Biology 1305
Modern Concepts in Bioscience (ICB Textbook)

Hello and welcome to the weekly resources for BIO-1305 - Biology 1

This week is Week 14 of class, and typically in this week of the semester, your professors are covering the topics below. If you do not see the topics your particular section of class is learning this week, please take a look at other weekly resources listed on our website for additional topics throughout the semester.

We also invite you **to look at the group tutoring chart on our website to see if this course has a group tutoring session offered this semester.**

If you have any questions about these study guides, group tutoring sessions, private 30 minute tutoring appointments, the Baylor Tutoring YouTube channel, or any tutoring services we offer, please visit our website www.baylor.edu/tutoring or call our drop in center during open business hours (M-Th 9am8pm on class days at 254-710-4135).

KEYWORDS: **Hemoglobin, Myoglobin, Oxygen, Affinity, pH, Cooperativity**

TOPIC OF THE WEEK:

Emergent Properties

In your book, **emergent properties** are defined as "*characteristics that become apparent at a higher level of biological complexity due to interactions among lower level components*." Essentially, emergent properties are properties which emerge as a result of multiple components, or parts, working together. These properties are not observed in any of the individual parts of the whole; the **entire** system needs to be functioning together in order for these properties to emerge.

One example of an emergent property is **cooperativity** in hemoglobin. Hemoglobin is a protein which is inside your red blood cells. It is responsible for **carrying and releasing oxygen** in your body.

In an experiment, investigators measured the amount of oxygen dissolved in a solution of hemoglobin as the concentration of oxygen was increased within an experimental chamber. As we can see from the graph below, the amount of dissolved oxygen increased as the concentration of oxygen increased. In water, the amount of dissolved oxygen increases **linearly** as oxygen concentration increases.

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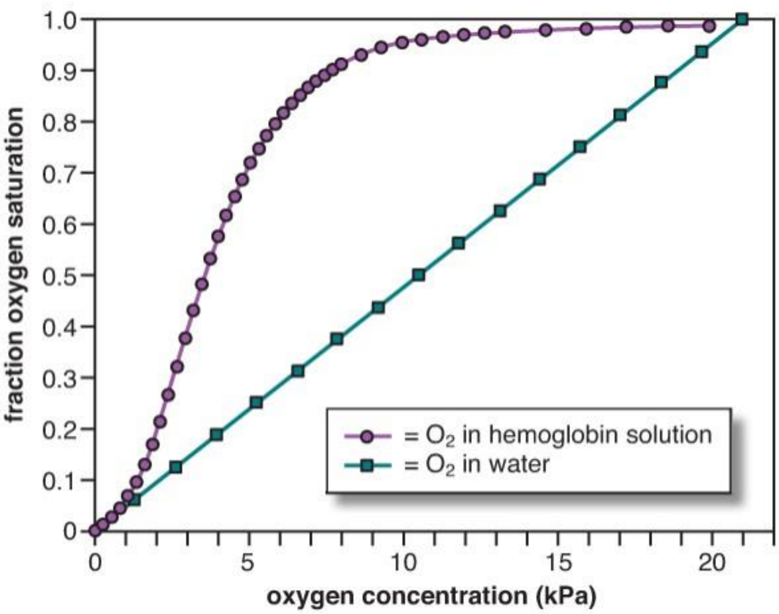
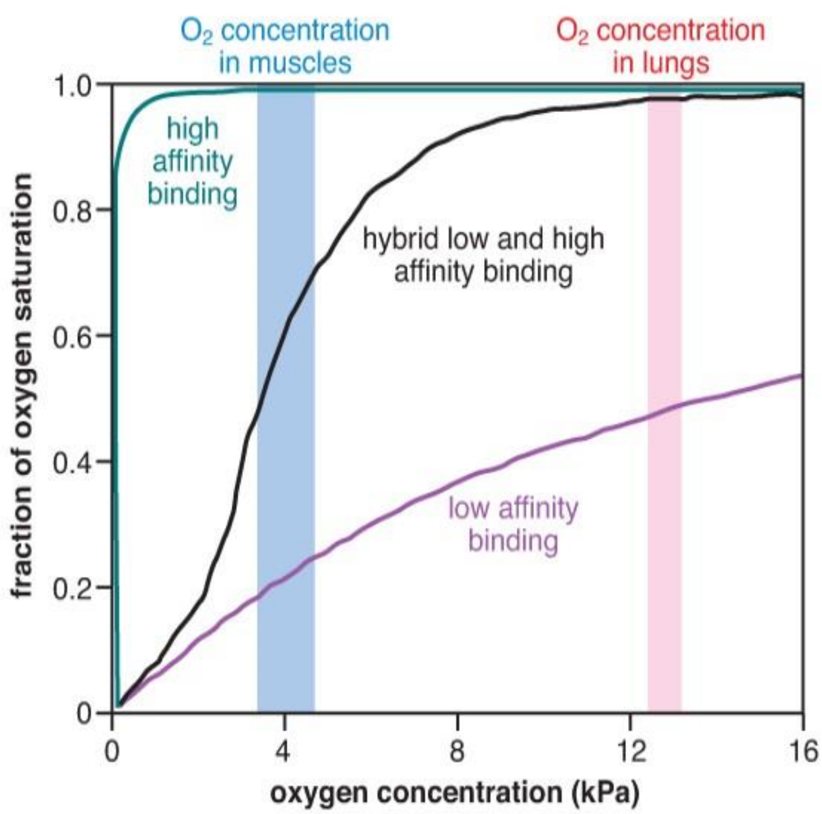


In a hemoglobin solution, the hemoglobin binds to oxygen very slowly until its concentration reaches about 1 kilopascal (kPa) of pressure. Between 1 and 9 kPa of oxygen concentration, the amount of oxygen dissolved in a hemoglobin solution increases very rapidly with very little increase in oxygen concentration. This **sigmoidal (S-shaped)** curve demonstrates the emergent property of hemoglobin. This sigmoid-shaped oxygen solubility curve is what allows hemoglobin to move oxygen from high to low concentration in your body.

Hemoglobin has both low and high **affinity** (molecular attraction) for oxygen. This graph depicts oxygen saturation curves for three different molecules. The first molecule binds to oxygen with high affinity, the second molecule binds to oxygen with hybrid affinity, and the third molecule binds to oxygen with low affinity. The high affinity molecule binds oxygen but does not release it, while the low affinity molecule easily releases oxygen, but does not bind a large fraction of it. The hybrid molecule binds oxygen when oxygen concentration is high and releases it when oxygen concentration is low.



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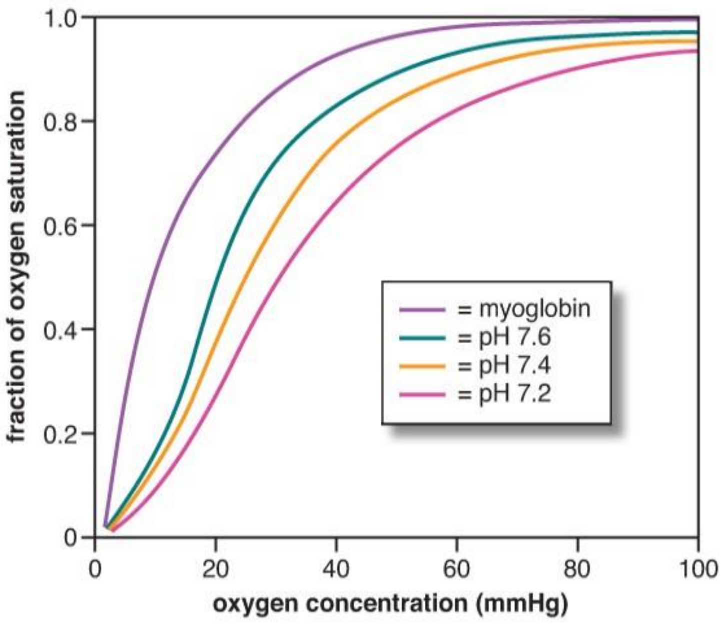
In the body, this means that hemoglobin, which exhibits this type of binding affinity, **can bind to oxygen in the lungs (where the oxygen concentration is high) and release oxygen in the muscles (where the oxygen concentration is lower).**

HIGHLIGHT #1: pH and Oxygen Solubility

Recall that a protein's shape is determined by its amino acid side chains and its primary structure. Proteins fold in response to how amino acids interact with each other, and the surrounding environment can affect the properties of the amino acids in a protein, resulting in a change in the shape of the protein. One factor which influences protein shape and function is pH.



This graph shows us the fraction of oxygen saturation in environments of various pH. Different amounts of oxygen, in units of millimeters of mercury (mm Hg), were added to a solution containing hemoglobin. The fraction of hemoglobin with bound oxygen was measured at three different pH values and compared to a myoglobin solution (purple line). As we can see, oxygen saturation is higher when the pH is higher (the surrounding solution is more basic). Since the pH in your lungs is 7.6, while the pH in your muscles is 7.2, it makes sense that hemoglobin binds to oxygen in your lungs and releases it when it travels to your muscles. Hemoglobin's sensitivity to pH is another example of an emergent property.

HIGHLIGHT #2:Cooperativity

Another emergent property of Hemoglobin is its cooperativity, which increases the capacity of hemoglobin to bind many oxygen molecules even when the concentration of O2 changes very little. Hemoglobin has four subunits, each of which can bind to an oxygen molecule. Because hemoglobin exhibits cooperativity, **the binding of one O2 molecule to one binding site results in a shape change in the hemoglobin molecule which results in a higher affinity between oxygen and the other three binding sites.**

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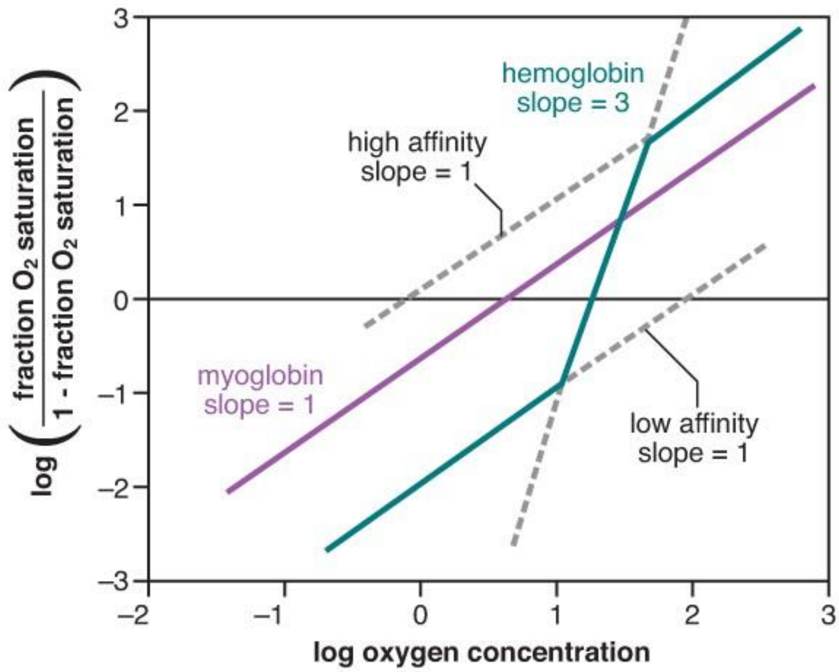

This Hill plot illustrates the significant difference between hemoglobin and three molecules that exhibit no cooperativity: myoglobin and two hypothetical proteins of high and low affinity binding for oxygen. Molecules that lack cooperativity (such as myoglobin) have a slope of one in a Hill plot, whereas hemoglobin has a slope of nearly three.

Slopes greater than one indicate positive cooperativity, which means that once the first oxygen molecule binds to one of the four hemoglobin subunits, the other three bind quickly. The theoretical maximum Hill coefficient is the number of molecules or subunits in the molecule. For hemoglobin, this value would be 4. The slope of hemoglobin is 3, but because a biological molecule cannot practically reach its theoretical maximum Hill plot slope, Hemoglobin's slope of almost 3 is close to the practical maximum and tells us that hemoglobin displays a high level of cooperativity.

CHECK YOUR LEARNING

(Answers below)

1) Why can't a biological molecule reach its maximum Hill plot slope? (Hint: You may have to check your textbook!)
2) What is another example of an emergent property?
3) Based on what we have learned so far, how do you think a change in pH causes a change in the structure of a protein?

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THINGS YOU MAY STRUGGLE WITH

- Remember that only molecules which display cooperativity have a sigmoidal oxygen solubility/oxygen saturation curve. For example, myoglobin would not have an S-shaped curve because it is a single subunit molecule and does not display cooperativity.
- Hemoglobin moves from a pH of 7.6 in your lungs to pH 7.2 in your muscles. The lower pH can be caused by an excessively high concentration of CO_2 (a weak acid) compared to O_2. When muscle cells consume oxygen, they produce CO_2 as a by-product. When the pH decreases as a result, Hemoglobin is able to more easily release O_2 to the muscles which need it.
- Hemoglobin is composed of four proteins. It is made up of two alpha (α) subunits and two beta (β) subunits. Each of these four subunits contains a heme group, which is a planar molecule with a centrally located iron ion (Fe^{2+}). The iron in the heme group is what gives hemoglobin (and blood) its red color.

ANSWERS

1) A molecule can't display its theoretical maximum Hill plot slope because this value indicates that all of the subunits bind at once. Recall that in a real biological system, one molecule binds first and this then increases the affinity of the other binding sites of the protein for the binding molecule.
2) N/A (Answers may vary)
3) A change in pH indicates a change in H+ concentration. When a protein is surrounded by more H+ ions, its side chains move in response to the increased acidity. For example, amino acids with a positive charge are repelled by the H+ ions, while negatively charged amino acids may move closer to the periphery of the protein surface. When a protein changes its shape, it also changes its function.

Thanks for checking out these weekly resources! Don't forget to check out our website for group tutoring times, video tutorials and lots of other resources: www.baylor.edu/tutoring! Answers to Check your Learning questions are below!

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