Homework 4

Distributed: Wednesday, February 7, 2001 **Due: Wednesday, February 14, 2001**

Name ________________________ Recitation Section (circle one): Dan: 9:30 10:30 Aimee: 9:30 10:30
Other members of your work group ____
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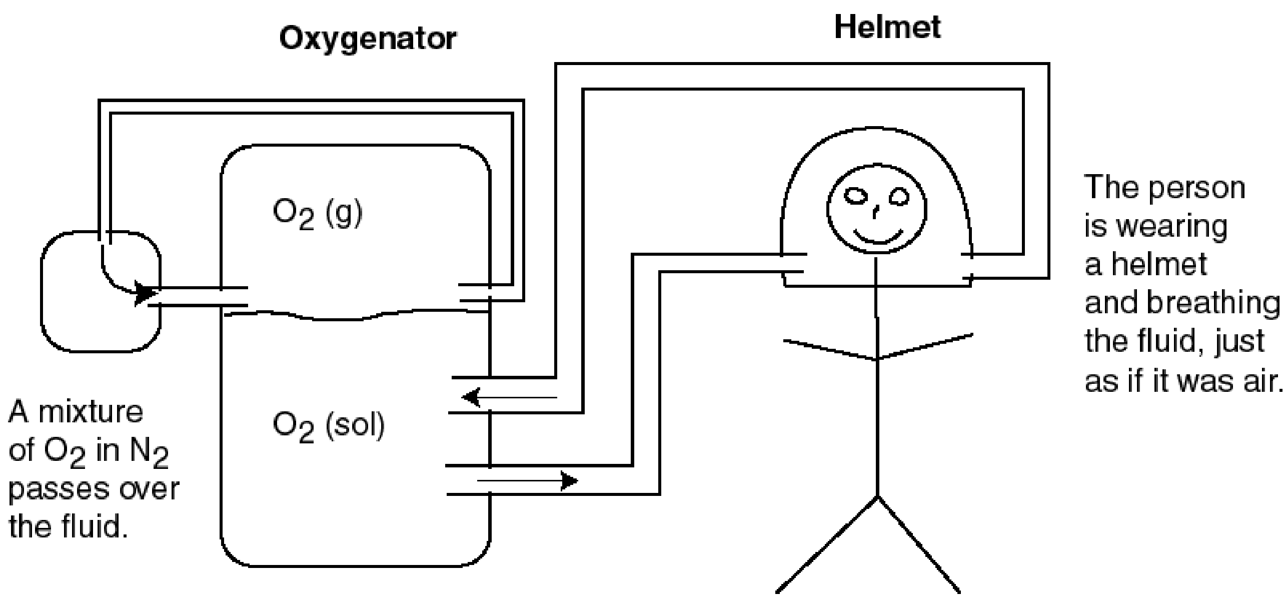
How much time did you spend on this assignment (include time spent on practice problems)?_____________________________(This is used only to monitor class work load.)

This homework assumes you have already done the practice problems for chapter 9.



The fluid carries the oxygen to the helmet. The flow rate is fast enough that the concentration of oxygen in the helmet is the same as that in the oxygenator.

In the movie "The Abyss" a deep-sea diver gets oxygen into his lungs by breathing a fluid instead of breathing air. This scene from the movie is based on actual research that was done on liquid breathing. In the June 24, 1966 issue of Science (pg. 1756) Clark and Golan reported that mice could survive for up to 20 hours when immersed in a liquid fluorocarbon. The fluid serves to bring oxygen into the lungs and remove CO_2 from the lungs. Since then, considerable research has been done on this subject. Some early work considered using liquid breathing for deep sea diving, since filling the lungs with a fluid may enable divers to go to great depths. The difficulty is that the contact of the fluid with the lungs damages the lung tissue. More recent research has focused on using liquid breathing to replace the respirators currently used in Intensive Care units. These respirators cause lung damage and it is possible that a fluid could be found that would allow patients to survive for longer periods. Most recently, the New England Journal of Medicine reported the use of liquid breathing on pre-mature babies, the first successful use of this approach in a clinical setting.

In the problems below, you will explore some of the details involved in making this type of system work, including the choice of O_2/N_2 mixture in the oxygenator and the choice of fluid.

Oxygenator One important aspect is the equilibrium governing the transfer of oxygen into the fluid. The amount of O_2 in the air flowing through the oxygenator is given by its partial pressure, P_{O2}, in atm. The concentration of O_2 in the fluid O_2(sol) is given as its concentration $[O_2]$ in molarity (moles/liter of solution). The following equilibrium expression describes the way in which O_2 dissolves in the fluid,

$$O_2\,(g) \leftrightarrow O_2\,(sol) \qquad\qquad K_1 = [O_2]/\,P_{O2}$$

In the equilibrium expression, you must use molarity for $[O_2]$ and atm for P_{O2}.

1) (2pts) Assume you are working with a fluid for which $K_1 = 0.064$, and that normal air (at 25°C) is flowing through the oxygenator. Given that the molar percent of O_2 in air is 21% (i.e. 21% of the molecules in the air are O_2) what is the concentration of O_2 in the fluid (in moles/liter)? [Assume that the flow rate of air over the fluid is sufficiently fast, that as O_2 is absorbed into the fluid, it is immediately replenished by new air. In other words, no matter how much O_2 is absorbed into the fluid, the air over the fluid remains 21% O_2.]

2) (2pts) You have constructed a liquid breathing apparatus similar to that shown above, and find that the amount of O_2 reaching the person is 60% of that needed to keep them comfortable. You decide to remedy this by replacing the air flowing through the oxygenator with a mixture of N_2 and O_2, again at 25°C. What percent of O_2 should this mixture have in order to keep the person comfortable?

3) (3pts) Lets assume that for the breathing apparatus to work, the number of oxygen molecules that enter the lungs on each breath of fluid must be equal to the number of oxygen atoms that enter the lungs when they take a breath of air. We'll also assume the person breathes the fluid in exactly the same way that they breathe air; such that the volume of fluid that enters the lungs with each breath is equal to the volume of air they would normally breath. Finally, we'll assume that we are using a fluid for which K_l= 0.044.

   You are flowing a mixture of O_2 and N_2 through the oxygenator. What % mixture of O_2 should you use so that the number of O_2 molecules that enter the lungs on each breath is equal to the number of oxygen atoms that would enter their lungs if they took a breath of normal air?

4) (3pts) Inside the lungs, Hemoglobin in the blood binds the O_2 and carries it to the body's tissues. A simplified view of this oxygen binding (***during normal air breathing***) is:

$$Hb\ (sol) + O_2\ (g) \leftrightarrow HbO_2\ (sol) \qquad K_2=83.6$$

The value of K_2 quoted above is for [Hb] and [HbO_2] expressed in moles/liter and P_{O2} expressed in atm. One liter of blood contains about 125g of Hemoglobin (total Hb + HbO_2), and Hemoglobin has a molecular weight of about 58,000 g/mole.
We will use the following simple model of what happens when a person takes a breath of the fluid.

(1) A person breathes in 0.40 liter of the liquid (i.e. their lung capacity is 0.40 liter).
(2) In the lungs, this 0.40 liters of liquid comes in contact with 0.15 liters of blood. To simplify the model, we will assume the liquid and blood mix together to form a single solution. We will also assume that before coming into contact with the fluid, all of the Hemoglobin is unbound (i.e. there is no HbO_2 present).
(3) The system comes to equilibrium based on the reaction

$$Hb\ (sol) + O_2\ (sol) \leftrightarrow HbO_2\ (sol)$$

(4) The person exhales the fluid.

Assume you are using a fluid for which K_1=0.064. A person breathes in 0.40 liters of fluid with an oxygen concentration of [O_2] = 0.014 moles/liter. In the lungs, this mixes with 0.15 liters of blood. The reaction shown in step (3) above then comes to equilibrium. What is the concentration of [Hb] in moles/liter, after equilibrium is reached (i.e. how much hemoglobin remains unbound, and therefore does not carry oxygen to the body's tissues)?

Hint 1: Don't forget about the dilutions involved in step 2.

Hint 2: Although you are not given the equilibrium constant for the reaction shown in step 3 above, you can get it from information you do have.