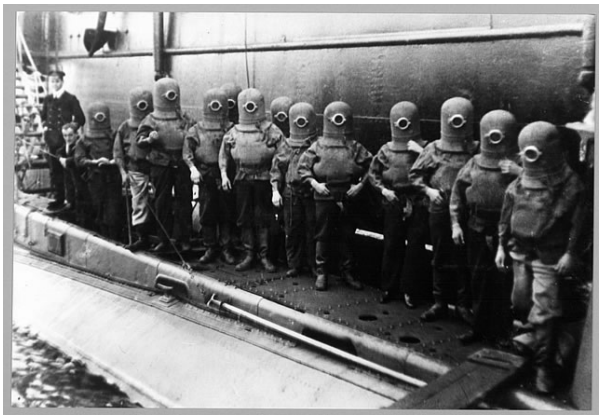
The Great Escape! Activity Four: Submarine Escape

Developed by Paul Mezick, ScienceTeacher, Daniel Hand High School, Madison CT
2014 Submarine Force Museum & Historic Ship *Nautilus* STEM-H Teacher Fellowship



TEACHER NOTE: If Activity One: Displacement and Buoyancy has not been previously completed, see the *introductory video activities* and the common core state mathematics standards, as well as physical science and engineering standards in that activity.

Objective: Use principles of buoyancy and pressure to identify and explain the possible physiological effects submarine escape can have on the human lung.

Middle School Standards:

1. **LS1.C: Organization for Matter and Energy Flow in Organisms:** Within individual organisms, food moves through a series of chemical reactions in which it is broken down and rearranged to form new molecules, to support growth, or to release energy. (MS-LS1-7)

2. MS-LS1-7 Develop a model to describe how food is rearranged through chemical reactions forming new molecules that support growth and/or release energy as this matter moves through an organism.

3. **PS3.D: Energy in Chemical Processes and Everyday Life:** Cellular respiration in plants and animals involve chemical reactions with oxygen that release stored energy. In these processes, complex molecules containing carbon react with oxygen to produce carbon dioxide and other materials. *(secondary to MS-LS1-7)*

High School Standards:

1. **LS1.C: Organization for Matter and Energy Flow in Organisms**

    - As matter and energy flow through different organizational levels of living systems, chemical elements are recombined in different ways to form different products. (HS-LS1-6),(HS-LS1-7)
    - As a result of these chemical reactions, energy is transferred from one system of interacting molecules to another. Cellular respiration is a chemical process in which the bonds of food molecules and oxygen molecules are broken and new compounds are formed that can transport energy to muscles. Cellular respiration also releases the energy needed to maintain body temperature despite ongoing energy transfer to the surrounding environment. (HS-LS1-7)

2. **HS-LS1-7:** Use a model to illustrate that cellular respiration is a chemical process whereby the bonds of food molecules and oxygen molecules are broken and the bonds in new compounds are formed resulting in a net transfer of energy**.**

Materials:

1 balloon
Water
1000 mL beaker
Vacuum flask (Erlenmeyer flask with side port)
Vacuum pump (hand operated)
Vacuum pump (0.2 atm capable, 150 mmHg)
Rubber tubing

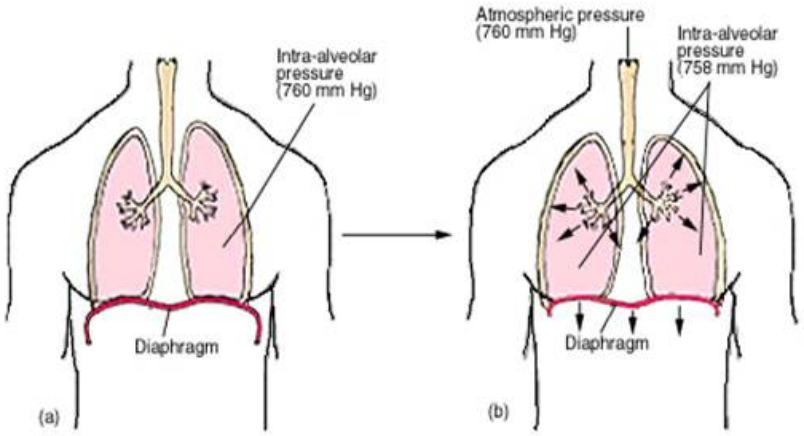
Introductory Activity:

1. View the following video about basic lung function.
   http://www.youtube.com/watch?v=gUUBKVJb7fU

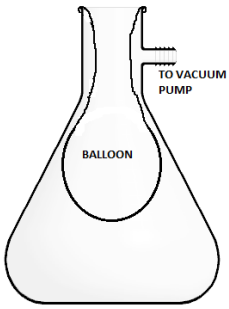
"Internal and External Respiration." *YouTube*. YouTube, n.d. Web. 24 July 2014.

2. Reference the lung diagram to help understand basic lung function:

Lung Diagram

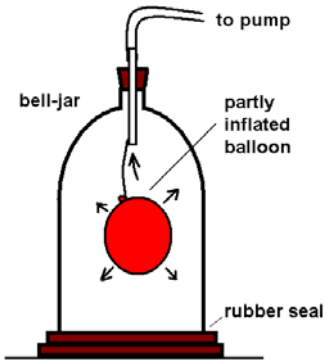


Lab Setup Option 1: (Conceptual)



1. Insert the balloon into the vacuum flask, but stretch the end of the balloon over the opening of the flask.
2. Attach hosing material from flask outlet to the vacuum pump.

Lab Setup Option 2: (Quantitative)



1. Partially inflate a balloon. Inflate balloon until enough air can stabilize the balloon's shape. Knot the balloon.
2. Follow step one, then proceed to insert the balloon into the bell jar.

Note: Suspending the balloon will make it easier to estimate changes in the volume.

Note: For teacher use or for independent learners to check their answers to the Activity 4 Lab Procedure and Summary Questions, see the red typed script following the Summary Questions below, at the end of the Activity 4 Submarine Escape

Lab Procedure:

1. Using what you learned about density and buoyancy, measure the initial volume of the balloon. What is the initial volume?

   _____

   _____

   _____

2. Begin to reduce the ambient pressure inside the bell jar by one atmosphere. What is the value of the change?

   _____

3. Describe the changes in the size of the balloon. Try to quantify your response by estimating.

_____

_____

_____

4. Continue to reduce the ambient pressure inside the bell jar by one additional atmosphere. What is the value of the change?

_____

5. Describe the changes in the size of the balloon. Try to quantify your response by estimating.

_____

_____

_____

6. Continue to reduce the ambient pressure inside the bell jar by one additional atmosphere. What is the value of the change?

_____

7. Describe the changes in the size of the balloon. Try to quantify your response by estimating.

_____

_____

_____

Summary questions:

1. Review your responses to the previous questions. Using Boyle's law and the table below, calculate the % change in volume for each change in atmosphere. How well do your estimations compare to the actual values?

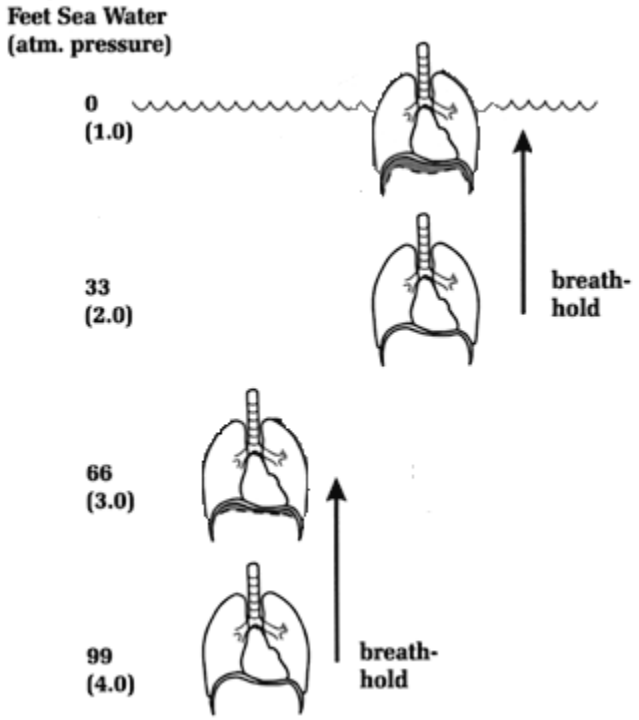
P1 (atm)	V1 (L)	P2 (atm)	V2 (L)	% change in volume
1				
0.5				
0.33				

2. View the following video that demonstrates submarine school students practice escaping from a submarine at the U.S. Naval Submarine Base in Groton's escape trainer.

http://www.theday.com/article/20100925/MEDIA0101/100929710

"The Day - Escaping from a Submarine: A Trial Run | News from Southeastern Connecticut" *The Day*. N.p., n.d. Web. 22 July 2014.

3. Consider the illustration below.



During submarine school training students practice an actual escape from a sunken vessel. Depending on the facility, students can practice submarine escapes from depths of 99 feet. If students practice escape at depths of 99 feet, at what change in atmosphere is the ascent most critical? Support your statement mathematically. **Note: The average human lung capacity is 4.0L**

_____

_____

_____

4. For a scuba diver ascending to the surface from the water, the recommended rate of ascent varies from 0.5 – 1 ft/second, depending on certification organizations. The maximum rate of 2 ft/second should be used only in emergencies. There are roughly 3.3 feet in 1.0 meter. Approximately how long would it take for a diver to reach the surface from a depth of 30 meters at the emergency rate 2 ft/second?

   _____

5. Based on what you learned about the factors that affect pressure, explain why extreme caution should be taken when transporting anyone by flight who has just executed an emergency ascent from under water.

   _____

   _____

   _____

   _____

6. View the following video: http://www.youtube.com/watch?v=EyPN7buaZUY What is decompression sickness, and how does a hyperbaric chamber help to treat it?

   _____

   _____

   _____

7. Compare and contrast submarine escape between the Activity 1 Submarine Rescue Chamber and DSRV, with the buoyant ascent from the Activity 4 escape from a submarine, viewed in question 2 above..

Answers

Lab Procedure:

1. Using what you learned about density and buoyancy, measure the initial volume of the balloon. What is the initial volume?

Students should recognize water displacement as a method for measuring volume. Estimated 0.2 L

2. Begin to reduce the ambient pressure inside the bell jar by one atmosphere. What is the value of the change?

ambient pressure is sea level, so one half of 1 = 0.5 atm

3. Describe the changes in the size of the balloon. Try to quantify your response by estimating.

The volume of the balloon should appear to double (100%)

4. Continue to reduce the ambient pressure inside the bell jar by one additional atmosphere. What is the value of the change?

1/3 or .33 atm

5. Describe the changes in the size of the balloon. Try to quantify your response by estimating.

The volume of the balloon should increase by half (50%)

6. Continue to reduce the ambient pressure inside the bell jar by one additional atmosphere. What is the value of the change?

¼ or .25 atm

7. Describe the changes in the size of the balloon. Try to quantify your response by estimating.

The volume of the balloon should increase by a third (33%)

Summary questions:

1. Review your responses to the previous questions. Using Boyle's law and the table below, calculate the % change in volume for each change in atmosphere. How well do your estimations compare to the actual values?

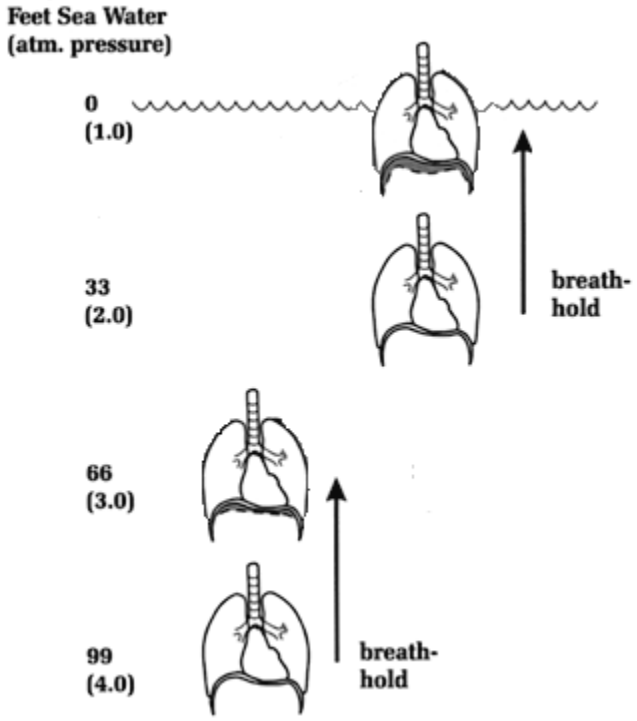
P1 (atm)	V1 (L)	P2 (atm)	V2 (L)	% change in volume
1	0.2	0.5	0.4	100
0.5	0.4	0.33	0.61	50
0.33	0.61	0.25	0.81	33

2. View the following video that demonstrates submarine school students practice escaping from a submarine at the U.S. Naval Submarine Base in Groton's escape trainer.

   http://www.theday.com/article/20100925/MEDIA0101/100929710

"The Day - Escaping from a Submarine: A Trial Run | News from Southeastern Connecticut" *The Day*. N.p., n.d. Web. 22 July 2014.

3. Consider the illustration below.



During submarine school training students practice an actual escape from a sunken vessel. Depending on the facility, students can practice submarine escapes from depths of 99 feet. If students practice escape at depths of 99 feet, at what change in atmosphere is the ascent most critical? Support your statement mathematically.
Note: The average human lung capacity is 4.0L

4.0 atm to 3.0 atm
33% change in volume

$P_1V_1 = P_2V_2$ $\quad \frac{(V_2-V_1)}{V_1} \times 100 = \%$ change

$1.0 \text{ atm} \times 4.0 \text{ L} = 3.0 \text{ atm} \times V_2$

$V_2 = 5.3 \text{ L}$

$\frac{(5.3 \text{ L} - 4.0 \text{ L})}{4.0 \text{ L}} \times 100 = 33\%$

3.0 atm to 2.0 atm
50% change in volume

2.0 atm to 1.0 atm
100% change in volume

Based on the calculations, the most critical part of a submarine escape is nearest to the surface because the % change in volume of your lungs increases so much more as you ascend.

4. For a scuba diver ascending to the surface from the water, the recommended rate of ascent varies from 0.5 – 1 ft/second, depending on certification organizations. The maximum rate of 2 ft/second should be used only in emergencies. There are roughly 3.3 feet in 1.0 meter. Approximately how long would it take for a diver to reach the surface from a depth of 30 meters at the emergency rate 2 ft/second

Approximately 50 seconds.

5. Based on what you learned about the factors that affect pressure, explain why extreme caution should be taken when transporting anyone by flight who has just executed an emergency ascent from under water.

Flying after executing an emergency ascent from the water could cause additional reductions in the atmospheric pressure that would mimic the conditions (changes in ambient pressure) experienced in the ascent. The changes in the ambient conditions may occur faster than the body can adjust to.

6. View the following video: http://www.youtube.com/watch?v=EyPN7buaZUY What is decompression sickness, and how does a hyperbaric chamber help to treat it?

7. Compare and contrast submarine escape between the Activity 1 Submarine Rescue Chamber and DSRV, with the buoyant ascent from the Activity 4 escape from a submarine, viewed in question 2 above.