

## Determinants of Blood Oxygen Content Instructor's Guide

### Time to Complete

This activity will take approximately 75 minutes, but can be shortened depending on how much time the instructor takes to review questions while moving through the activity.

### Prior Knowledge

- Awareness of Dalton's Law of partial pressures
- Performing calculations using basic algebraic equations
- The basic function of oxygen in metabolism

### Content Objectives/Learning Goals

Students will be able to:

- Explain the concept of hemoglobin saturation and determine approximate hemoglobin saturation when provided with the partial pressure of oxygen in blood.
- Students will be able to calculate the content of bound oxygen in blood.
- Students will be able to explain how blood  $PO_2$  and oxygen content change as blood moves through the circulatory system.

### Process Objectives

- **Information Processing:** Students will interpret graphical images of individual hemoglobin saturation and the hemoglobin dissociation curve.
- **Information Processing:** Students will apply content from graphical images to explain physiological functions.

### Roles

Manager – keeps the team on task

Reader – reads the questions aloud

Recorder – records “official” team answers

Reporter – reports team answers when requested by the instructor

Librarian – uses their book or the Internet to look up information on 2 of the questions

### Implementation Notes for Instructors:

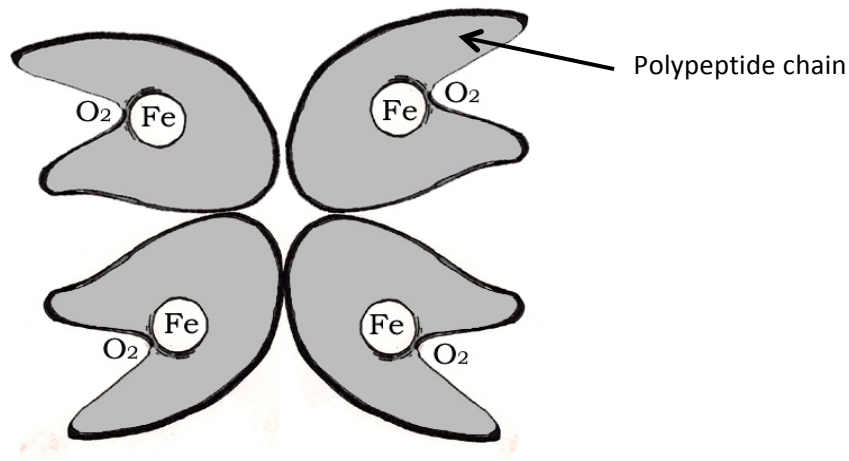
Instructors are encouraged to read through the entire activity and make adjustments based on their particular needs before making copies for their students.

## Determinants of Blood Oxygen Content

### Model 1: Oxygen Binding to a Single Hemoglobin Molecule

Hemoglobin (Hb) is a large molecule consisting of four peptide chains. Each peptide contains a heme group with an iron in the center. An oxygen molecule has the ability to bind to each heme group under the appropriate conditions. The number of oxygen molecules bound determines its saturation.

### Saturated Hemoglobin Molecule



### QUESTIONS:

1. When a hemoglobin molecule is completely saturated, how many oxygen molecules are attached?

4

2. When a hemoglobin molecule is 75% saturated, how many oxygen molecules are attached?

3

3. Assuming you started with the molecule in Model 1, how many molecules of oxygen would need to be released in order for the hemoglobin to be 75% saturated?

1

4. The number of oxygen molecules bound to hemoglobin tends to fluctuate up and down. (*Discuss the following questions with your group, and then write your answer*)

a) Where in the body does oxygen bind to hemoglobin?

*Oxygen is added to hemoglobin molecules in the lungs, increasing the amount of bound hemoglobin.*

b) Where in the body are oxygen molecules released from hemoglobin?

*Some of this oxygen is released from hemoglobin when it travels through the capillary beds of the various tissues and organs of the body*

5. Is it possible for one hemoglobin molecule to be 82% saturated? Why or why not?

*No, there are only 4 spots, so a single molecule can only be in the states of 0, 25, 50, 75 or 100% saturated.*

6. How many molecules of oxygen are carried on 100 molecules of hemoglobin when all the hemoglobin molecules are completely saturated?

$$100 \times 4 = 400$$

7. If after passing through a capillary bed, those 100 molecules of hemoglobin become 75% saturated with oxygen, how many molecules of oxygen were unloaded (released)?

$$100$$

### **Model 2: Hemoglobin (Hb) Values and Their Effect on Oxygen Carrying Capacity**

Hemoglobin is found in very high numbers within red blood cells, and there are lots of red blood cells in our blood. Because dealing with such large numbers can be challenging, hemoglobin is typically measured by mass and oxygen is measured by volume. The following table provides information about common parameters used in calculating blood oxygen levels.

<b>Parameter</b>	<b>Normal value</b>
Number of hemoglobin molecules per red blood cell	250 million molecules
Number of red blood cells per deciliter (dL) of blood (There are 10 deciliters in 1 liter of blood)	500 billion cells
Mass of hemoglobin in a deciliter (dL) of blood	15 grams (g)
Amount of oxygen that 1 gram of hemoglobin can hold (carry) when 100% saturated	1.34 milliliters (mL)

### **QUESTIONS:**

8. How many molecules of oxygen can one red blood cell carry?

*250 million hemoglobin molecules x 4 oxygen molecules = 1 billion oxygen molecules*

9. Is it possible for the total hemoglobin inside a red blood cell to be 82% saturated? Explain your answer.

*Yes, a cell could be carrying 820 million oxygen molecules out of a possible 1 billion*

10. Set up a mathematical equation that illustrates how to calculate the number of oxygen molecules that could be carried in 1 dL of blood when it is fully saturated with oxygen (you do not have to solve your calculation):

*250 million hemoglobin molecules per red blood cell x 4 oxygen molecules per hemoglobin molecule x 500 billion red blood cells per deciliter*

11. Calculate the amount (in mL) of oxygen that could be carried in 1 dL of blood when the hemoglobin is 100% saturated:

$$15 \text{ grams Hb/dL of blood} \times 1.34 \text{ ml oxygen/gram Hgb} \times 1.00 = 20 \text{ ml of oxygen/dL}$$

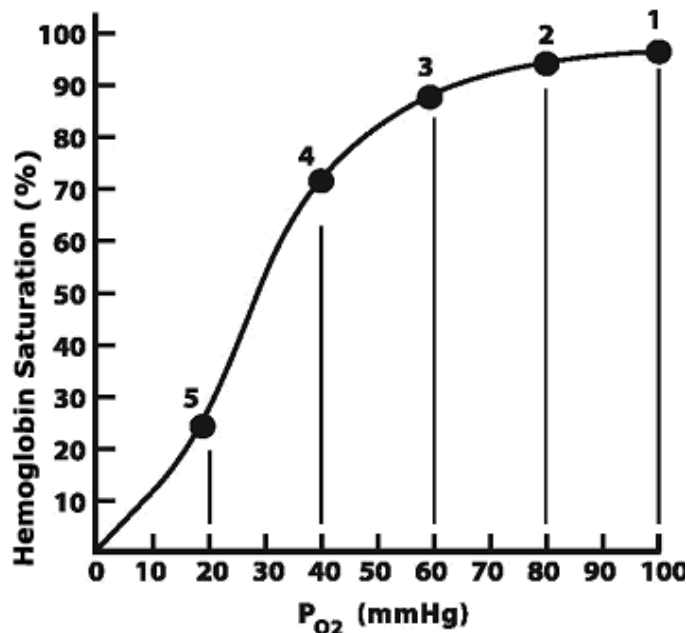
12. Calculate the amount (in mL) of oxygen carried in 1 dL of blood when the hemoglobin is 50% saturated:

$$15 \text{ grams Hb/dL of blood} \times 1.34 \text{ ml oxygen/gram Hb} \times .5 = 10 \text{ ml of oxygen/dL}$$

### Model 3: Oxyhemoglobin Dissociation Curve

A major determinant of how much oxygen is found in blood is the saturation of hemoglobin (which determines the amount of “bound” oxygen). This saturation level is mainly determined by the amount of oxygen dissolved in the blood plasma, because the dissolved and bound oxygen are in chemical equilibrium. The amount of dissolved oxygen is indirectly measured as  $PO_2$ , the partial pressure of oxygen in plasma. When the  $PO_2$  increases, saturation typically increases as well. This relationship is illustrated by the oxyhemoglobin dissociation curve, as shown below.

#### **Oxyhemoglobin Dissociation Curve**



#### QUESTIONS:

13. What is the label on the X-axis?

*Oxygen partial pressure*

14. What are the units specified on the X-axis?

*mmHg*

15. What is the label on the Y-axis?

*Hemoglobin saturation*

16. What are the units specified on the Y-axis?

*%*

17. As partial pressure of oxygen ( $PO_2$ ) increases, what happens to hemoglobin saturation?

*As oxygen partial pressure increases, the hemoglobin saturation increases until saturation is reached*

18. At  $PO_2$  of 100 mm Hg, what is the hemoglobin saturation?

*98%*

19. At  $PO_2$  of 20 mm Hg, what is the hemoglobin saturation?

*About 25%*

20. Answer questions a, b, and c assuming the numbered points on the graph in Model 3 represent:

- 1:** Blood at the distal end of alveolar capillaries in a normal individual.
- 2:** Blood in the distal end of alveolar capillaries in a person with slightly impaired oxygen exchange in their lungs.
- 3:** Blood in the middle of a capillary of systemic organs.
- 4:** Blood at the distal end of a typical (resting) capillary of systemic organs.
- 5:** Blood at the distal end of a metabolically active (working) capillary.

a) What is the "distal end" of a capillary?

*Generally the proximal and distal end relate to the direction of blood flow through a capillary. Blood enters a capillary at the proximal end and flows out at the distal end.*

b) Where are the distal ends of alveolar capillaries located?

*The distal ends of the alveolar capillaries are in the lungs. More specifically, they are the far end ("distal") of the capillary beds where blood oxygen levels should be at their highest.*

c) Where might you find the distal end of a metabolically active (working) capillary?

*The distal ends of a metabolic active capillary would be in, for example, a working muscle. The distal ends of a capillary bed of a working muscle would contain blood that has relatively low blood oxygen levels.*

21. Complete the following table. Assume a “normal” individual with a Hb concentration of 15 g/dL. There is space for your calculations after the table.

<b>Vessel</b>	<b>PO<sub>2</sub> (mmHg)</b>	<b>Hb Saturation (%)</b>	<b>Oxygen content (mL/dL)</b>
Pulmonary vein	100	100	20
Distal end of resting capillaries	40	75	15
Distal end of working capillaries	20	25	5
Vena Cava	40	75	15
Pulmonary Artery	40	75	15

*Calculations are same as in 12, except that the saturation level varies.*

*15 grams Hb/dL of blood x 1.34 ml oxygen/gram Hb x saturation = Y mL of oxygen/dL*



22. Using the results of your calculations in Question #21, complete the following table.  
*(Assume all references to capillaries refer to the distal end of the capillary)*

<b>Relationship</b>	<b>Difference (number)</b>
PO <sub>2</sub> difference between the pulmonary and resting capillaries	60
PO <sub>2</sub> difference between the pulmonary and working capillaries	80
Oxygen content difference between the pulmonary and resting capillaries	5
Oxygen content difference between the pulmonary and working capillaries	15

23. When a person exercises, what happens to the oxygen saturation of hemoglobin in capillaries leaving muscle tissue? Discuss with your group and write one answer.

*The oxygen saturation of the blood leaving muscle that is being exercise will be less than for muscle that is not being exercised.*

24. Does a change in PO<sub>2</sub> always correspond to a proportional change in oxygen content? Explain why or why not:

*No, the curve is non-linear, therefore you can have fairly large changes in PO<sub>2</sub> with fairly small changes in content over one region of the curve, while another region can give you a large change in content for a small change in PO<sub>2</sub>*

### **Extension Questions:**

25. There is an oxygen bar in town where you can pay to breathe air with higher than normal oxygen content. The owners claim it will improve your alertness and ability to function. Using data from the graph in Model 2, discuss with your group whether you think this statement is true or not. Explain your answer in complete sentences below:

*The claim is untrue because under normal conditions hemoglobin is 98% saturated*

26. A person with anemia has a decreased concentration of hemoglobin in the blood.

a) Would this affect the person's oxyhemoglobin dissociation curve? Explain:

*It would not affect their curve, as it only shows the relationship between  $PO_2$  and saturation, not the relationship with  $PO_2$  and content.*

b) Would it affect their blood oxygen content? Explain:

*A decreased concentration of hemoglobin would reduce the ability of the blood to carry oxygen due to a reduced number of hemoglobin molecules.*

27. Describe a specific situation or circulatory location that could be represented by point 3 in Model 3:

*Answers may vary, but might include:*

- 1. Point 3 might represent the  $PO_2$  of alveolar capillary blood in someone with significant gas exchange problems such as in severe pneumonia or pulmonary edema.*
- 2. It might represent normal alveolar capillary values in someone at high altitude.*
- 3. It would represent a point along the systemic capillary. As blood moves along the systemic capillary it moves along the curve as it unloads oxygen. Somewhere in the capillary it would be at point 3.*
- 4. This could represent venous blood in tissues such as the skin that have a very low rate of oxygen removal (blood is often sent to the skin for temperature regulation, not to unload much oxygen).*