thought of as a stream of particles. Each particle of light carries a quantum of energy. Einstein called these particles photons. *A* **photon** *is a particle of electromagnetic radiation having zero mass and carrying a quantum of energy.* The energy of a particular photon depends on the frequency of the radiation.

$$E_{photon} = h\nu$$

Einstein explained the photoelectric effect by proposing that electromagnetic radiation is absorbed by matter only in whole numbers of photons. In order for an electron to be ejected from a metal surface, the electron must be struck by a single photon possessing at least the minimum energy required to knock the electron loose. According to the equation $E_{photon} = h\nu$, this minimum energy corresponds to a minimum frequency. If a photon's frequency is below the minimum, then the electron remains bound to the metal surface. Electrons in different metals are bound more or less tightly, so different metals require different minimum frequencies to exhibit the photoelectric effect.

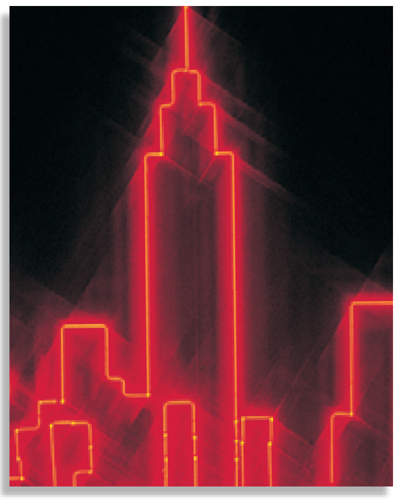

FIGURE 4 Excited neon atoms emit light when electrons in higher energy levels fall back to the ground state or to a lower-energy excited state.

The Hydrogen-Atom Line-Emission Spectrum

When current is passed through a gas at low pressure, the potential energy of some of the gas atoms increases. *The lowest energy state of an atom is its* **ground state.** *A state in which an atom has a higher potential energy than it has in its ground state is an* **excited state.** When an excited atom returns to its ground state, it gives off the energy it gained in the form of electromagnetic radiation. The production of colored light in neon signs, as shown in **Figure 4,** is a familiar example of this process.

When investigators passed electric current through a vacuum tube containing hydrogen gas at low pressure, they observed the emission of a characteristic pinkish glow. *When a narrow beam of the emitted light was shined through a prism, it was separated into four specific colors of the visible spectrum.* The four bands of light were part of what is known as hydrogen's **line-emission spectrum.** The production of hydrogen's line-emission spectrum is illustrated in **Figure 5.** Additional series of lines were discovered in the ultraviolet and infrared regions of hydrogen's line-emission spectrum. The wavelengths of some of the spectral series are shown in **Figure 6.** They are known as the Lyman, Balmer, and Paschen series, after their discoverers.

Classical theory predicted that the hydrogen atoms would be excited by whatever amount of energy was added to them. Scientists had thus expected to observe *the emission of a continuous range of frequencies of electromagnetic radiation,* that is, a **continuous spectrum.** Why had the hydrogen atoms given off only specific frequencies of light? Attempts to explain this observation led to an entirely new atomic theory called *quantum theory.*