

# Circulation and Respiration: Vital Signs

## Teacher Version

In this lab, you will learn about the circulatory and respiratory systems. You will test the capacity of your lungs, measure your blood pressure and pulse, and explore the effects of exercise on your vital signs.

### California Science Content Standards:

- 9. Physiology: As a result of the coordinated structures and functions of organ systems, the internal environment of the human body remains relatively stable (homeostatic) despite changes in the outside environment.
- 9a. Students know how the complementary activity of major body systems provides cells with oxygen and nutrients and removes toxic waste products such as carbon dioxide.

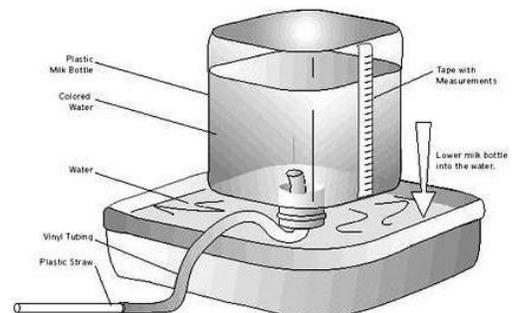
### Complete List of Materials (per group):

- Model lung (made from a cut-off 0.5 L or 2 L bottle, with a balloon inserted inside and a balloon / plastic membrane around the cutoff end; see picture below)
- Spirometer (available at hospital)
- Alcohol wipes to clean off the spirometer mouthpiece
- Jug capable of holding at least 4 L of water, marked off at 0.5 L marks
- Tub capable of holding more water than the jug
- Stop watch
- Plastic tubing (eg: aquarium tubing) and a straw to serve as a mouthpiece
- Calculator
- Pair of non-latex gloves per student
- Sphygmomanometer
- Stethoscope

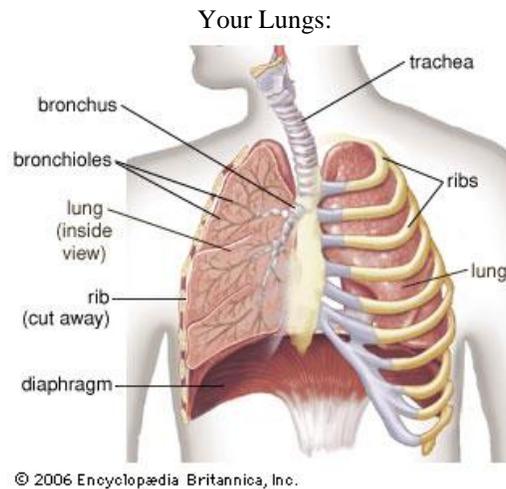


### Preparation and Lab Notes:

- To set up the model lung: cut off the bottom of the bottle. If using a smaller bottle, cut the neck off a non-latex glove and stretch it over the cut-off end. Use a rubber band or duct tape to secure it in place. If using a larger bottle, use a plastic-wrap membrane over the cutoff end. Insert another non-latex glove into the bottle, and hook the neck around the neck of the bottle.
- To set up the spirometer: Use a measuring cup to pour in 500 mL at a time into the large jug and mark off the level of the water, all the way to the top of the jug. To use, fill the whole jug with water, invert it into a tub with some water, and insert tubing into the open mouth of the jug (under water). Use a straw as a disposable mouthpiece for the tubing.



- Before beginning this lab, teacher (test subject) should test own heart rate, both at rest and after exercise, to get controlled results. (Student results are often not in the right ballpark).



## Part 1 – Lung Capacity

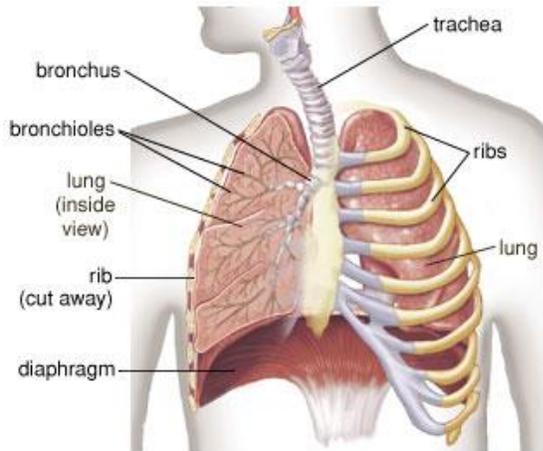
### Key Concepts:

- Your respiratory system is the one that lets you breathe in air and take the oxygen it has to bring it into your blood. The blood then carries this oxygen to other parts of your body where all cells use it to make energy.
- The **tidal volume** is the amount of air moved in or out during an ordinary breath. Of course, it is also possible to take a much deeper breath than you normally would, as if you were about to dive under water.
- The **inspiratory capacity** is the maximum volume of air you can inhale after an ordinary breath out.
- The **vital capacity** is the maximum amount of air that you can voluntarily move out of your lungs by breathing in as much as possible and then exhaling as far as possible.
- The **diaphragm** is a skeletal muscle tissue that helps in breathing. It is located beneath the rib cage and above your abdomen, and normally remains in a slightly bent U-shape. When it relaxes, the diaphragm moves up and pushes on the lung space, expelling the air in them (exhale). When the diaphragm contracts, it moves down and increases the volume of the lungs, which means there is higher pressure outside that makes the air rush into the lungs (inhale).

**Lab:** At this station, you will measure the lung capacity of your test subject.

- The **lung capacity** is the total volume of air that your lungs can hold.
- An **inspirometer** is an instrument used to measure how much air is breathed in.
- A **spirometer** is used to measure how much air is breathed out.
- **SAFETY CONCERNS:** Clean off the inspirometer mouthpiece with alcohol and replace the straw at the spirometer mouthpiece between subjects to avoid spreading germs.

## Labeled Chest Cavity



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## Model Lung

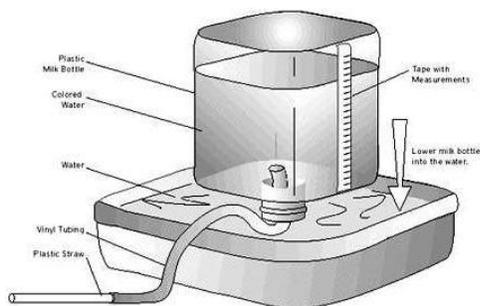


Q1. Which parts of the model corresponds to the following components in the diagram?

- diaphragm:** *the bottom membrane*  
**lung:** *the balloon inside the bottle*  
**trachea:** *the neck of the bottle / balloon*  
**chest cavity:** *the bottle itself*

## Procedure:

1. Use the **inspirometer** to measure how much air your subject takes in during a normal breath (have them take a normal breath out and then a normal breath in by sucking on the mouthpiece of the inspirometer).
2. Look at the volume mark on the device and *record this as the **tidal volume** on the chart below.*
3. Now have the subject breathe in as hard as possible using the inspirometer. *Record the result as the **inspiratory capacity**.*



(source: <http://howtosmile.org/record/1404>)

4. Now use the homemade **spirometer** consisting of a large jug inverted in a tub of water.

Read in the original mL marking at the level of the water in the jug. Then have your subject breathe in as far as possible and then exhale, slowly and steadily, as far as possible into the straw connected to the inverted jug. *Record the level of the water again.*

**Starting volume:** \_\_\_\_\_

**Ending volume:** \_\_\_\_\_

In the table below, record the **vital capacity** as ending volume minus starting volume.

4. Find the **breathing rate** of the subject by counting the number of breaths they take in 30 seconds and then multiplying by 2 to get breaths per minute.

Tidal volume (mL)	
Inspiratory Capacity (mL)	
Vital capacity (mL)	
Breathing Rate (breaths per minute)	

5. What volume of air is moved in and out of your subject's lungs each minute? (use tidal volume \* breaths per minute)  
 volume moved each minute = \_\_\_\_\_

**STUDENT ADVANCED VERSION ONLY**

6. Research has shown that lung capacity is proportional to the surface area of the body. A handy formula for estimating the body surface area (in m<sup>2</sup>) is:

$$\text{surface area} = \sqrt{\frac{\text{height (in inches)} \times \text{weight (in lb)}}{3118}}$$

The approximate relationship between surface area and vital capacity is given by

For males: vital capacity (in mL) = 2500 \* surface area

For females: vital capacity (in mL) = 2000 \* surface area

Use the equations to fill in the following table (ask the subject for their height and weight). To calculate % error use: **(measured – predicted)/predicted \* 100**

height (in inches)	
weight (in pounds)	
Approximate body surface area (in m <sup>2</sup> )	
Predicted vital capacity	
Measured vital capacity (from previous table)	
% error	

## Questions:

Q2. Which was larger, the subject's vital capacity or their inspiratory capacity? If the inspiratory capacity was larger, where did the extra inhaled air go? If the vital capacity was larger, where did the extra air come from?

*Vital capacity should be greater than inspiratory capacity. On the previous breath, you only breathed out a small fraction of the air in your lungs. When you breathe all the way out into the spirometer, that air comes out as well.*

Q3. Would larger people tend to have larger or smaller lung capacities? Why do you think this makes sense biologically?

*Larger people should have larger lung capacity because they need more oxygen to support more tissue mass.*

Q4. Regular exercise can increase lung capacity. Suggest why this might be the case? Would some types of exercise have a greater effect than others, and why?

*Aerobic exercise (such as brisk walking, jogging, swimming, and dancing) should have the greatest effect. By exercising, you increase your body's demand for oxygen and the lungs, diaphragm, etc. will adapt to provide more oxygen.*

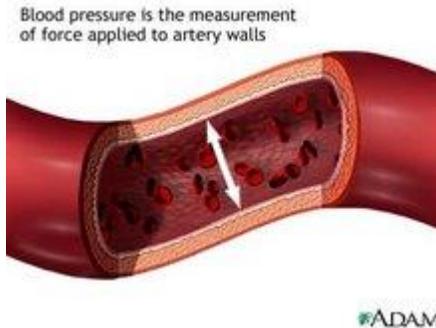
Q5. Who would you expect to have a larger lung capacity, a person living high up the mountains of Tibet or a person living by the sea in the Caribbean? Why?

*People living at high altitudes tend to have higher lung capacity because the concentration of oxygen is lower, so they need to inhale more air to get the same amount of oxygen.*

## Part 2 – Blood Pressure

### Key Concepts:

- **Blood pressure** is the **force** exerted by circulating blood on the walls of blood vessels.

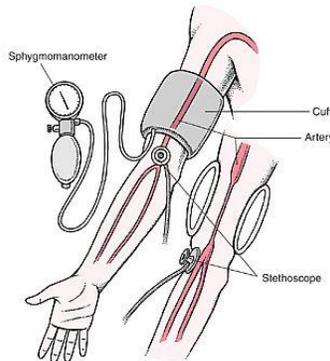


- Blood flows **away** from the heart through vessels called **arteries** and **capillaries** and **towards** the heart through **veins**. Blood pressure is used as a vital sign measure.
- Since blood pressure is used as a vital sign measure, there are two measurements that are usually taken – the diastolic and systolic pressures.
- *Systolic Pressure* = the peak pressure in the arteries, which occurs when the ventricles of the heart are pumping blood out.
- *Diastolic Pressure* = the minimum pressure in the arteries which occurs when the ventricles of the heart are filling with blood. In adults, the healthy range is 90-119 mmHg (systolic) and 60-79 mmHg (diastolic). (mmHG stands for millimeters of mercury (Hg) – this is standard unit of pressure)

Many factors affect blood pressure including heart rate, blood volume, resistance from the blood vessels, and blood viscosity or thickness. In this lab we will explore some of the factors that can influence blood pressure.

### Procedure:

1. Clean off the ear pieces of the stethoscope with an alcohol wipe.
2. Have the subject seated comfortably and relaxed with the forearm placed on a smooth surface at heart level.
3. Wrap the deflate cuff snugly around the subjects upper arm (2-3 cm above the elbow).



([http://i.ehow.com/images/GlobalPhoto/Articles/4880677/cuffposition.jpg\\_Full.jpg](http://i.ehow.com/images/GlobalPhoto/Articles/4880677/cuffposition.jpg_Full.jpg))

4. Locate the brachial artery with your two fingers as if you were to take a pulse. Make sure you can feel the pulse with your fingers
  5. Increase the pressure in cuff while monitoring the pulse. Stop increasing pressure when the pulse ceases. **DO NOT EXCEED 140-150 mmHg**
  6. Place the disc of the stethoscope in the inside of the elbow as in the diagram. Slowly release cuff pressure (2-5 mmHg per second) as you listen with the stethoscope for a tapping sound.
  7. *Record the pressure at which you heard the first clear tapping sound.* This is the **systolic pressure**.
  8. Listen for the sounds to become louder and then disappear. When you do not hear the sounds anymore, *record the pressure.* This is the **diastolic pressure**.
  9. Deflate the cuff rapidly after this measurement has been recorded.
- \*\* Remember not to leave the cuff inflated on the subject for more than a few seconds.

Now that you are familiar with how to measure blood pressure, we'll measure blood pressures for different physical positions.

Position	Systolic Pressure	Diastolic Pressure
Standing		
Sitting		
Sitting with one arm raised		
Lying down (on your back)		
Lying down (knees to chest)		

### Questions:

Q6. *What trend do you see when comparing blood pressures while standing, sitting, and laying down?*

*We should notice that blood pressure increases from laying down to sitting and from sitting to standing.*

Q7. *Given what we know about blood pressure, why might we see this trend?*

*When we are in an upright position, it takes the heart more effort to pump the blood through our body. The increase in force required for this consequently raises the blood pressure.*

Sometimes, the physical factors that influence blood pressure (mentioned above) can be influenced by physiological factors or habits that cause changes to our body. These can include diet and exercise.

Q8. *Salt is one part of our diet that can affect our blood pressure. Increased salt intake causes the kidney to retain more fluids. This leads to an increased preload in the heart. Preload is the pressure stretching the ventricle of the heart after it has been filled. How would this affect blood pressure?*

*Excess salt in diet increases the pre-load and the volume of fluid that is circulating. This increased volume exerts more pressure against the artery walls and therefore increases blood pressure.*

**Q9. Saturated fats** are not good for the heart and blood vessels because they increase the viscosity of blood, making the blood that flows through thicker than it normally would be. How would this affect blood pressure?

*Because the blood is thicker, it is more difficult to pass through the arteries and therefore the pressures that push it through must increase, causing an increase in blood pressure.*

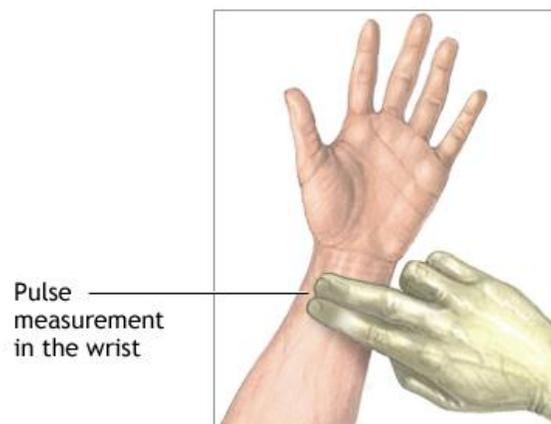
**Q10. Exercise** What do you think would happen to your blood pressure during exercise? Why?

*As you exercise, your muscles require more oxygen. This oxygen is delivered by blood as it passes through the arteries. Therefore blood pressure will increase to deliver more oxygen through the blood to muscles. Usually, only the systolic pressure will change while the diastolic pressure will remain similar to the non-exercise case. This is because systolic corresponds to the pumping of the heart whereas diastolic corresponds to the filling of the heart.*

## Part 3 – Heart Rate

### Key Concepts:

- Exercising requires energy
- Energy is the product of the cellular respiration reaction that uses oxygen
- The only way to elevate the amount of oxygen delivered to cells is to increase the rate at which blood is pumped to them, through an increase in heart beats per minute.
- An person's heart rate is a measure of the number of times the heart contracts per minute for the purpose of pumping blood through the circulatory system. It can be measured by applying slight pressure to an artery near the skin and feeling for a pulse. A common place to check for a pulse is at the radial artery, which is located on the inside of the wrist, right below the base of the palm and on the thumb-side, as illustrated in Figure 1.
- *It may be tricky to accurately feel the pulse if the students aren't familiar with it. Find the pulse first as a teacher and have the students place their fingers on the same spot, as needed. Students need to be able to accurately sense the pulse in order to get meaningful results.*



ADAM.

- An individual's heart rate is affected by the rate at which blood must deliver oxygen to the cells for energy generation through respiration.

## Procedure:

The following segment of the lab illustrates the effects of physical activity on heart rate. It requires two different types of participants:

*Doctors:* Several students who measure and record the heart rate of the patient. There should be a stopwatch available for their use.

*Patients:* Either a teacher or a student who is able to perform strenuous physical exercises and have his/her heart rate measured by the “doctors”

### Step 1: Measuring Heart Rate Accurately

- Have the patient sit down and relax for two minutes. He or she should already be fairly relaxed (not someone who is out of breath from running to class)
- One doctor should position his or her fingers on the patient’s left radial artery, while the other checks the patient’s right radial artery, so that both can feel a pulse (see Figure 1).
- Once both doctors have detected a pulse, another doctor (or one who is taking a pulse if the group has 2 members) should tell the doctors feeling the pulse when to start counting beats, corresponding to the time he or she starts the stopwatch. They should count beats silently until the person with the stopwatch tells them to stop after 30 seconds.
- Compare the two amounts of beats that each doctor measured. If the two counts are more than one beat different from each other, repeat the exercise until the two counts match up, at which point it seems that they have both measured correctly.

### Step 2: Resting heart rate

- Multiply the count of beats from the previous part by 2 to get the beats per minute (BPM) of the patient in a resting state.
- *Patient’s resting heart rate* = \_\_\_\_\_ *bpm*

### Step 3: Active heart rate

- Doctors should now decide on an exercise for the patient to perform for 2 mins (e.g. run in place, pushups, sit-ups). Be prepared to measure their pulse the moment they finish.
- *What exercise did the patient do?* \_\_\_\_\_
- Immediately after the patient is finished exercising, have him or her sit down again.
- A single doctor should measure the patient’s pulse once again for 30 seconds, and multiply by two to get the beats per minute of the patient in the active state. The timing doctor should restart the stopwatch once the pulse has been measured.
- *Patient’s active heart rate* = \_\_\_\_\_ *bpm*

### Step 4: Recovery Heart Rate

- Once a minute has passed after the active heart rate has been recorded, repeat the process of measuring the beats over a 30 second period and calculate the beats per minute. Do not start or stop the stopwatch this time.
- *Patient’s 1 minute recovery heart rate* = \_\_\_\_\_ *bpm*

- After recording the 1 minute recovery heart rate, wait another 2 minutes and repeat the heart rate measurement process
- ***Patient's 4 minute recovery heart rate = \_\_\_\_\_ bpm***
- If the 4 minute recovery heart rate is within 5 bpm of the resting heart rate, then the patient's recover time is less than 4 minutes.
- If the 4 minute recovery heart rate is still more than 5 bpm greater than the resting heart rate, continue the process of measuring the patient's heart rate until this threshold is reached, and record the time when this happens
- ***Patient's recovery time after 2 minutes of exercise is less than \_\_\_\_\_***

A commonly used prediction of someone's maximum heart rate is the number 220 minus their age.

***Patient's maximum heart rate = \_\_\_\_\_ bpm***

### **Questions:**

*Q11. Did the patient ever achieve his or her maximum heart rate in this experiment?*

*Probably not, but perhaps possible if the patient is working very hard.*

*Q12. If the patient did not achieve his or her maximum heart rate, what could have been done differently to achieve it?*

*More strenuous exercise, over longer periods of time.*

One effect of exercise is the strengthening of the heart muscle, allowing it to pump more blood through the body in a single stroke.

*Q13. Endurance athletes often have resting heart rates that are much lower than the typical person. Even 30 bpm is not abnormal among elite runners. Why is this resting heart rate so low?*

*These athletes have the same oxygen requirement as typical people when they are resting, but their hearts are capable of pumping much more oxygen in each stroke, requiring less beats per minute to deliver the same amount of oxygen.*

### **References**

1. Lung model: <http://www.smm.org/heart/lessons/lesson7.htm>
2. Lung capacity: <http://www.biologycorner.com/worksheets/lungcapacity.html>
3. Spirometer: [http://www.tryscience.org/teachers/files/handout\\_lung.pdf](http://www.tryscience.org/teachers/files/handout_lung.pdf)