Oxygen Extraction During Respiration

Oxygen is required for cell metabolism. During inhalation air is brought into the lungs. Once in the lungs, oxygen gas diffuses into the bloodstream at the membrane between the alveoli and pulmonary capillaries (see Figure 1). The quantity of oxygen extracted from the air is dependent on the composition of the air and the efficiency of the lungs. The percent concentration of oxygen in air on earth is almost uniformly 21% between sea level and the stratosphere. At sea level the density of the air (molecules/unit volume) is greater than it is at higher altitudes, allowing a greater number of molecules to be inhaled with each breath.

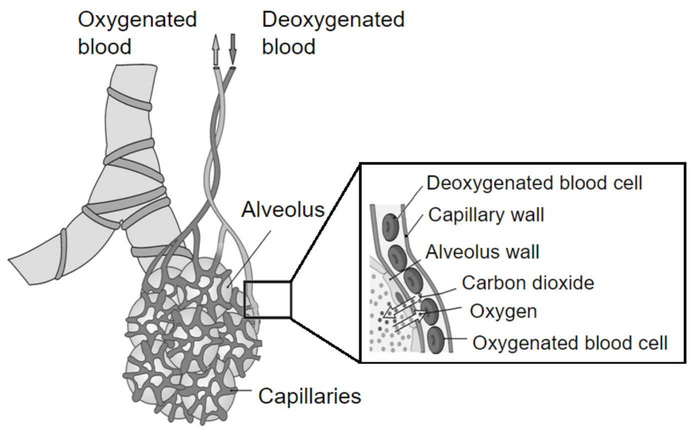

Figure 1

Diseases that damage lung tissue reduce the ability of oxygen to diffuse across the membranes in the lungs. Examples include *emphysema*, in which there are fewer total alveoli, and *pulmonary fibrosis*, in which scarring hinders oxygen transfer across a thickened membrane. Depending on the severity of the disease, people with lung disease may require supplemental oxygen. Oxygen may be supplied in concentrations anywhere from 21% to 100%. In less severe cases oxygen may not be required at sea level but needed at higher elevations or when traveling by air.

The majority of oxygen is carried in the blood by hemoglobin molecules. This is dependent upon the partial pressure of oxygen, but the binding of oxygen is efficient over a wide range of oxygen pressures. This relationship is demonstrated in the Oxygen-Hemoglobin Dissociation Curve (see Figure 2). In conditions where hemoglobin concentration is low (anemia), oxygen delivery to the tissues is proportionately decreased. Blood transfusions, rather than supplemental oxygen, will increase oxygen delivery to the tissues.

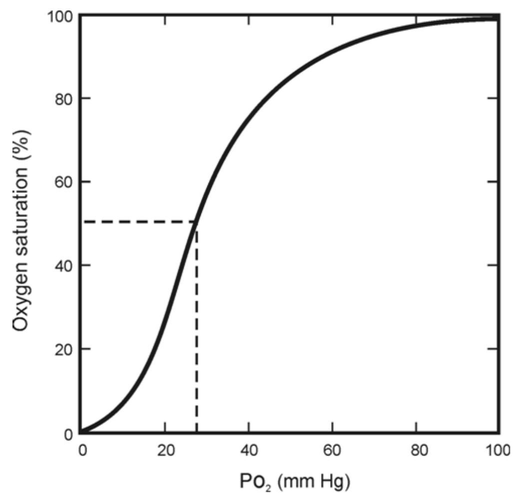

Figure 2

In this experiment, you will observe the quantity of oxygen that is absorbed from inhaled air by measuring the concentration of oxygen remaining in exhaled air. Successive breaths will further lower the oxygen concentration, allowing you to observe the efficiency of oxygen extraction by the lungs at lower oxygen concentrations.

OBJECTIVES

- Measure the concentration of exhaled oxygen.
- Observe the efficiency of oxygen extraction by the lungs as the inhaled oxygen concentration is reduced.

MATERIALS

Chromebook, computer, **or** mobile device
Graphical Analysis 4 app
Go Direct O_2 Gas
disposable mouthpiece for spirometer
ring stand
utility clamp
rubber band
clear tape
gallon size plastic bag

PROCEDURE

1. Set up the ring stand and use the utility clamp to hold the O_2 gas sensor (see Figure 3).
2. Secure the bag to the O_2 gas sensor by cutting a small hole the size of a quarter in the top of the bag and feeding the shaft of the sensor through the hole. Use tape to seal the bag to the sensor (see Figure 3).

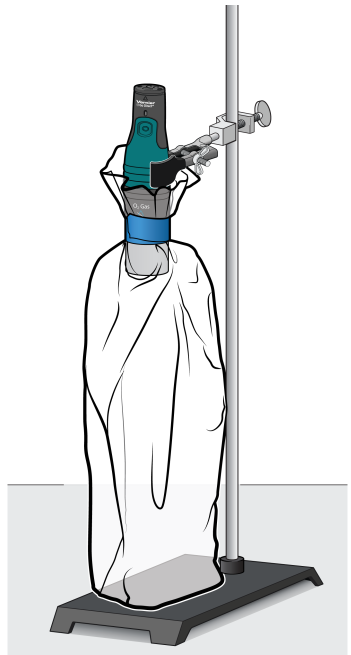

Figure 3

3. Connect the cardboard tube to the open end of the plastic bag with a rubber band.
4. Launch Graphical Analysis. Connect Go Direct O_2 Gas to your Chromebook, computer, or mobile device.
5. Set up the data-collection mode.
   a. Click or tap Mode to open Data Collection Settings.
   b. Change Rate to 1 sample/s and End Collection to 80 s.
   c. Click or tap Done.
6. The subject should be seated comfortably. Hold the tube lightly around the rubber band to avoid blocking the holes. Use the opposite hand to squeeze all of the air out of the bag.
7. Check the oxygen concentration in the meter to be sure that it reads 20−22% concentration. If it does not, remove the cardboard tube from the bag and expose the shaft of the sensor to the air by inverting the bag. When the meter reads correctly, reattach the tube and proceed with Step 8.
8. Click or tap Collect to start data collection. Take a large breath during the first 10 s. At 10 s, exhale through the tube into the bag. Without removing your mouth from the tube, wait 10 s, and then inhale the air from the bag. Repeat this process alternately exhaling and inhaling every 10 s. *Stop immediately if you feel dizzy.* Data collection will end at 80 s.

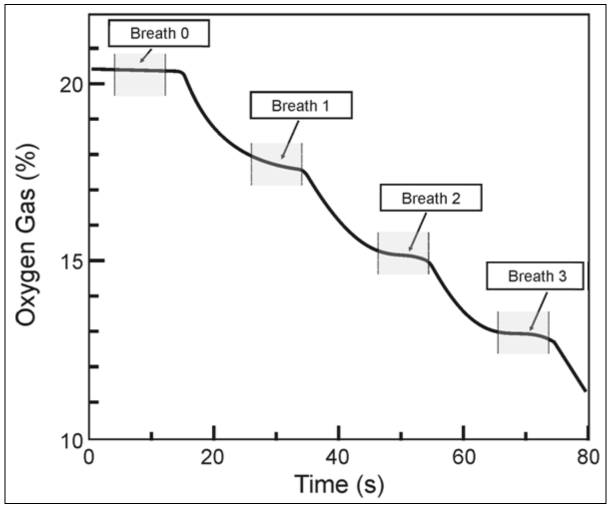

Figure 4

9. Determine the mean O_2 concentration in the bag after each exhalation.
   a. Select the Breath 0 plateau (see Figure 4).
   b. Once the area has been selected, click or tap Graph Tools, , and choose View Statistics.
   c. Record the mean O_2 concentration in Table 1 for Breath 0.
   d. Dismiss the Statistics box.
   e. Select the Breath 1 exhalation plateau.
   f. Click or tap Graph Tools, , and choose View Statistics.
   g. Record the mean O_2 concentration in Table 1 for this breath.
   h. Dismiss the Statistics box.
   i. Repeat this process for each successive exhalation plateau.

10. Determine the difference between each successive mean O_2 concentration. Enter your results in column 3 of Table 1.

11. Determine the percent of the existing O_2 that is removed with each successive breath.
    a. Divide the change in O_2 concentration value by the beginning concentration for that breath (i.e., Divide the number in column 3 by the number in the previous row in column 2).
    b. Multiply the value by 100 to determine the percent change in O_2 concentration with each successive breath.
    c. Enter your results in column 4 of Table 1 (round to the nearest whole number).

DATA

Table 1			
Breath	Mean O_2 concentration (%)	ΔO_2 concentration (%)	Percent of existing O_2 removed with each breath (%)
0			
1			
2			
3			

DATA ANALYSIS

1. Extrapolating from the graph, how many more breaths would it take to use up all of the oxygen in the bag?
2. Use the data from column 4 in Table 1 to decide whether there was any significant change in the efficiency of oxygen extraction by the lungs with successive breaths. Use your knowledge of oxygen binding to hemoglobin to explain your findings. Does this support the idea that lack of oxygen is what leads to the discomfort you may have experienced at the end of the experiment?
3. While the O_2 concentration in the bag declines with each breath, the volume of air breathed in remains the same. What is replacing the volume of oxygen that is being lost with each breath?
4. Air is humidified by the lungs such that the partial pressure of water (in the form of gas molecules) in the alveoli is 6.266 kPa (47 mm Hg). Use this information to explain why the windows in your car may fog up after you have been driving for 30 minutes.
5. Assume that the volume of air breathed in and out with normal breathing is 500 mL, or ¼ the volume breathed in and out during this experiment (1 gallon ≈ 4 L). Also assume that the efficiency of oxygen extraction is the same for these smaller breaths. How long would it take without supplemental oxygen tanks to use up all of the oxygen in a Gemini space capsule (2-person space capsule with 2.26 m^3 of habitable space)?
6. Barometric or atmospheric pressure refers to the sum total of the pressure of all gases present. At sea level it is approximately 101.3 kPa (760 mm Hg). What is the oxygen pressure in the bag at the start of the experiment? What is it at the end of the experiment? (Perform these calculations using the current barometric pressure at your location, if available.)
7. Assume the barometric pressure at the top of Mt. Everest (8,850 m) is 32.7 kPa (245 mm Hg). What is the oxygen pressure there? What percent of oxygen would need to be breathed at the top of Mt. Everest, or in a commercial airliner flying at that altitude, to equal the pressure of oxygen breathed at sea level?

EXTENSION

Perform this experiment taking normal or shallow breaths. Compare the results of this to the results you obtained in this exercise, in which you were instructed to take very large breaths.