when light shines on the metal,* as illustrated in **Figure 3.**

The mystery of the photoelectric effect involved the frequency of the light striking the metal. For a given metal, no electrons were emitted if the light's frequency was below a certain minimum—regardless of the light's intensity. Light was known to be a form of energy, capable of knocking loose an electron from a metal. But the wave theory of light predicted that light of any frequency could supply enough energy to eject an electron. Scientists couldn't explain why the light had to be of a minimum frequency in order for the photoelectric effect to occur.

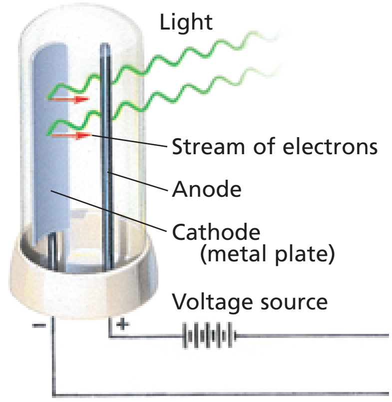


**FIGURE 3** The photoelectric effect: electromagnetic radiation strikes the surface of the metal, ejecting electrons from the metal and causing an electric current.

### The Particle Description of Light

The explanation of the photoelectric effect dates back to 1900, when German physicist Max Planck was studying the emission of light by hot objects. He proposed that a hot object does not emit electromagnetic energy continuously, as would be expected if the energy emitted were in the form of waves. Instead, Planck suggested that the object emits energy in small, specific packets called quanta. *A* **quantum** *of energy is the minimum quantity of energy that can be lost or gained by an atom.* Planck proposed the following relationship between a quantum of energy and the frequency of radiation.

$$E = h\nu$$

In the equation, $E$ is the energy, in joules, of a quantum of radiation, $\nu$ is the frequency, in $s^{-1}$, of the radiation emitted, and $h$ is a fundamental physical constant now known as Planck's constant; $h = 6.626 \times 10^{-34}$ J•s.

In 1905, Albert Einstein expanded on Planck's theory by introducing the radical idea that electromagnetic radiation has a dual wave-particle nature. While light exhibits many wavelike properties, it can also be