

Dissolved oxygen transfers easily through the capillary walls to the cells, and carbon dioxide transfers from cells to capillaries. The CO<sub>2</sub>-loaded blood continues through all the capillaries, onward to venules, then veins, and back to the heart. The heart pumps the blood to the lungs where CO<sub>2</sub> is removed and more oxygen is received. A small amount of oxygen and nutrient-rich blood reaches the lungs directly from the left side of the heart; the lungs, like all other tissues, need oxygen to function.

Another part of the circulatory system is the lymph system. As blood passes through capillary networks, pressure inside capillaries pushes fluid out of the capillaries. About one percent of the liquid is not resorbed and remains in the spaces between capillaries and cells. The lymph system drains this extra fluid so it can return to the blood vessels to maintain proper blood volume. The lymph system also filters cell debris and foreign substances in the blood, and makes and stores infection-fighting white cells (lymphocytes) in bean-shaped storage bodies called lymph nodes. Whenever lymphocytes collect to fight invaders, the swollen piles of them can be felt in the lymph nodes.

### 3.2.4.1 Blood Transport of Carbon Dioxide

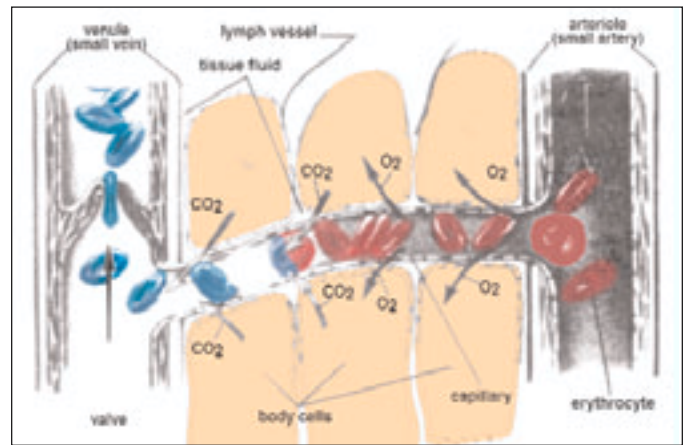
Blood transport of carbon dioxide involves several mechanisms. Dissolved CO<sub>2</sub> diffuses from the body. This section discusses the transport of bicarbonate ions (HCO<sub>3</sub><sup>-</sup>) in bringing oxygen to the body and back to the lungs.

Blood is made of water, particularly in warm water, as in the body. As a result, at sea level pressure, only a small amount of oxygen dissolves in blood plasma (the part of blood without cells). The oxygen-carrying problem is solved with a red protein molecule called hemoglobin found inside red blood cells. Red blood cells carry far more oxygen with hemoglobin than they could without it. Up to four oxygen molecules loosely attach to each hemoglobin molecule to form oxyhemoglobin. At sea level, about 98 percent of the oxygen in blood is carried by hemoglobin.

A hemoglobin molecule with four oxygen molecules bound to it looks red, while hemoglobin without bound oxygen is so dark-red that it looks blue. This is why oxygenated (arterial) blood looks red, and deoxygenated (venous) blood looks blue. It is also why, if all of the blood is deoxygenating from a serious injury or disease process, the victim can look blue; this is called cyanosis, from the word root *cyan*, meaning blue.

Carbon dioxide is easier to transport in the blood than oxygen; it can be transported in higher quantity, and in more ways (see Figure 3.9). Dissolved CO<sub>2</sub> diffuses out of cells into capillary blood. A small amount stays in the dissolved state in blood plasma all the way to the lung. Hemoglobin can loosely bond a small amount, and when combined, it is called carbaminohemoglobin. An even smaller amount of CO<sub>2</sub> can bond with plasma proteins. These three ways are minor and slow.

The bulk of CO<sub>2</sub> (about 70%) reacts quickly with water inside red blood cells to form first the weak, unstable



**FIGURE 3.9**  
**Carbon Dioxide Exchange**

carbonic acid (H<sub>2</sub>CO<sub>3</sub>), and then, just as quickly (another small fraction of a second) loses hydrogens to become bicarbonate ions (HCO<sub>3</sub><sup>-</sup>), many of which diffuse into the plasma where it is transported to the lungs. Bicarbonate is alkaline, and so it is a buffering agent in the blood against acids, such as carbonic acid. Hemoglobin also functions as a powerful acid-base buffer and scavenges the acidic hydrogen ions. These are useful reactions in the body. Acid from carbon dioxide and its reactions may form in great quantities, yet still not build to unhealthy levels.

Ordinarily, the reaction of changing carbonic acid to bicarbonate ions would take seconds to minutes—too slow to be useful, so an enzyme called carbonic anhydrase inside red blood cells decreases the reaction time by a factor of 5,000 times so that great amounts of CO<sub>2</sub> can react with water, even before blood leaves the capillaries on the way back to the lung. Drugs called carbonic anhydrase inhibitors block the reaction of carbonic anhydrase, slowing CO<sub>2</sub> transport so that tissue levels rise. Carbonic anhydrase inhibitors are used to combat glaucoma, fluid retention, and altitude sickness.

Carbonic acid is used to carbonate soft drinks. Just as bicarbonate in soda releases carbon dioxide gas when a pop can is opened, bicarbonate in blood becomes carbonic acid again, releasing carbon dioxide into the alveoli so that CO<sub>2</sub> can be exhaled. The difference between the soft drink and the body is that the reaction to release carbon dioxide in soda has no catalyst to speed it up. Though seemingly fast, it is far too slow to keep one alive if it occurred at the same rate in the body. The lungs have enzymes to speed the reaction.

Carbon dioxide is also released in the lung by hemoglobin. When hemoglobin arrives in the alveolar capillaries with excess carbon dioxide, it first wants to pick up new oxygen. The oxygen makes the hemoglobin a stronger acid. Having just become more acidic, hemoglobin does not want the existing acid from the acidic carbon dioxide any more, so it releases it. This effect, called the Haldane Effect, means that picking up oxygen in the lung

Should Read as Follows: