A number of methods have been devised to measure N_A, and the accepted value today is

$$N_A = 6.02 \times 10^{23}. \qquad \text{[molecules/mole]}$$

Avogadro's number

Since the total number of molecules, N, in a gas is equal to the number per mole times the number of moles ($N = nN_A$), the ideal gas law, Eq. 13–3, can be written in terms of the number of molecules present:

$$PV = nRT = \frac{N}{N_A}RT,$$

or

$$PV = NkT, \qquad \textbf{(13–4)}$$

IDEAL GAS LAW (in terms of molecules)

where $k = R/N_A$ is called **Boltzmann's constant** and has the value

$$k = \frac{R}{N_A} = \frac{8.314\ \text{J/mol}\cdot\text{K}}{6.02 \times 10^{23}/\text{mol}} = 1.38 \times 10^{-23}\ \text{J/K}.$$

Boltzmann's constant

EXAMPLE 13–14 **Hydrogen atom mass.** Use Avogadro's number to determine the mass of a hydrogen atom.

APPROACH The mass of one atom equals the mass of 1 mol divided by the number of atoms in 1 mol, N_A.

SOLUTION One mole of hydrogen atoms (atomic mass = 1.008 u, Section 13–1 or Appendix B) has a mass of 1.008×10^{-3} kg and contains 6.02×10^{23} atoms. Thus one atom has a mass

$$m = \frac{1.008 \times 10^{-3}\ \text{kg}}{6.02 \times 10^{23}} = 1.67 \times 10^{-27}\ \text{kg}.$$

NOTE Historically, the reverse process was one method used to obtain N_A: that is, a precise value of N_A can be obtained from a precise measurement of the mass of the hydrogen atom.

EXAMPLE 13–15 **ESTIMATE** **How many molecules in one breath?** Estimate how many molecules you breathe in with a 1.0-L breath of air.

PHYSICS APPLIED
Molecules in a breath

APPROACH We determine what fraction of a mole 1.0 L is using the result of Example 13–10 that 1 mole has a volume of 22.4 L at STP, and then multiply that by N_A to get the number of molecules in this number of moles.

SOLUTION One mole corresponds to 22.4 L at STP, so 1.0 L of air is $(1.0\ \text{L})/(22.4\ \text{L/mol}) = 0.045$ mol. Then 1.0 L of air contains

$$(0.045\ \text{mol})(6.02 \times 10^{23}\ \text{molecules/mole}) \approx 3 \times 10^{22}\ \text{molecules}.$$

13–10 Kinetic Theory and the Molecular Interpretation of Temperature

The analysis of matter in terms of atoms in continuous random motion is called the **kinetic theory**. We now investigate the properties of a gas from the point of view of kinetic theory, which is based on the laws of classical mechanics. But to apply Newton's laws to each of the vast number of molecules in a gas ($>10^{25}/\text{m}^3$ at STP) is far beyond the capability of any present computer. Instead we take a statistical approach and determine averages of certain quantities, and these averages correspond to macroscopic variables. We will, of course, demand that our microscopic description correspond to the macroscopic properties of gases; otherwise our theory would be of little value. Most importantly, we will arrive at an important relation between the average kinetic energy of molecules in a gas and the absolute temperature.