Answer to Essential Question 14.6: 600 K. An isotherm is a line connecting all the points satisfying the equation $PV = nRT =$ a particular constant that depends on *n* and *T*. Because we're talking about the same line on both *P*-*V* diagrams, we have $PV = n_A R T_A = n_B R T_B$. Solving for the temperature in cylinder *B* gives:

$$T_B = \frac{n_A R T_A}{n_B R} = \frac{n_A}{n_B} T_A = \frac{2n_B}{n_B} T_A = 2T_A = 2(300\text{K}) = 600\text{K}.$$

In this sense, then, the *P*-*V* diagrams for different ideal gas systems are unique, because the temperature of a particular isotherm depends on the number of moles of gas in the system.

14-7 Diffusion and Osmosis

In Chapter 9, we learned a little bit about how surface tension is important in the alveoli of the lungs. Another key process involved is diffusion. Each time we breathe in, oxygen-rich air fills the alveoli of the lungs. Some of this oxygen will then diffuse through the membrane between the alveoli and blood inside the capillaries, infusing the blood with oxygen. Carbon dioxide diffuses in the other direction, from the blood into the lungs, and we then breathe the carbon dioxide out. This can be a highly efficient process in the human body, because the total surface area inside the alveoli can approach 100 m^2, and the membrane thickness is extremely thin, generally several hundred nanometers.

Diffusion is a flow of molecules without requiring a net flow of a medium. For instance, in the case of the lungs described above, oxygen molecules diffuse from a region of high concentration of oxygen (in the lungs) to a region of lower concentration (in the blood). The carbon dioxide goes the other way because the high concentration of carbon dioxide is in the blood, and the lower concentration is in the lungs. From a physics perspective, diffusion simply comes from the random motion of molecules, as in an ideal gas.

The process of a molecule randomly moving is known as a **random walk**. This was studied by Robert Brown in 1827, hence the term **Brownian motion** for the motion of a small particle immersed in a fluid. Albert Einstein was also a key figure in our understanding of diffusion, as it was he who developed the theory of Brownian motion.

Another example of diffusion is a mylar balloon that is filled with helium. As time passes, helium atoms diffuse through the wall of the balloon, and the balloon gradually deflates.

Osmosis

The process of osmosis involves the diffusion of molecules of a solute through a membrane that is selectively permeable. Take a container that is divided by a semi-permeable membrane. The membrane allows molecules of the solvent (which might be water, for example) to pass through because these molecules are small. On the other hand, the solute molecules may not pass through because they are too large. If two different concentrations of the solution are placed in the two parts of the container, the solvent molecules will diffuse through the membrane from the low-concentration side to the high-concentration side (thereby diluting the high-concentration side, and increasing the concentration on the low-concentration side). We can refer to an osmotic pressure across the membrane that drives this flow - as shown in Figure 14.14, this osmotic pressure can balance a hydrostatic pressure difference between the two sides, coming from the difference in the height of the fluid columns.

Note that osmotic pressures can be rather large, up to many atmospheres of pressure, even. Because of this, osmosis is a key part of many biological systems.

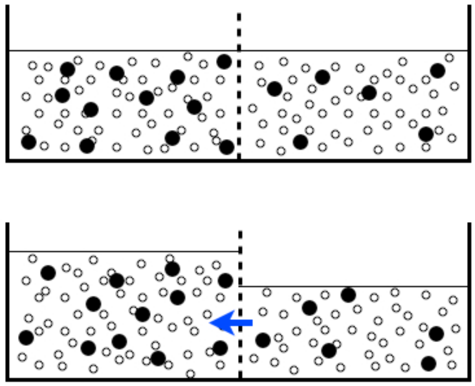

Figure 14.14: In the top diagram, the fluid levels are equal on both sides of a semi-permeable membrane, but the concentration is higher on the left. As shown in the bottom diagram, solvent molecules (small open circles) will then diffuse from right to left until the osmotic pressure balances the hydrostatic pressure. The membrane allows solvent molecules to pass through, but does not allow the larger (dark circles) solute molecules through.

A related phenomenon, which is important in many desalination plants (removing salt from water so that humans can drink it), is reverse osmosis, described below.

Reverse osmosis and desalination

Let's calculate the osmotic pressure of seawater. This is done by multiplying the molarity (*M*) of the solution, (the concentration in moles / liter), by the universal gas constant (*R*), in units of liter atm / (K moles), and multiplying that by the temperature (*T*) in Kelvin. A typical molarity of seawater is 1.1 moles / L. If we use a temperature of 300 K, the osmotic pressure works out to:

$$P = M\,R\,T = (1.1 \text{ moles / L})\,[0.082 \text{ L atm / (K moles)}\,]\,(300 \text{ K}) = 27 \text{ atm.}$$

Thus, the osmotic pressure of seawater is about 27 atmospheres! This means that if you have a semi-permeable membrane (impermeable to the sodium and chlorine ions) separating fresh water from seawater, there is a very large pressure that drives the pure water through the membrane to the seawater side.

In the reverse-osmosis desalination process, however, we want the flow to go in the other direction, driving pure water from the seawater to the freshwater side. This can be done if the seawater is placed under hydrostatic pressure larger than the 27 atmospheres of osmotic pressure - thus, typical pressures for the seawater in a reverse-osmosis desalination facility are in the range of 40 - 80 atmospheres. A very recent development, in 2013, was the announcement of a new type of membrane, just one atom thick - this is made from graphene (a single sheet of carbon), with holes in it just the right size to pass water molecules but not the salt molecules. Such a very thin sheet offers a lot of promise, as it should be much easier for the water molecules to diffuse through than through the membranes that are currently used, which are many atomic layers thick.

Reverse osmosis is also used in the maple syrup industry, to remove most of the water from the sap before boiling down the rest to make maple syrup and maple sugar.

A related process, **active transport**, is at work in the cells of living things. For instance, the concentration of potassium ions (K^+) inside a cell may be 20 times larger than the concentration outside the cell. Just the opposite happens for sodium ions (Na^+), for which the outside concentration may be 15 times higher than the concentration inside the cell. Normally, we would expect these ions to diffuse from the high-concentration region to the low-concentration region, but active transport, through the action of a **sodium-potassium pump**, works to maintain the significant imbalance in concentrations. This takes energy, which comes from hydrolyzing ATP. The net result of the sodium-potassium pump is that for every three sodium ions that are pumped out of the cell, two potassium ions are pumped in. This is a key part of why there is generally a potential difference across the cell membrane (positive outside, negative inside).

Essential Question 14.7: As fresh water is being removed from seawater in a desalination plant, what happens to the molarity of the seawater? Does this make it harder or easier to remove the pure water? How do you think this issue is addressed in a desalination facility?