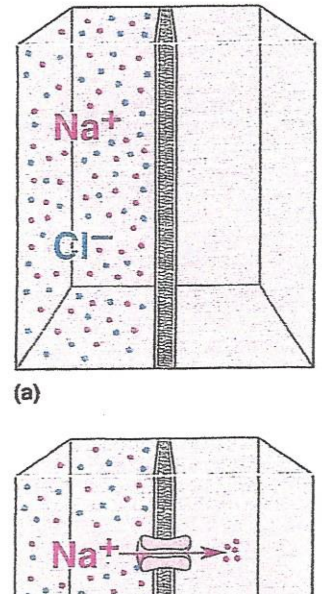

Figure 3.8
Diffusion. (a) NaCl has been dissolved on the left side of an impermeable membrane. The sizes of the letters Na^+ and Cl^- indicate the relative concentrations of these ions. **(b)** Channels inserted in the membrane allow passage of Na^+ and Cl^-. Because there is a large concentration gradient across the membrane, there will be a net movement of Na^+ and Cl^- from the region of high concentration to the region of low concentration, from left to right. **(c)** In the absence of any other factors, the net movement of Na^+ and Cl^- across the membrane ceases when they are equally distributed on the two sides of the permeable membrane.

adenosine triphosphate (ATP) is the energy currency of cells. Ion pumps are enzymes that use the energy released by the breakdown of ATP to transport certain ions across the membrane. We will see that these pumps play a critical role in neuronal signaling by transporting Na^+ and Ca^{2+} from the inside of the neuron to the outside.

THE MOVEMENT OF IONS

A channel across a membrane is like a bridge across a river (or in the case of a gated channel, like a drawbridge): It provides a path to cross from one side to the other. The existence of a bridge does not necessarily compel us to cross it, however. The bridge we cross during the weekday commute may lie unused on the weekend. The same can be said of membrane ion channels. The existence of an open channel in the membrane does not necessarily mean that there will be a net movement of ions across the membrane. Such movement also requires that external forces be applied to drive them across. Because the functioning nervous system requires the movement of ions across the neuronal membrane, it is important that we understand these forces. Ionic movements through channels are influenced by two factors: diffusion and electricity.

Diffusion

Ions and molecules dissolved in water are in constant motion. This temperature-dependent random movement tends to distribute the ions evenly throughout the solution so that there is a net movement of ions from regions of high concentration to regions of low concentration; this movement is called **diffusion.** As an example, consider adding a teaspoon of milk to a cup of hot tea. The milk tends to spread evenly through the tea. If the thermal energy of the solution is reduced, as with iced tea, the diffusion of milk molecules takes noticeably longer.

Although ions typically do not pass through a phospholipid bilayer directly, diffusion causes ions to be pushed through channels in the membrane. For example, if NaCl is dissolved in the fluid on one side of a permeable membrane (i.e., with channels that permit Na^+ and Cl^- passage), the Na^+ and Cl^- ions cross until they are evenly distributed in the solutions on both sides (Figure 3.8). As with the previous example, the net movement is from the region of high concentration to the region of low concentration. (For a review of how concentrations are expressed, see Box 3.1.) Such a difference in concentration is called a **concentration gradient.** Thus, we say that ions flow down a concentration gradient. Driving ions across the membrane by diffusion, therefore, happens when (1) the membrane possesses channels permeable to the ions, and (2) there is a concentration gradient across the membrane.

Electricity

Besides diffusion down a concentration gradient, another way to induce a net movement of ions in a solution is to use an electrical field, because ions are electrically charged particles. Consider the situation in Figure 3.9, in which wires from the two terminals of a battery are placed in a solution containing dissolved NaCl. Remember, *opposite charges attract and like charges repel.* Consequently, there will be a net movement of Na^+ toward the negative terminal (the cathode) and of Cl^- toward the positive terminal (the anode). The movement of electrical charge is called **electrical current,** represented by the symbol I and measured in units called amperes (amps). According to the convention established by Benjamin Franklin, current is defined as being posi-