Department of Physics and Biophysics; Institute of Biology

First name ....   Date   ....

Last name ....   Degree program name ....

Exercise B46

Spirometry: pulmonary function

Table 1: Measured Lung Volumes

Lung volume measurement	Run #	Subject's volume (L)	Subject's average volume (L)	Subject's volume after exercise (L)	Subject's average volume after exercise (L)	Average volume (L)
Tidal Volume (TV)	1					0.3-0.5 + up to 50% on exercise
	2					
	3					
Inspiratory reserve volume (IRV)	1					1.9 (females) 3.3 (males)
	2					
	3					
Expiratory reserve volume (ERV)	1					0.7 (females) 1.2 (males)
	2					
	3					
Forced expiratory volume in 1 sec (FEV_1)	1					4.6 ± 0.6
	2					
	3					

Table 2: Measured Lung Capacities

Lung capacity measurement	Run #	Subject's volume (L)	Subject's average volume (L)	Subject's volume after exercise (L)	Subject's average volume after exercise (L)	Average volume (L)
Inspiratory capacity (IC)	1					2.4 (females) 3.8 (males)
	2					
	3					
Forced vital capacity (FVC)	1					5.1 ± 0.5 (males) 3.5 ±0.5 (females)
	2					
	3					
$\frac{FEV_1}{FVC} \times 100\%$						>83%

Table 3: Estimated Lung Volumes and Capacities

Name of estimate	Subject's volume (L)	Average volume (L)	
Residual volume (RV)		1.7 ± 0.6 (males) 1.3 ± 0.3 (females)	Chosen value:
Functional residual capacity (FRC)		3.3 ± 0.6 (males) 2.5 ± 0.5 (females)	
Total lung capacity (TLC)		6.8 ± 0.7 (males) 4.9 ± 0.5 (females)	
Maximum flow rate:			

Name of estimate	Subject's volume (L)	Average volume (L)
Maximum change in volume:		

INTRODUCTION:

Breathing is one of the activities of the respiratory system. The body cells need a continuous supply of oxygen for the metabolic processes that are necessary to maintain life. The respiratory system works with the circulatory system to provide oxygen, remove the waste products of metabolism and helps to regulate pH of the blood. Respiration is the sequence of events that results in the exchange of oxygen and carbon dioxide between the atmosphere and the cells of living organisms and is controled by nerve impulses (stimulation every 3 to 5 seconds). It can be divided into external respiration (gas exchange between the lungs and the blood), internal respiration (gas exchange betwen blood and tissue cells) and cellular metabolism (oxygen utilization by the cells).

Each lung is surrounded by an invaginated sac. The layer of tissue that covers the lung and dips into spaces is called the visceral **pleura**. A second layer of parietal pleura lines the interior of the thorax (Figure 1). The space between these layers, the **intrapleural space**, contains a small amount of fluid that protects the tissue and reduces the friction generated from rubbing the tissue layers together as the lungs contract and relax.

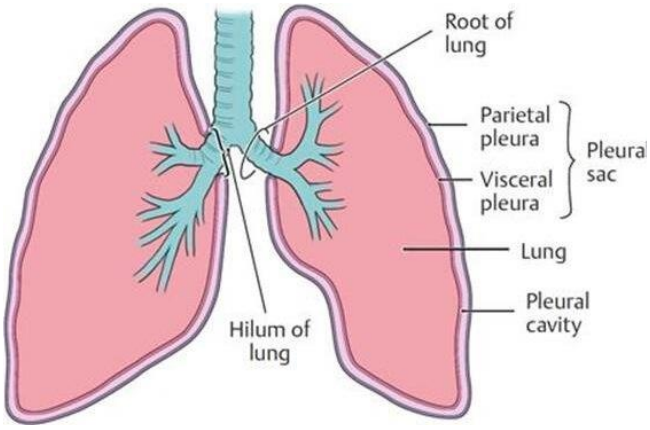


Figure 1. Pleural cavities (learnanatome.com)

The movement of air in and out of the lungs is caused by pressures (Figure 2). During the end of tidal expiration, the lungs tend to recoil inward while the chest wall tends to recoil outwards leading to a negative pressure within the potential space between the parietal and visceral pleurae. The negative intrapleural pressure (P_{Pl}) is one of the important factors that keep the patency of small airways, which lack cartilaginous support. The rhythmic contraction of inspiratory muscles causes cyclic changes in the dimensions of the thoracic cage and consequently comparable cyclic fluctuation of P_{Pl}. During tidal inspiration, P_{Pl} drops from −5 to −8 cmH_2O enforcing the intra-alveolar pressure (P_{alv}) to drop one cmH_2O below atmospheric pressure (P_{atm}) - Figure 3a. As a result, air flows into the alveoli. The drop of P_{Pl} also decreases the airways resistance by dilating the small airways enhancing the air flow. During tidal expiration the sequence is reversed. Muscles relaxation decreases dimensions of the thoracic cage, P_{Pl} increases from −8 back to −5 cmH_2O and P_{alv} increases one cmH_2O above P_{atm}. As a result, air flows outside the alveoli following the pressure gradient, Figure 3b. Tidal expiration is therefore a passive process, which needs

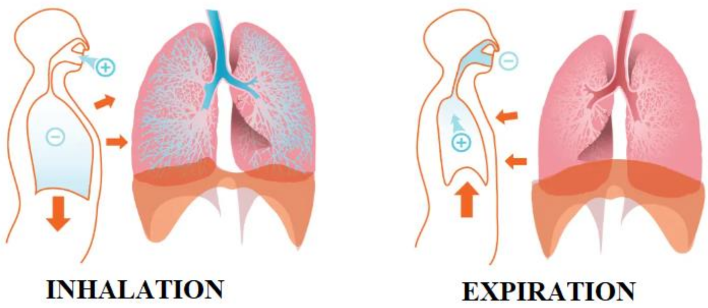


Figure 2. Coordinated work of lungs, chest wall and diaphragm in respiration (adapted from OpenStax).

no further muscle contraction. During tidal breathing, whether inspiratory or expiratory, intra-airways (P_{aw}) pressure is always more than P_{Pl}. This explains why small airways are always opened, even at the end of tidal expiration.

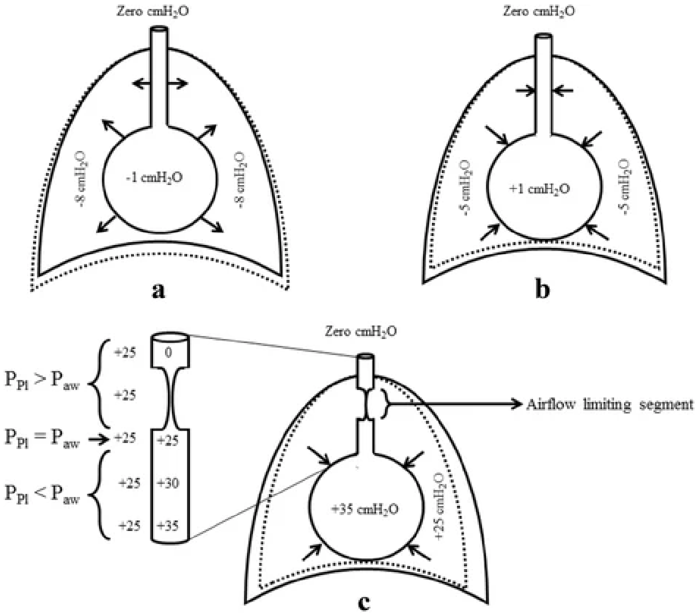


Figure 3. Intrapleural and alveolar pressures towards the end of inspiration (**a**), expiration (**b**), and forceful expiration (**c**). The dotted line indicates the change in thoracic dimensions;
during **a**, **b** and **c** compared with the previous phase of the respiratory cycle (adapted from Lutfi, M.F. The physiological basis and clinical significance of lung volume measurements. *Multidiscip Respir Med* **12**, 3 (2017)

Pulmonary ventilation can be studied by recording the volume movement of air into and out of the lungs, a method called spirometry. A *spirometer* is a device that measures the air volume moved in and out of the lungs while breathing and can be used as either a lung health diagnostic tool or for recovery following a lung illness. The Figure 4 shows a spirogram indicating changes in lung volume under different conditions of breathing.

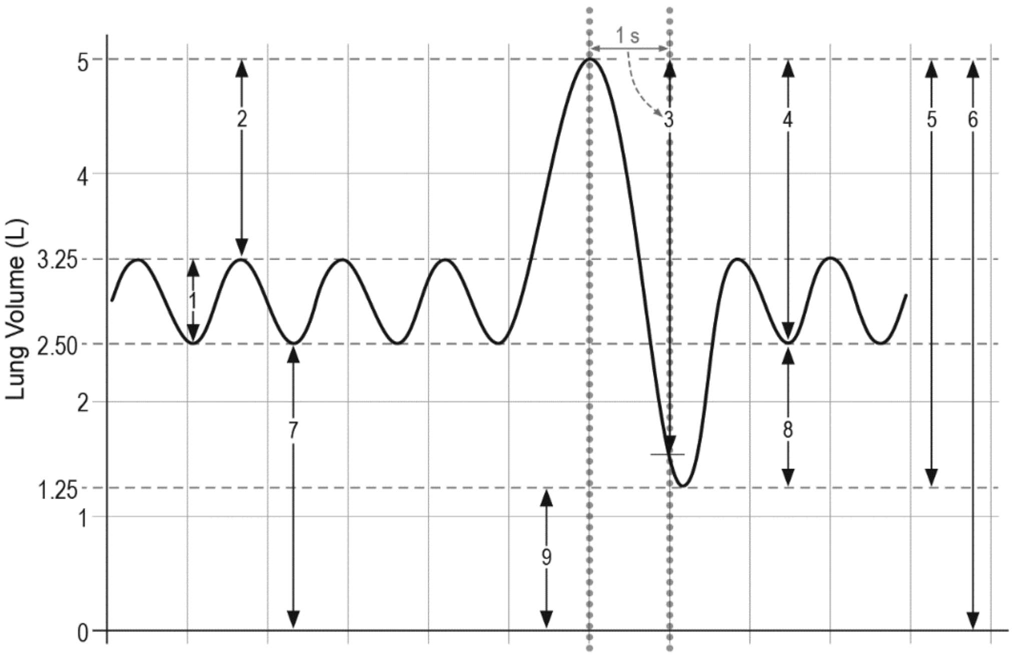


Figure 4: Spirometry test results (see table below for graph legend)

Number	Measurement	Description
1	TV: Tidal volume	Volume of air moved into and out of the lungs during a quiet, *normal* breath cycle; measured at the beginning of the test.
2	IRV: Inspiratory reserve volume	Air volume inhaled beyond a quiet, normal breath during *forced* inhalation.
3	FEV1: Forced expiratory volume in 1 second	Volume of air *forcefully* exhaled in 1 second; immediately follows maximum forced inhalation.
4	IC: Inspiratory capacity	Total volume of air inhaled at the beginning of the *forced* breath cycle; maximum possible air intake.
5	FVC: Forced vital capacity	Total volume of air exhaled out of the lungs as *forcefully* as possible; maximum possible air exhalation.
6	TLC: Total lung capacity	Maximum volume of air lungs hold at peak *forced* inhalation.
7	FRC: Functional residual capacity	Volume of air that remains in lungs at the end of a quiet, *normal* exhalation.
8	ERV: Expiratory reserve volume	The air volume exhaled beyond a quiet, normal breath during *forced* exhalation.
9	RV: Residual volume	Always-present volume of air remaining in the lungs at the end of a *forceful* exhalation.

For ease in describing the events of pulmonary ventilation, the air in the lungs has been subdivided into **volumes** and **capacities (see Table above)**. The significance of each of these volumes is the following: A) The **tidal volume** is the volume of air inspired or expired with each normal breath; it amounts to about 500 milliliters in the adult male; B) The **inspiratory reserve** volume is the extra volume of air that can be inspired over and above the normal tidal volume when the person inspires with full force; it is usually equal to about 3000 milliliters; C) The **expiratory reserve volume** is the maximum extra volume of air that can be expired by forceful expiration after the end of a normal tidal expiration; this normally amounts to about 1100 milliliters; D) The **residual volume** is the volume of air remaining in the lungs after the most forceful expiration; this volume averages about 1200 milliliters. In describing events in the pulmonary cycle, it is sometimes desirable to consider two or more of the volumes together. Such combinations are called **pulmonary capacities**, which can be described as follows: A) **The inspiratory capacity** equals the tidal volume plus the inspiratory reserve volume. This is the amount of air (about 3500 milliliters) a person can breathe in, beginning at the normal expiratory level and distending the lungs to the maximum amount; B) The **functional residual capacity** equals the expiratory reserve volume plus the residual volume. This is the amount of air that remains in the lungs at the end of normal expiration (about 2300 milliliters); C) The **vital capacity** equals the inspiratory reserve volume plus the tidal volume plus the expiratory reserve volume. This is the maximum amount of air a person can expel from the lungs after first filling the lungs to their maximum extent and then expiring to the maximum extent (about 4600 milliliters). 4. **The total lung capacity** is the maximum volume to which the lungs can be expanded with the greatest possible effort (about 5800 milliliters); it is equal to the vital capacity plus the residual volume. The lung capacities that can be calculated include vital capacity (ERV+TV+IRV), inspiratory capacity (TV+IRV), functional residual capacity

(ERV+RV), and total lung capacity (RV+ERV+TV+IRV). All pulmonary volumes and capacities are about 20 to 25 percent less in women than in men, and they are greater in large and athletic people than in small and asthenic people.

We can divide lung ventilation disorders by mechanism of action into obstructive and restrictive. Obstructive lung diseases are characterized by obstructed airflow through the lungs, which is caused by narrowing of the airways. Obstructive diseases include asthma, chronic obstructive pulmonary disease (COPD), cystic fibrosis and bronchitis, among others. In restrictive diseases, lung expansion is impaired - the lungs do not fill properly with air and their functional vital capacity decreases. Such disorders can be caused by interstitial lung diseases, tuberculosis or pulmonary fibrosis.

Experimental procedure

Part 1: Pulmonary Function Test

1. Turn on the power of the table (see the dashboard of the table - by your right leg, when you sit in front of the computer) - turn the red "knob" in the direction of the arrows (it should pop out), turn the key as in a car and let go. Turn on the computer.

2. Connect the spirometer to your device. Make sure **Lung Volume (L)** is the only measurement selected, then choose the **Graph** template.

3. Note the location of the green flashing LED light near the Bluetooth® icon on the spirometer sensor box. This LED acts as an indicator light in a future step.

4. Refer to Figure 5 while assembling the spirometer. Locate the three pins on the mouthpiece (1) and align them with the holes inside the spirometer handle (3), then snap the mouthpiece to the handle. Securely fit the filter (2) to the tapered end of the mouthpiece. If the filter does not seem secure, try fitting the opposite side to the tapered end of the mouthpiece.

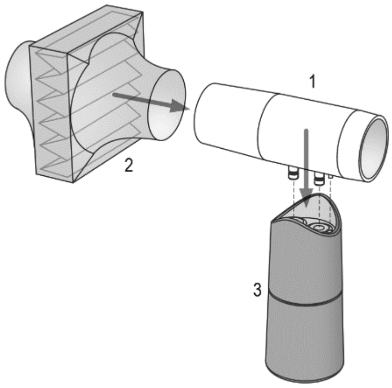


Figure 5: Mouthpiece (1), filter (2), handle (3)

5. Work in pairs. One student will be the data recorder while the other will be the test subject whose lung function will be measured. *The data recorder and test subject must read through steps 5-6 together before completing them to avoid errors caused by delays or extra breaths. Practice these two steps without breathing through the filter until you are both ready for data collection.*

6. To make sure all breath flows through the mouthpiece during data collection, the subject must consider the following during step 6:

    - You may have a tendency to move during deep breaths, but remember, you must stay still during the entire lung function test.

- A single breath consists of an inhalation followed by an exhalation. Breathe only through the mouth during data collection and follow your partner's breathing instructions. The test consists of 4 normal breaths followed by a forceful breath, ending with two normal breaths. Your partner will count breaths for you.

- *Avoid breathing through the filter until data collection has begun.* Grasp the spirometer handle and set the filter opening in your mouth. Gently bite the filter tube with your front teeth and create a tight seal around the filter with your lips. Place your tongue against your lower teeth and beneath the filter tube. Hold the sensor upright as shown in Figure 6 throughout data collection.

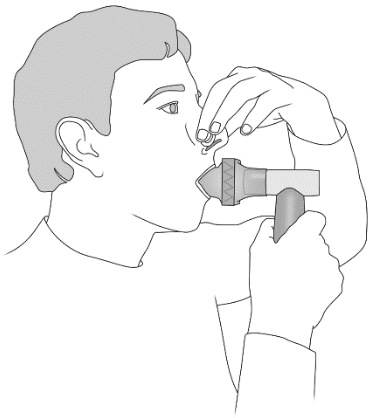


Figure 6: Proper spirometer use

- *Pinch* your nose closed and stand perfectly still. Do not look at the data while it is being recorded. *Once you pinch your nose, hold your breath until your partner tells you to begin breathing.*

7. When the subject is ready, the data recorder will perform the following:

   a. Tell the subject to hold their breath, place teeth and lips on the filter, pinch their nose closed, stand still, and relax.

   b. Start collecting data and keep your eye on the LED. Wait for the LED to finish flashing red. Once the LED returns to green, move on to step (c).

   c. Use the following script to verbally coach the subject and help them count breaths: "Take 4 normal breaths, 1… 2… 3… 4… inhale as deeply as possible… exhale deeply with maximum effort… and take 2 normal breaths, 1… 2…

> ***NOTE:*** *You should see a rise-and-fall action of the subject's chest for each breath at their normal breathing pace; use this action to help you count out breaths during the test.*

8. Stop collecting data. The graph should look similar to Figure 4; it is okay if the last two recovery breaths are lower than the first four breaths. Repeat the test if necessary. Store the subject's spirometer in a clean zip seal bag until ready for the next trial.

9. You will be collecting several measurements in all three parts of this investigation. For all measurements, report the absolute value to the nearest tenths place.

10. Open the **Graph Tools** menu and toggle from **Move** mode to **Select** mode.

11. Draw a box to select volume data for the four normal breaths through the last two breaths. **Scale** the selection.

12. Refer to Figure 4 to locate the following regions; however, *do not use the last two breaths for analysis as the recovery breaths may provide skewed results*. Use abbreviations to label each measurement in Graph 1: tidal volume (TV); inspiratory reserve volume (IRV); expiratory reserve volume (ERV); forced expiratory volume in 1 second (FEV_1); inspiratory capacity (IC); forced vital capacity (FVC).

13. Lung Volumes: Add a **Coordinates** tool and move it to the peak TV of any single gentle breath before the forced inspiration. Click the coordinate bubble to display and select the delta tool Δ. Move the new coordinate box to the adjacent trough to the right. The region between peak and trough should now be shaded and the value for Δy should represent the value for TV; record the result in Table 1.

14. Use the **Coordinates** and **Delta** tools to find IRV and ERV volumes and record the results in Table 1.

15. To determine the forced expiratory volume in 1 second (FEV_1), add a **Coordinates** tool to the peak volume of the forced inhalation. If the same peak value occurs over multiple points in time, choose the value that happened most recently in time, or, farthest to the right. Activate the **Delta** tool and move the new coordinate box to select exactly 1.000 second of data to the right of the peak. When the Δx value equals exactly 1.000 second, record the Δy value as FEV_1 in Table 1.

16. Repeat steps 5 through 15 for a total of three runs. Use the check mark option in the graph legend to display one run at a time ☑.

17. Calculate average values for each measurement and record the results in Table 1.

18. Lung Capacities: Use SPARKvue tools to determine inspiratory capacity (IC) and forced vital capacity (FVC) for all three runs and enter the results in Table 2.

19. Calculate average values for each measurement and record the results in Table 2.

20. Use average values to calculate the average forced expiratory volume percentage expelled in one second (FEV_1/FVC ratio) for the subject average and record it in the Table 2.

21. Estimated lung volumes and capacities: The average residual volume (RV) for adult males is 1.2 L and for adult females the average is 1.1 L. Enter the value the subject will use for calculations in Table 3 (“Chosen value”).

22. Use averages to calculate the subject's estimated functional residual capacity (FRC = ERV + RV) and estimated total lung capacity (TLC = FVC + RV). Enter results in Table 3.

23. **The subject should find a suitable area to perform aerobic exercise (like running in place or doing jumping jacks) for 3 minutes.**

24. Immediately after 3 minutes of exercise, the subject will stand comfortably and repeat the pulmonary test

25. Analyze the results for measurements taken after aerobic exercise.

Part 2: Max Flow Rate

1. Review Table 1 data to identify the single run that has values closest to average. Display only that run.

2. Select the **Total Flow (L)** measurement on the y-axis. In the menu that opens to the right, select **Max Flow Rate (L/s)**.

3. Use the **Coordinates** tool to identify the highest maximum air flow rate during the pulmonary function test and record the value in the space provided below Table 3; include units.

4. Move the **Coordinates** tool to find the second highest maximum air flow rate for the run and record the value in the space provided below Table 3; include units.

Part 3: Spirometric Flow Volume Loop

1. Use the same run from Part 2. Select the **Max Flow Rate (L/s)** measurement on the y-axis. In the menu that opens to the right, select **Flow Rate (L/s)**.

2. Select the **Time (s)** measurement on the x-axis and replace it with **Lung Volume (L)**.

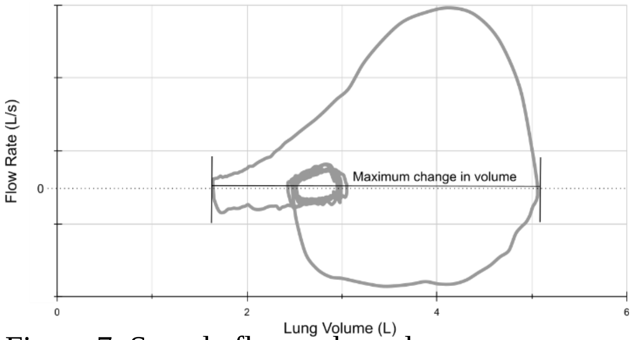


Figure 7: Sample flow volume loop

3. **Scale** the graph so both axes are maximized, then click the **Lock** icon at the top of the y-axis to toggle from unlocked to locked.

4. Manually adjust the x-axis scale to achieve a range of 0 to 6.0 L (or higher if needed) as shown in Figure 7.

   a. Click and hold an area that contains no data points inside the graph. Move the graph to the right until the x-axis reaches a volume of exactly 0 L.

   b. Hover over the right side of the x-axis values. Click and hold, then drag until 6.0 appears at the end.

5. Use the **Coordinates** and **Delta** tools to determine the maximum change in volume across the widest part of the volume flow loop. This should occur between the two outermost points of the loop that intersect the y-axis at 0 L/s (refer to Figure 7). Record the value in the space provided below Graph 2; include units.

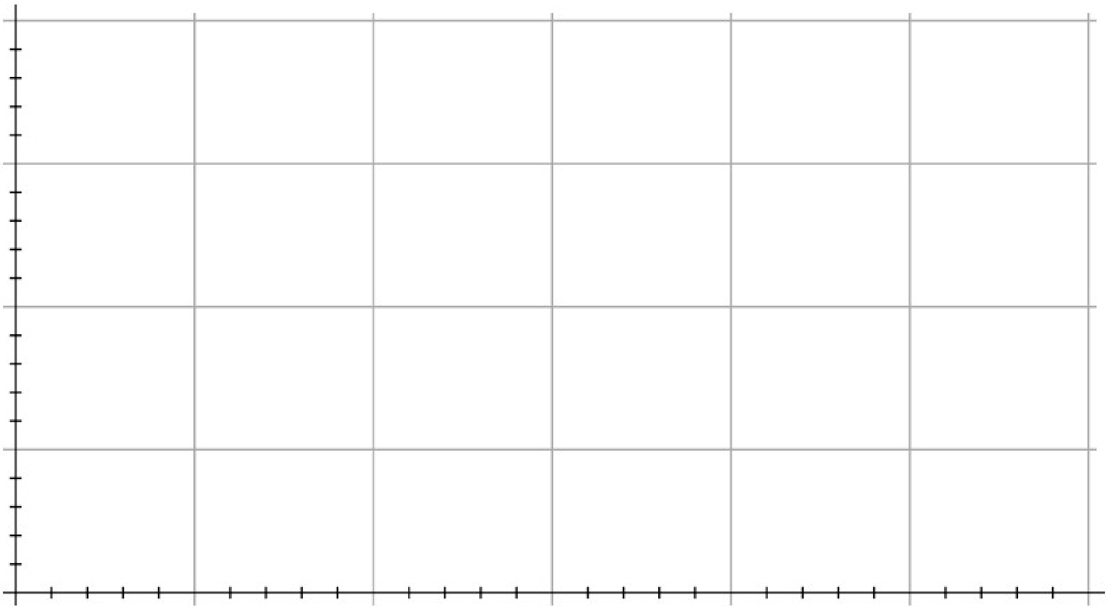
6. Use the **Coordinates** tool to identify the maximum value as well as minimum value in the flow volume loop. Record the results including units.

7. Analyze the shape of the resulting Flow-Volume LOOP with the following in mind:

   - the graph of a healthy person: on the lower side of the graph a semicircle (inspiration), on the upper side a triangle (expiration)

- patient with COPD (fine bronchial obstruction) - concavity of the upper triangle (expiration), inspiration normally

- patient with fibrosis (restriction) - curve shape similar to normal, but reduced with low airflow velocities and low volumes



Maximum change in volume across flow volume loop: ………………………………