EXERCISE D What speed would a 1-gram paper clip have if it had the same KE as a molecule of Example 13–17?

Equation 13–8, $\overline{\text{KE}} = \frac{3}{2}kT$, implies that as the temperature approaches absolute zero, the kinetic energy of molecules approaches zero. Modern quantum theory, however, tells us this is not quite so. Instead, as absolute zero is approached, the kinetic energy approaches a very small nonzero minimum value. Even though all real gases become liquid or solid near 0 K, molecular motion does not cease, even at absolute zero.

* 13–11 Distribution of Molecular Speeds

The molecules in a gas are assumed to be in random motion, which means that many molecules have speeds less than the rms speed and others have greater speeds. In 1859, James Clerk Maxwell (1831–1879) derived, on the basis of kinetic theory, that the speeds of molecules in a gas are distributed according to the graph shown in Fig. 13–17. This is known as the **Maxwell distribution of speeds.**[†] The speeds vary from zero to many times the rms speed, but as the graph shows, most molecules have speeds that are not far from the average. Less than 1% of the molecules exceed four times v_{rms}.

Maxwell distribution of speeds of molecules in a gas

Experiments to determine the distribution in real gases, starting in the 1920s, confirmed with considerable accuracy the Maxwell distribution and the direct proportion between average kinetic energy and absolute temperature, Eq. 13–8.

Figure 13–18 shows the Maxwell distribution for two different temperatures; just as v_{rms} increases with temperature, so the whole distribution curve shifts to the right at higher temperatures. This Figure illustrates how kinetic theory can explain why many chemical reactions, including those in biological cells, take place more rapidly as the temperature increases. Two molecules may chemically react only if their kinetic energy is above some minimum value (called the *activation energy*), E_{A}, so that when they collide, they penetrate into each other somewhat. Figure 13–18 shows that at a higher temperature, many more molecules have a speed and kinetic energy KE above the needed threshold E_{A}.

PHYSICS APPLIED

How chemical reactions depend on temperature

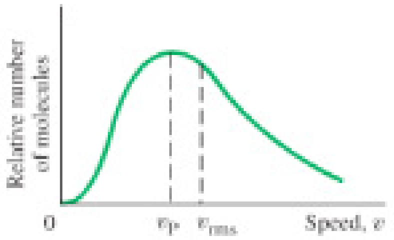

FIGURE 13–17 Distribution of speeds of molecules in an ideal gas. Note that v_{rms} is not at the peak of the curve (that speed is called the "most probable speed," v_{P}). This is because the curve is skewed to the right: it is not symmetrical.

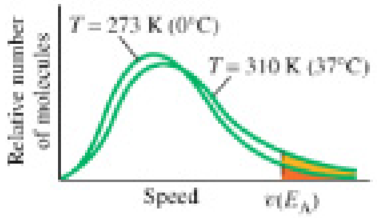

FIGURE 13–18 Distribution of molecular speeds for two different temperatures.

* 13–12 Real Gases and Changes of Phase

The ideal gas law is an accurate description of the behavior of a real gas as long as the pressure is not too high and as long as the temperature is far from the liquefaction point. But what happens when these two criteria are not satisfied? First we discuss real gas behavior and then we examine how kinetic theory can help us understand this behavior.

[†] Mathematically, the distribution is given by $\Delta N = Cv^2 \exp\left(-\frac{1}{2}mv^2/kT\right)\Delta v$, where ΔN is the number of molecules with speed between v and $v + \Delta v$, C is a constant, and exp means the expression in parentheses is an exponent on the natural number $e = 2.718\ldots$.