However, because small regions of ventilation-perfusion inequality and shunt exist in the normal lung, the P_{O_2} in the pulmonary veins from the lungs as a whole is usually about 90 mm Hg. Therefore, the difference between the alveolar and arterial partial pressures of oxygen, known as the *A-a gradient*, is typically about 10 mm Hg in health.

The pressure gradient that drives carbon dioxide from the mixed venous blood into the alveolus is the difference in partial pressure of carbon dioxide (45 mm Hg in mixed venous blood and 40 mm Hg in the alveolus). Despite the lower driving pressure for carbon dioxide compared with oxygen, the greater solubility of carbon dioxide allows complete equilibration between the alveolus and plasma during each respiratory cycle (Fig. 15-13).

Most of the oxygen contained in the blood is bound to hemoglobin; a small fraction is dissolved and measured as the P_{aO_2}. The amount of oxygen dissolved is about 3 mL/L in arterial blood, whereas the amount of oxygen bound to hemoglobin is about 197 mL/L, assuming a normal hematocrit. Each molecule of hemoglobin is capable of carrying four molecules of oxygen. The shape of the oxyhemoglobin association curve reflects the cooperative binding of oxygen to hemoglobin (Fig. 15-14). In general, the hemoglobin saturation is between 80% and 100% with P_{aO_2} values greater than 60 mm Hg and drops dramatically when the P_{aO_2} is less than 60 mm Hg. Factors that decrease the affinity of hemoglobin for oxygen include a reduction in blood pH, an increase in temperature, an increase in P_{aCO_2}, and an increase in the concentration of 2,3-diphosphoglyceric acid (2,3-DPG) (Fig. 15-15). These factors facilitate unloading of oxygen into tissues, which is seen as a shift of the oxyhemoglobin dissociation curve to the right. The oxygen-carrying capacity of hemoglobin is also affected by competitive inhibitors for binding sites, such as carbon monoxide. Carbon monoxide has an affinity for hemoglobin that is 240 times greater than that of oxygen and preferentially binds to the hemoglobin molecule. However, this does not affect the amount of oxygen dissolved in the blood. Someone with carbon monoxide poisoning may have a normal P_{aO_2} but a very low blood oxygen content because of the high amount of desaturated hemoglobin.

About 5% of carbon dioxide in the blood is dissolved in plasma, and about 10% is bound to hemoglobin. However, carbon dioxide does not exhibit cooperative binding; therefore, the shape of the carbon dioxide–hemoglobin dissociation curve is linear. Carbon dioxide binds to the protein component of the hemoglobin molecule and to the amino groups of the polypeptide chains of plasma proteins to form carbamino compounds. About 10% of carbon dioxide is transported in this fashion. Most of the carbon dioxide is transported as bicarbonate ion: As carbon dioxide diffuses from metabolically active tissue into the blood, it reacts with water to form carbonic acid. This reaction primarily occurs in the red blood cells because it is catalyzed by the enzyme carbonic anhydrase, which resides in those cells. Carbonic acid then dissociates to bicarbonate and hydrogen ion. Although there is more carbon dioxide dissolved in blood than oxygen, it is still a small fraction of the total carbon dioxide transported by blood.

Abnormalities of Pulmonary Gas Exchange

The arterial P_{O_2} and P_{CO_2} are determined by the degree of equilibration between the alveolar gas and capillary blood, which depends on four major factors: ventilation, matching of ventilation with perfusion, shunt, and diffusion. *Hypoxemia* refers to a reduction in the oxygen content of the blood and is determined by measuring the P_{O_2} of arterial blood. In contrast, *hypoxia* refers to a decrease in oxygen content of an organ, for example, myocardial hypoxia. Aberrations in the four factors listed can result in hypoxemia. A fifth cause of hypoxemia is a low inspired P_{O_2}, which may occur at altitude.

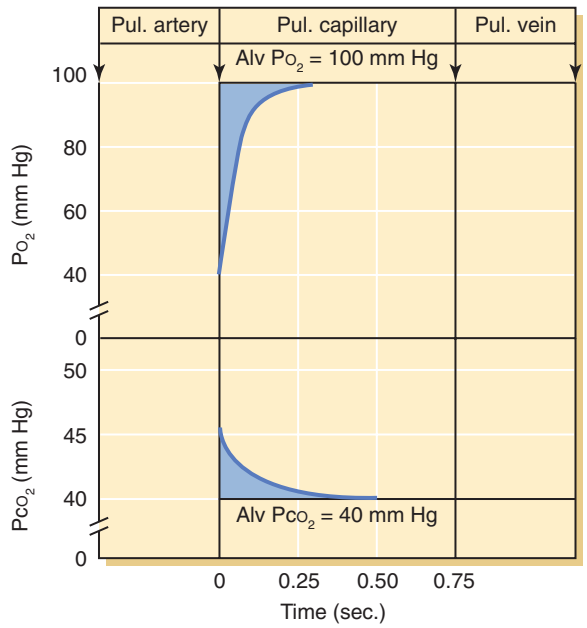

FIGURE 15-13 Changes in the partial pressures of oxygen (P_{O_2}) and carbon dioxide (P_{CO_2}) as blood courses from the pulmonary artery through the capillaries and into the pulmonary veins. The diffusion gradient is greater for O_2 than for CO_2. However, equilibration of capillary and alveolar gas occurs for both molecules within the 0.75 second it takes for blood to traverse the capillaries. Alv, Alveolar; Pul., pulmonary.

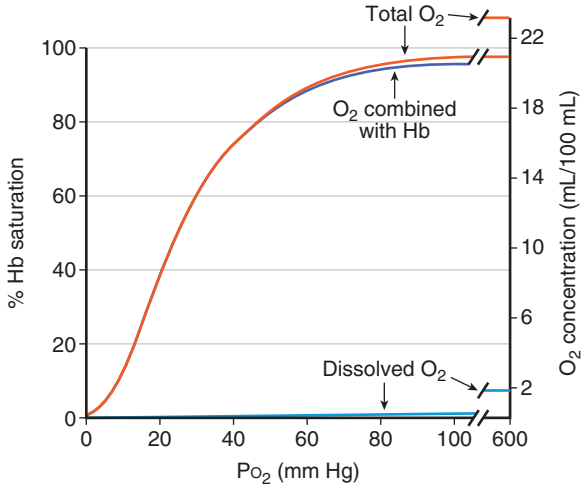

FIGURE 15-14 The oxyhemoglobin dissociation curve. The bulk of the oxygen (O_2) is combined with hemoglobin (Hb). Little is dissolved in plasma. P_{O_2}, Partial pressure of oxygen.