

## Atomic Energy-Level Diagrams

Today's view of the atom owes much to the Bohr model, but it is different in certain ways. The modern picture is based on *quantum mechanics*, a branch of physics dealing with photons and subatomic particles that was developed during the 1920s. As a result of this work, physicists no longer picture electrons as moving in specific orbits about the nucleus. Instead, electrons are now said to occupy certain *energy levels* in the atom.

An extremely useful way of displaying the structure of an atom is with an *energy-level diagram*, such as that shown for hydrogen in Figure *a*. The lowest energy level, called the *ground state*, corresponds to the  $n = 1$  Bohr orbit. Higher energy levels, called *excited states*, correspond to successively larger Bohr orbits.

An electron can jump from the ground state up to the  $n = 2$  level only if the atom absorbs a Lyman-alpha photon with a wavelength of 122 nm. The energy of a photon is determined by the relationship  $E = h\nu = hc/\lambda$  and is commonly expressed in electron volts (eV). As explained in Section 5-5 of *Universe*, an electron volt is a tiny amount of energy ( $1 \text{ eV} = 1.602 \times 10^{-19} \text{ J}$ ). The Lyman-alpha photon has an energy of 10.19 eV, so the energy level of  $n = 2$  is shown in the figure as having an energy 10.19 eV above the energy of the ground state (which is conventionally assigned a value of 0 eV). Similarly, the  $n = 3$  level is 12.07 eV above the ground state, and so forth. Electrons can make transitions to a higher energy level by absorption of a photon

or in a collision between atoms; they can make transitions to lower energy levels by emission of a photon.

On the energy-level diagram for hydrogen, the  $n = \infty$  level has an energy of 13.6 eV. If the electron is initially in the ground state and the atom absorbs a photon of any energy greater than 13.6 eV, the electron will be removed completely from the atom and the atom will be *ionized*. The gaseous nebula NGC 2363 shown in Figure 5-16 on page 105 of *Universe* has hot stars in its neighborhood that produce copious amounts of ultraviolet photons with energies greater than 13.6 eV. These photons cause some of the hydrogen atoms in the nebula to become ionized. When the electrons recombine with the nuclei, they cascade down the energy levels to the ground state and emit visible light in the process.

The atoms of heavier elements have more complex energy-level diagrams. Figure *b* shows the energy-level diagram for sodium, along with the wavelengths of photons absorbed or emitted in some of sodium's major electron transitions. At visible wavelengths, the sodium spectrum is dominated by two strong lines, called the sodium D lines, at 588.99 and 589.59 nm. These two lines are strong because they correspond to two transitions that are the primary avenue through which electrons cascade from high orbits down to the ground state. Astronomers find energy-level diagrams useful in understanding the lines they observe in the spectra of stars and nebulae.

