Problem Description to Accompany the Mt. Everest Applet

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A Introduction

This Java applet provides a simple simulation of a climb up Mt. Everest and the body's response to the decrease in atmospheric oxygen. At sea level, the air pressure is 760 torr and the atmosphere consists of 21% oxygen. This corresponds to a partial pressure of about 160 torr of oxygen. By the time the air gets into your lungs and mixes with the air left from the last breath, the partial pressure of oxygen is about 100 torr. At the top of Mt. Everest, the amount of available oxygen has dropped by 50% to about 50 torr. If a person has spent their entire life at sea level and is then suddenly transported to the top of Mt. Everest, the decrease in atmospheric oxygen will almost certainly cause a medical condition known as hypoxia. This will lead to severe disorientation and possibly death. Hypoxia may have contributed to the Everest tragedy in May of 1996, which claimed the lives of 8 climbers. For more information on this tragedy and other aspects of climbing Mt. Everest, see www.mountainzone.com.

The Sherpas are natives to the Mt. Everest region and ever since the first British expedition up Mt. Everest in 1921, have served as expert guides to western climbers. Sherpas can survive life at high altitudes because their bodies have become accustomed to low oxygen levels. One aspect of this acclimatization is an increase in the concentration of red blood cells and thus the concentration of Hemoglobin in the blood. Hemoglobin is a protein molecule that binds oxygen in the lungs, transports it through the blood stream, and releases it where it is needed in the body. Since it takes a long time for a person to acclimatize to high altitude, many climbers take along bottled oxygen for use near the summit. In this applet, you will climb Mt. Everest without bottled oxygen. Instead, you will rest at each climbing camp long enough for your body to acclimatize such that it is safe to move on to the next camp.

B Problem Statement

The applet uses the following simple model of your body's respiration. Each Hemoglobin molecule can bind 4 oxygen molecules. In your lungs, essential all of the Hemoglobin molecules have bound at least 3 oxygen molecules. We will consider the binding of the fourth oxygen molecule, which is governed by the equation,

$$Hb(O_2)_3 + O_2 \Leftrightarrow Hb(O_2)_4 \quad . \qquad \text{(EQ 1)}$$

The equilibrium expression governing this reaction is,

$$K = \frac{[Hb(O_2)_4]}{[Hb(O_2)_3]P_{O_2}} = 0.11\,\text{torr}^{-1} \quad \text{(EQ 2)}$$

In the applet, we use units of torr for the partial pressure of oxygen, and micromoles/liter (μM) for the concentration of $Hb(O_2)_4$ and $Hb(O_2)_3$. A micromole is 10^{-6} moles. Your body has a total of about 150 grams of Hemoglobin per liter of blood. This corresponds to a concentration of about 2,600μM.

As you proceed up the mountain, the partial pressure of oxygen drops. You can determine the partial pressure at a particular camp by passing your mouse over that camp. (Be careful, because clicking on a camp takes you to that camp, and you may not yet have enough Hemoglobin to survive at that altitude.) In this simulation, your body's optimal concentration of bound Hemoglobin $[Hb(O_2)_4]$ is 2,400μM. If it drops below this level, your body will produce Hemoglobin until the bound Hemoglobin is optimal. If the concentration of bound Hemoglobin drops below 2,300μM, you will pass out. Try to make it to the top of the mountain before winter hits (about 180 days). Good luck.

C Additional Information

This applet oversimplifies the complex phenomena that occur to a human body at high altitude. The biggest simplification is the manner in which the body grows Hemoglobin in response to a decrease in available oxygen. In the applet, we assume the rate is simply proportional to the amount of Hemoglobin needed by the body. In reality, the time it takes to adjust to high altitude varies widely between different people and conditions. Even if you have been hugely successful climbing the Mt. Everest in this applet, we do not advise you attempt the real thing without training.

We have also simplified the equilibrium between Hemoglobin and oxygen. The binding constants are different for each of the four oxygen molecules that a Hemoglobin can bind. The above equilibrium constant was chosen to reproduce the binding behavior in the pressure ranges of interest for this simulation.