

# Week 9: Pulmonary Function (PF) II

BIOE 320 Systems Physiology Laboratory

## Objectives

1. To perform mass balances on  $O_2$  and  $CO_2$  during respiration.
2. To calculate alveolar and pulmonary ventilation rates.
3. To obtain a value for  $VO_2$ , the volume of oxygen consumed at STP per 1 minute interval, at rest, after exercise, and during hyperventilation.

## Background

### Dead Space

Defined as the volume of gas that does not participate in gas exchange.

- Anatomical dead space (about 150 mL) results from the dead space in the conducting airways (trachea, bronchi, and bronchioles). The air in the conducting airways does not reach the alveoli and, as a result, does not participate in gas exchange.
- Alveolar dead space (very small in healthy subjects) results from poor perfusion to the alveoli. When blood perfusion is limited, some alveoli (even when they contain air) will not participate in gas exchange.
- Physiological dead space is the sum of the anatomical and alveolar dead space and it represents the volume of air that is inspired but does not participate in gas exchange with blood flowing through the lungs.

### Ventilation Rate

Defined as the number of breaths in a given time:

- Pulmonary or minute ventilation rate represents the volume of air breathed in and out in one minute.
- Alveolar ventilation rate represents the volume of air that reaches the alveoli and is available for gas exchange in 1 minute.

### Gas Exchange

The goal of breathing is to provide a continuous supply of  $O_2$  to the tissues and to constantly remove  $CO_2$ . This gas exchange at both the pulmonary and the tissue capillary levels involves simple passive diffusion of  $O_2$  and  $CO_2$  down partial pressure gradients.

Atmospheric air is a mixture of gases (about 79% nitrogen and 21% oxygen, with almost negligible percentages of  $\text{CO}_2$ , water vapor, other gases, and pollutants. Altogether, these gases exert a total atmospheric pressure of 760 mmHg at sea level. This total pressure is equal to the sum of the pressures that each gas in the mixture partially contributes. The pressure exerted by a particular gas is directly proportional to the percentage of that gas in the total air mixture. For example, the partial pressure (or the individual pressure exerted by a gas within a mixture of gases) of oxygen ( $P_{\text{O}_2}$ ) in atmospheric air is normally 160 mmHg, whereas the atmospheric partial pressure of  $\text{CO}_2$  ( $P_{\text{CO}_2}$ ) is 0.03 mmHg. Since there is a difference in partial pressures between alveolar air and pulmonary capillary blood (e.g.  $P_{\text{O}_2, \text{alveoli}} > P_{\text{O}_2, \text{blood}}$ ), gas will diffuse down its partial pressure gradient from the area of higher partial pressure to the area of lower partial pressure (Fig. 1).

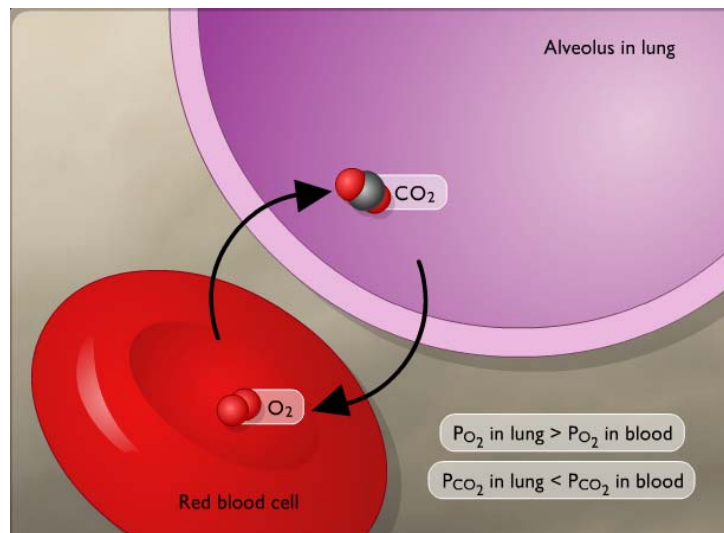


Figure 1: Gas exchange in the lungs

In addition to partial pressure gradients, there are several factors that can influence the rate of gas transfer:

- **Surface area:** An increase in surface area of the alveolar membrane will result in an increased rate of transfer. Surface area remains fairly constant under resting conditions, but can change with exercise by increasing the number of pulmonary capillaries open (as a result of changes in cardiac output) and by expanding the alveoli as breathing becomes deeper. Pathological conditions, such as emphysema or lung collapse, can decrease the surface area.
- **Membrane thickness:** As the barrier separating the air and blood across the alveolar membrane increases, the rate of transfer will decrease. Thickness can increase in the pathologic conditions such as pulmonary edema and pulmonary fibrosis.
- **Diffusion coefficient:** As the diffusion coefficient (solubility of the gas in the membrane) increases, the rate of transfer will increase. The diffusion coefficient for  $\text{CO}_2$  is 20 times higher than that of  $\text{O}_2$  offsetting the smaller  $P_{\text{CO}_2}$  gradient.

## Experimental Methods

### Hardware and Software Setup

1. Set up the gas analysis system.
  - (a) Connect Gas-System2 to power supply and turn on to allow it to warm up for 5 minutes before calibration.
  - (b) Connect AFT7 tubing to the inlet of Gas-System2 (Fig. 2).

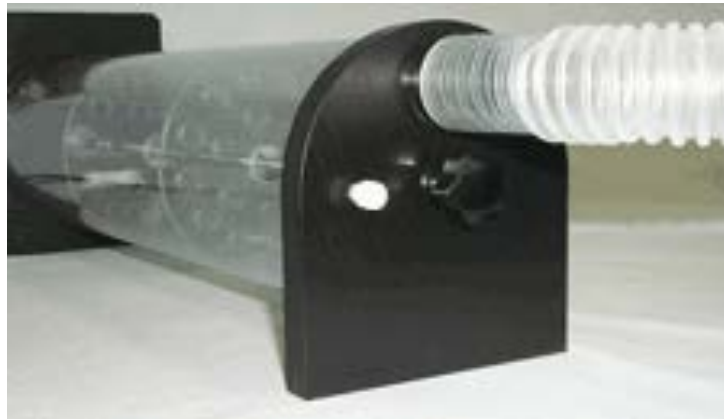


Figure 2: Inlet of Gas-System2 connected to AFT7 tubing

2. Assemble airflow accessories and connect them to the gas chamber. Keep in mind that some of these components might already be assembled (Fig. 3).
  - (a) Attach your disposable bacteriological filter (AFT1) to inlet side of the airflow transducer (SS11LA).
  - (b) Connect AFT22 T-valve to opposite side of airflow transducer. Check that the arrows indicating airflow are pointing away from the airflow transducer.
  - (c) Connect AFT11C couplers to remaining two ports of T-valve.
  - (d) Use AFT11E (blue coupler) to connect AFT7 tubing to T-valve in the port opposite of SS11LA connection.
  - (e) Attach AFT6 calibration syringe to remaining port of T-valve.
3. Connect SS11LA airflow transducer to channel 1.
4. Connect O<sub>2</sub> output from Gas-System2 to channel 2.
5. Connect CO<sub>2</sub> output from Gas-System2 to channel 3.
6. Turn on MP3X.

### Calibration

1. Open BIOPAC student lab lessons software and select *H19 - VO<sub>2</sub> and RER* (located under PRO lessons).
2. Pump calibration syringe 15-20 times to flush Gas-System2 chamber with ambient air.

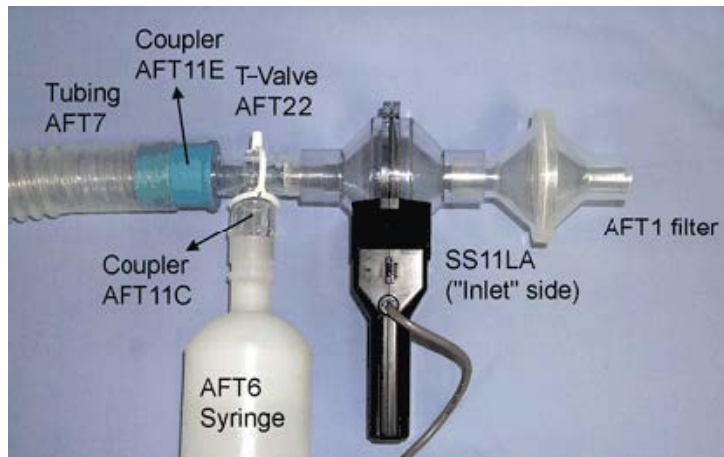


Figure 3: Schematic of airflow accessories connected to Gas-System2

3. Select *MP3X* from the menu bar at the top of the screen, then choose *Set Up Data Acquisition*.
4. Make sure the sampling rates of all three channels are set to 100 Hz. Check all boxes (Acquire, Plot, and Value) for channels 1, 2, and 3.
5. Calibrate airflow (channel 1).
  - (a) Select row 1 (Airflow) and click *Setup* in the top right corner of the window.
  - (b) Click *Scaling* at the bottom of the pop up window.
  - (c) Hold airflow transducer still and upright and press *Cal 1* button.
  - (d) Subtract 3000 from *Cal 1* value and enter as *Cal 2* input value field.
  - (e) Check *Cal 1* Map value is zero and *Cal 2* value is 10.
  - (f) Click *OK* twice to exit.
6. Calibrate O<sub>2</sub> (channel 2).
  - (a) Select row 2 (O<sub>2</sub>e) and click *Setup* in the top right corner of the window.
  - (b) Click *Scaling* at the bottom of the pop up window.
  - (c) Click on *Cal 2* button.
  - (d) Enter value 20.93 as *Cal 2* Map value.
  - (e) Confirm that both *Cal 1* input value and *Cal 1* Map value are zero.
  - (f) Click *OK* twice to exit.
7. Calibration CO<sub>2</sub> (channel 3).
  - (a) Select row 3 (CO<sub>2</sub>e) and click *Setup* in the top right corner of the window.
  - (b) Click *Scaling* at the bottom of the pop up window.
  - (c) Click on *Cal 1* button.
  - (d) Enter value 0.04 as *Cal 1* Map value.
  - (e) Add 10 to *Cal 1* input value and enter as *Cal 2* input value.
  - (f) Set *Cal 2* scale value to 1.04.
  - (g) Click *OK* twice to exit.

## Test Procedure

### General Guidelines

1. Before every trial, pump calibration syringe 15-20 times to flush the mixing chamber with ambient air.
2. While recording, hold airflow apparatus very still parallel to floor. Make sure to keep the airflow transducer handle perpendicular to floor.
3. Begin every recording with inhalation and end with exhalation. This will prevent receiving  $O_2$  inspiration values less than that of total expiration.
4. Record for a few seconds without breathing at the beginning of each experiment to ensure that the baselines are correct. Hit the vertical autoscale button, as needed, to confirm the magnitude of the baseline traces. If baseline values are not correct, stop and troubleshoot.
5. Replace calibration syringe with AFT1 filter and AFT2 mouthpiece (Fig. 4).

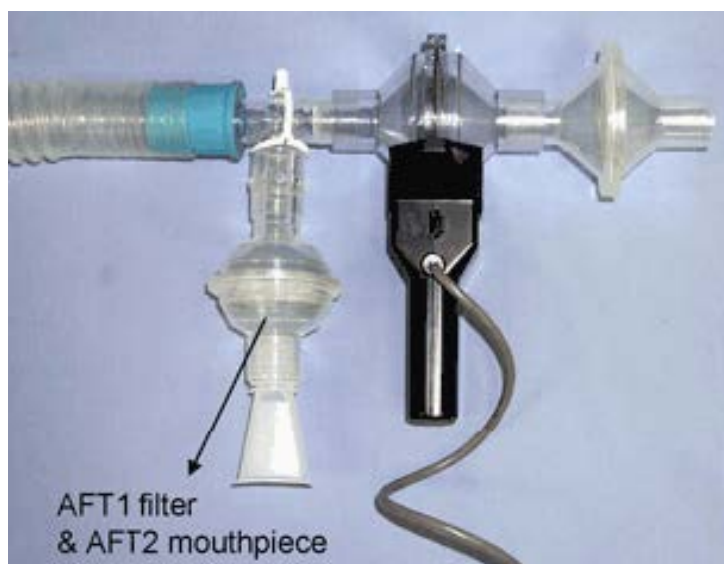


Figure 4: Schematic of airflow accessories with AFT1 filter and AFT2 mouthpiece

The output from the BIOPAC Pro Software is summarized in Table 1.

Table 1: BIOPAC Pro Software output

Output	Abbreviation	Units
Airflow through the pneumotachometer	Airflow	[L/sec]
$O_2$ concentration in the mixing chamber	$O_2E$ (expired)	[volume %]
$CO_2$ concentration in the mixing chamber	$CO_2E$ (expired)	[volume %]
Volume of $O_2$ consumed at STP per 60 sec interval	$VO_2^*$	[L/min]
Respiratory Exchange Ratio	RER	[-]

## Test Procedure

### Normal Breathing

1. Have the subject put a nose clip on.
2. Press Start button in the lower right corner of the Pro Software.
3. Record for a few seconds without breathing to ensure the baselines are correct.
4. Have the subject breathe normally in and out of the mouthpiece for at least 2 minutes. This ensures that mixing occurs and that the tank fills completely with exhaled air.
5. Press the Stop button in the Pro Software and save your data.

### Hyperventilation

1. Have the subject put a nose clip on.
2. Press Start button in lower right corner of the Pro Software.
3. Record for a few seconds without breathing to ensure the baselines are correct.
4. Have the subject breathe normally for 1 minute.
5. Have the subject hyperventilate for 1 minute.
6. Resume normal breathing for 1 minute.
7. Press the Stop button in the Pro Software and save your data.

### Recovery from Exercise

1. Perform the exercise of your choice that gets your heart rate up.
2. Following exercise, immediately attach nose clip.
3. Press Start button in lower right corner of the Pro Software.
4. Record for a few seconds without breathing to ensure the baselines are correct.
5. Breathe in and out of the mouthpiece for at least 2 minutes.
6. Press the Stop button in the Pro Software and save your data.

## Data Analysis

Use the following values, if necessary:

- Ambient air composition by volume: 20.93% O<sub>2</sub>, 0.04% CO<sub>2</sub>, 79.03% N<sub>2</sub>
  - Vapor pressure of water is 22.4 mmHg at 75°F and 47.07 mmHg at 98.6°F
1. Complete the chart for O<sub>2</sub> %, CO<sub>2</sub> %, and VO<sub>2</sub> over the three test conditions.
  2. Complete the chart for molar concentrations of O<sub>2</sub> over the listed conditions.

3. Compare and explain the results. Focus on comparisons between A & B, B & C, D & E, and B & E.
4. For each of the three test conditions, determine the mean measured breathing or respiratory rate and the tidal volume. *Hint*: obtain tidal volume from the airflow trace.
5. Explain your method for determining the breathing rate and the tidal volume.
6. Based on your data, how many moles of  $O_2$  are consumed per breath for normal breathing? How many moles of  $CO_2$  are produced per breath for normal breathing? The volume of the mixing chamber is 5 L. Record these numbers for the post-lab.
7. Calculate the pulmonary ventilation rate for each of the three conditions through the following steps:
  - (a) Calculate the minute respiratory rate (total pulmonary ventilation rate) and record in the chart below. Explain how you performed the calculation.
  - (b) Compare and briefly explain differences in minute respiratory rate among the test conditions.
  - (c) Calculate the alveolar ventilation rate and record in the chart below. Assume a dead space volume of 150 mL/breath. Explain how you performed the calculation.
  - (d) Compare and briefly explain differences in alveolar ventilation rate among the test conditions. Use the dead space of 150 mL to fill in the table.
  - (e) Which of the two ventilation rates is a more accurate indicator of the efficiency of actual breathing/ventilation? Explain.
8. The rate of oxygen consumption is equal to the rate of oxygen diffusion across the respiratory membrane. Determine the rate of oxygen consumption for the normal and exercise conditions based on your experimental data.
9. How do the measured  $O_2$  consumption rates at rest and after exercise compare?