considered to be discrete. After the calculations are made, the discrete units are taken to be infinitesimally small. Planck found that the calculations worked if he omitted this step and considered energy to come in discrete units throughout his calculations. With this method, Planck found that the total energy (E_n) of a resonator with frequency f is an integral multiple of hf, as follows:

$$E_n = nhf$$

In this equation, n is a positive integer called a *quantum number,* and the factor h is Planck's constant, which equals $6.626\,068\,96 \times 10^{-34}$ J•s. To simplify calculations, we will use the approximate value of $h = 6.63 \times 10^{-34}$ J•s in this textbook. Because the energy of each resonator comes in discrete units, it is said to be *quantized,* and the allowed energy states are called *quantum states* or *energy levels.* With the assumption that energy is quantized, Planck was able to derive the red curve shown in **Figure 3(b)** on the previous page.

According to Planck's theory, the resonators absorb or give off energy in discrete multiples of hf. Einstein later applied the concept of quantized energy to light. The units of light energy called *quanta* (now called *photons*) are absorbed or given off as a result of electrons "jumping" from one quantum state to another. As seen by the equation above, if the quantum number (n) changes by one unit, the amount of energy radiated changes by hf. For this reason, the energy of a light quantum, which corresponds to the energy difference between two adjacent levels, is given by the following equation:

ENERGY OF A LIGHT QUANTUM

$$E = hf$$

energy of a quantum ($n = 1$) = Planck's constant × frequency

A resonator will radiate or absorb energy only when it changes quantum states. The idea that energy comes in discrete units marked the birth of a new theory known as *quantum mechanics.*

If Planck's constant is expressed in units of J•s, the equation $E = hf$ gives the energy in joules. However, when dealing with the parts of atoms, energy is often expressed in units of the electron volt, eV. An *electron volt* is defined as the energy that an electron or proton gains when it is accelerated through a potential difference of 1 V. Because 1 V = 1 J/C, the relation between the electron volt and the joule is as follows:

$$1 \text{ eV} = 1.60 \times 10^{-19} \text{ C•V} = 1.60 \times 10^{-19} \text{ C•J/C} = 1.60 \times 10^{-19} \text{ J}$$

Planck's idea that energy is quantized was so radical that most scientists, including Planck himself, did not consider the quantization of energy to be realistic. Planck thought of his assumption as a mathematical approach to be used in calculations rather than a physical explanation. Therefore, he and other scientists continued to search for a different explanation of blackbody radiation that was consistent with classical physics.

Did you know?

Max Planck became president of the Kaiser Wilhelm Institute of Berlin in 1930. Although Planck remained in Germany during the Hitler regime, he openly protested the Nazis' treatment of his Jewish colleagues and consequently was forced to resign his presidency in 1937. Following World War II, he was reinstated as president, and the institute was renamed the Max Planck Institute in his honor.