O₂ Extraction by the Lungs

Oxygen is required for cell metabolism. During inhalation air is brought into the lungs, where oxygen is extracted. Oxygen passes 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 on 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.

Diseases in which lung tissue is damaged reduce the ability of the lungs to absorb oxygen. 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.

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

In this experiment, you will

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

MATERIALS

- computer
- Vernier computer interface
- Logger Pro
- Vernier O2 Gas Sensor
- cardboard paper towel roll
- rubber band
- clear tape
- gallon size plastic bag
- Phillips screwdriver or pointed scissors
- pen or pencil

PROCEDURE

1. Prepare the cardboard paper towel roll by cutting it to approximately 15 cm in length. Place the tube on a stable surface. Starting 3 cm from one end of the tube, mark 3 cm intervals to the other end of the tube. Draw four lines evenly spaced around the cylinder. Use a screwdriver or scissors to punch holes where indicated by the marks (see Figure 3).

2. Use clear tape to completely cover one end of the tube. On the opposite end, place tape around the circumference of the tube (Figure 3). This will prevent direct contact of the lips with the cardboard, which can result in the cardboard sticking to the lips.

3. Secure the bag to the O2 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 4).

4. Connect the cardboard tube to the open end of the plastic bag with a rubber band. The tube should be inside the bag (see Figure 4).

5. Open the file “23 O2 Extraction” from the Human Physiology with Vernier folder.

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. Allow the sensor to hang upside down for the duration of the experiment.

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 [Collect] to begin data collection. During the first 10 s take a large breath. At 10 s, exhale through the tube into the bag. Without removing your mouth from the tube, wait 10 s and 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.

9. Determine the mean O₂ concentration in the bag after each exhalation.
   a. Click and drag across the Breath 0 plateau (see Figure 5).
   b. Once the area has been highlighted, click the Statistics button, \( \square \), to display the Statistics box.
   c. Record the mean O₂ concentration in Table 1 for Breath 0.
   d. Move the brackets to highlight the Breath 1 exhalation plateau. As you move the brackets, the statistics in the Statistics box will be updated.
   e. Record the mean O₂ concentration in Table 1 for this breath.
   f. Repeat this process for each successive exhalation plateau.
   g. Close the Statistics box by clicking the × in the corner of the box.

10. Determine the difference between each successive mean concentration of O₂. Enter your results in column 3 of Table 1.

11. Determine the percent of the existing O₂ that is removed with each successive breath.
   a. Divide the change in O₂ 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 O₂ concentration with each successive breath.
   c. Enter your results in Column 4 of Table 1 (round to the nearest whole number).

## DATA

<table>
<thead>
<tr>
<th>Breath</th>
<th>Mean O₂ concentration (%)</th>
<th>( \Delta )O₂ concentration (%)</th>
<th>Percent of existing O₂ removed with each breath (%)</th>
</tr>
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</tbody>
</table>
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-man space capsule used between 1964–1966 with 2.26 m³ 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.
This is an evaluation copy of the Vernier Student Lab.

This copy does not include:

- Safety information
- Essential instructor background information
- Directions for preparing solutions
- Important tips for successfully doing these labs

The complete Human Physiology with Vernier lab manual includes 24 labs and essential teacher information. The full lab book is available for purchase at: http://www.vernier.com/cmat/hpa.html