EXAMPLE 33–7 **Given z, what is v?** What is the speed of a galaxy whose redshift parameter is measured to be $z = 5$?

APPROACH We make an approximation by using the Doppler formula, Eq. 33–5a (see footnote ‡ on previous page), and solve for v.

SOLUTION We add 1 to both sides of Eq. 33–5a:

$$z + 1 = \sqrt{\frac{1 + v/c}{1 - v/c}}.$$

We set $z = 5$ and square both sides of this equation, and then solve for v:

$$6^2 = \frac{1 + v/c}{1 - v/c}$$

$$36\left(1 - \frac{v}{c}\right) = 1 + \frac{v}{c}.$$

We collect terms in v/c on one side:

$$35 = 37\frac{v}{c},$$

so

$$v = \frac{35}{37}c = 0.95c.$$

NOTE This speed represents how fast the universe (and space itself) is expanding at the position of this galaxy as viewed from Earth.

EXERCISE C If $v = 0.70c$, what is z?

In the spectra of stars in other galaxies, lines are observed that correspond to lines in the known spectra of particular atoms (see Section 27–11). What Hubble found was that the lines seen in the spectra from distant galaxies were generally *redshifted*, and that the amount of shift seemed to be approximately proportional to the distance of the galaxy from us. That is, the velocity, v, of a galaxy moving away from us is proportional to its distance, d, from us:

$$v = Hd. \quad \textbf{(33–6)}$$

HUBBLE'S LAW

This is **Hubble's law**, one of the most fundamental astronomical ideas. The constant H is called the **Hubble parameter**. Hubble's law does not work well for nearby galaxies—in fact nearby galaxies can even be "blueshifted" (moving toward us) which merely represents random local motion. For more distant galaxies, the velocity of recession (Hubble's law) is much greater than that of random motion, and so is dominant. We then say it is a **cosmological redshift**, and we have come to view it as due to the expansion of space itself. Indeed, we can think of the originally emitted wavelength λ_0 as being stretched out (becoming longer) along with the expanding space around it.

The value of H until recently was uncertain by over 20%, and thought to be between 50 and 80 km/s/Mpc. But recent (2003) measurements now put its value more precisely at

$$H = 71\ \text{km/s/Mpc}$$

Hubble parameter

(that is, 71 km/s per megaparsec of distance). The uncertainty is about 5%, or ± 4 km/s/Mpc. If we use light-years for distance, then $H = 22$ km/s per million light-years of distance:

$$H \approx 22\ \text{km/s/Mly}$$

with an estimated uncertainty of ± 1 km/s/Mly.