Cooperativity in Hemoglobin Binding Oxygen

This page contains information extracted from one section of Integrating Concepts in Biology. There is a short introduction and then a data figure. Your task is to interpret Figures 13.1 and 13.3, and answer the Integrating Questions. This sample has been reformatted for this DIBS workshop.

Physiologists measured the amount of oxygen dissolved in a solution of hemoglobin as the concentration of oxygen increased within their experimental chamber (Figure 13.1). Oxygen dissolving in a solution of hemoglobin is very different than oxygen dissolving in water. Notice that in water, the amount of dissolved oxygen increases linearly as oxygen concentration increases. In a hemoglobin solution, the amount of dissolved oxygen increases in an unexpected way, revealing an emergent property of hemoglobin. The hemoglobin binds to oxygen very slowly until its concentration reaches about 1 kilopascal (kPa) of pressure, which is 1% of standard atmospheric pressure (100 kPa). The emergent property of hemoglobin is revealed between 1 and 9 kPa of oxygen concentration. With very little increase in oxygen concentration, the amount of oxygen dissolved in a hemoglobin solution increases very rapidly.

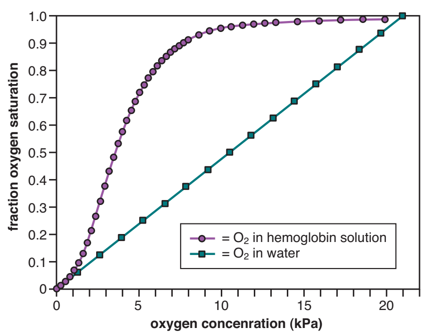

Figure 13.1 Solubility of gaseous O_2 in water and hemoglobin solutions. The units of oxygen concentration in the air over the liquids are kilopascals (kPa). Original Art with help from Durwin Striplin, Davidson College Chemistry Dept. Raw data from Severinghaus, 1979, his table I.

When you read about protein structure and folding in Section 7.1, you learned that a protein's shape was determined by its amino acid side chains and its primary structure. Proteins fold in response to how amino acids interact with each other and their environment, such as pH (Figure 13.3). Hemoglobin moves from blood with a pH of 7.6 in your lungs to pH 7.2 in your muscles. The lower pH is caused by a number of factors including the fact that CO_2 is a weak acid, and muscle cells consume O_2 and produce a lot of CO_2 as a waste product. Changing the pH from 7.6 to 7.2 is a change of $10^{0.4}$ or 2.5-fold increase in H^+ ion concentration. When a protein is surrounded by more H^+ ions, its side chains move in response to the increased acidity. When a protein changes its shape, it also changes its function. In this case, hemoglobin alters the way it binds and releases oxygen. The pH-sensitive switch of hemoglobin is another example of an emergent property.

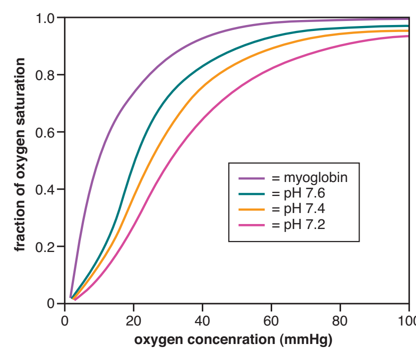

Figure 13.3 The effect of pH on oxygen solubility in a hemoglobin solution. Oxygen concentration was measured in units of millimeters of mercury (mm Hg); 100 mm of mercury equals about 13.3 kPa. Open source http://en.wikipedia.org/wiki/Cooperative_binding.

Integrating Questions

3. Use Figure 13.1 to explain why so little oxygen dissolves in serum compared to whole blood.
4. Use Figure 13.3 to determine how much more oxygen is released by hemoglobin at 40 mm Hg when blood moves from pH 7.6 to 7.2. What is the functional consequence of hemoglobin changing its shape depending on the pH?
5. What is the function of myoglobin given its oxygen saturation curve in Figure 13.3?