Pressure In A Fluid

Note that this unit contains the word "fluid" in the title. Let us carry on by examining the relationship between pressure and fluids.

Exploration

GE 1.
1. Define fluid in your own words.

2. Is a liquid a fluid? Is a gas a fluid? Explain your reasoning.

Invention

Ask the instructor or look in a physics textbook for a physics definition of fluid. Write it here.

Application

GE 2.
1. Reconsider a gas. Would a physicist consider a sample of gas as a fluid? Why?

Exploration

Let us now explore ways in which pressure can help us characterize a fluid and any vessel containing that fluid.

Equipment:
• beaker
• flask
• graduated cylinder
• DataStudio software
• gas pressure sensor

If you fill a beaker with water, does the water exert a force on the beaker? Does it exert the same force on all parts of the beaker? How might you perform a simple experiment to support your
prediction? If you fill a flask with water, does the water exert a force on the flask? Does it exert the same force on all parts of the flask? Let's try to find answers to these questions.

**GE 3.**

1. If the beaker and the flask contain the same amount (mass and volume) of water, do you think the pressure exerted by the water is the same at the bottom of each of the containers? Explain.

2. Fill the flask nearly full with water and using what you learned about pressure, calculate the pressure of the water at the bottom of the flask. Set aside the nearly full flask (don't dump any water out yet!). Show your calculation to your instructor.

3. Predict the pressure at the bottom of the beaker if you pour all the water from the flask into the beaker. Don't actually pour the water yet – just make a best estimate!

Connect your pressure sensor to the ScienceWorkshop interface and calibrate it. Ask your instructor to help you with this.

4. Using your pressure sensor attached to the long glass tube (be careful, it will break easily!) measure the pressure at the bottom of your flask filled with water and record the answer below. Now pour all the water from the flask into the beaker and measure the pressure of the water at the bottom of the beaker and record your answer below. How well do your measured values compare with your calculations in part 2 above?

\[
P_{\text{flask}} = \quad P_{\text{beaker}} =
\]

4. Obtain a tall cylinder and fill it nearly to the top with water. Measure the pressure for at least 6 different heights using the pressure sensor. Record your data in the table below.

<table>
<thead>
<tr>
<th>Height (m)</th>
<th>Pressure (Pa)</th>
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5. Graph your data in Excel and find the best-fit line. Be sure to show the equation on your graph! Paste your graph in the table cell below.

6. What is the relationship between the pressure exerted by the water on the wall of the container as a function of height as measured from the bottom of the container? Include the units of any of the constants in your equation.

7. Does the relationship between pressure and height seem reasonable? Does it describe the pressures you measured in your flask and beaker?

8. Without actually doing this experiment, predict what would happen if you were to drill three identical holes in the side of the cylinder. Would the water pour out at the same rate? Shoot the same distance from the cylinder? Explain.

Invention

Pascal said that the pressure at any point in a fluid is the same in all directions and that the pressure at a particular point depends on the depth.

GE 4.

1. Is Pascal’s statement consistent with what you found above? What evidence do you have that indicates the pressure is the same in all directions? Explain.

Pascal also said that if the pressure at any point in an enclosed fluid at rest is changed, the pressure is changed by an equal amount at all points in the enclosed fluid. This is known as Pascal’s Law.

Application

Obtain an apparatus that consists of a large cylinder (syringe in this case) and a small cylinder connected by a tube, as in the diagram below. Fill the tube and cylinders with fluid. Apply a known amount of force to the large cylinder.
GE 5.

1. Assume that Pascal’s Law is true and show the mathematical relationship between the pressures in the two cylinders in the space below.

2. Substitute the definition of pressure into both sides of the mathematical expression above and calculate the force on the piston in the small cylinder. Show your work.

Show your result to your instructor.

This is the concept behind the hydraulic lift. A small force can lift a very heavy load! Consider the lift your dentist (or hair stylist) uses to raise your chair (and you) to a more comfortable height. Many chairs of this type are still operated by pumping with the foot.

3. Compare both the force exerted by the foot and distance the foot moves, to the force needed to lift the chair and the distance the chair moves.

4. What would you have to do to lift a car with such a device?

5. As with many machines, there are tradeoffs that allow us to lift heavy objects with small forces. Recall our discussion of work last semester. Write that definition in the space below.

6. Are the two forces that are involved in the hydraulic lift adequately described by our definition of work? Explain.
**Invention (Volume and Density)**

**GE 6.**

1. Write a qualitative definition of volume.

2. Describe what happens when you place an object in a container of water. Could you use this to write an operational definition for finding the volume of an object? Write an operational definition for finding the volume of an object by submerging that object in a container of water.

Show your definition to an instructor.

**Equipment:**
- 2 pieces of aluminum
- Several objects that sink and float
- 1 balance
- 1 mass set
- 1 beaker

**GE 7.**

1. Give a qualitative explanation of density. (This should be an explanation in your own words.)

2. Use a physics textbook to find a technical definition of density.

3. Is this definition consistent with your qualitative explanation? Explain.

**Application**

**GE 8.**

1. Do you think 30 ml of water have the same density as 50 ml of water? Explain.

2. Perform a quick experiment to check your prediction.
3. Do you think two different sized pieces of aluminum have the same density?

4. Perform a quick experiment to check your prediction.

**Exploration**

We are going to look at whether the shape of container influences the pressure in the contained fluid.

**Equipment:**
- 1 large Erlenmeyer flask
- 1 graduated cylinder

**GE 9.**

1. Suppose you fill the Erlenmeyer flask and the graduated cylinder to the same height with water. Now you measure the pressure at the bottom of each container. How do you think the measurements would compare?

2. If the flask was filled with water to a depth of 25cm calculate the pressure on the bottom of the container due to the water above it.

3. Calculate the pressure at an arbitrary depth, \( h \), below the surface of the water, due to the water above it. Write your final answer in terms of the density of water, the acceleration due to gravity, \( g \), and the depth, \( h \).

4. If the graduated cylinder was filled with water to a depth of 25 cm calculate the pressure at a depth, \( h \), below the surface of the water. Write your final answer in terms of the density of water, the acceleration due to gravity, \( g \), and the depth, \( h \).

5. Would the pressure at a depth, \( h \), below the surface of the liquid be the same in two different containers, both filled with water? Explain.
6. Would the pressure at a depth, $h$, below the surface of the liquid be the same in two different containers, if the containers had *different liquids* in them? Explain.

7. Now fill both the graduated cylinder and the flask with water to a depth of 25 cm and measure the pressure at two different depths in the differently shaped containers with the gas pressure sensor to test your calculations. Record your observations below.

**Invention**

Discuss the results of your exploration with the instructor. Write down an equation that describes the pressure in a fluid as a function of the depth below the surface.

**Application**

**GE 10.**

1. Obtain a sample of an unknown fluid from your instructor and determine the density of the fluid. Record your observations below.

2. Fill your cylinder with the unknown fluid and measure the pressure at the bottom. Using what you've learned above, calculate the pressure at the bottom of the cylinder with the unknown fluid. Record the values below and compare the two. Are they within experimental uncertainties?

**Application: Measuring atmospheric pressure**

**GE 11.**

1. Is there a pressure at the surface of the liquid in either of the containers in considered above (Erlenmeyer flask and graduated cylinder)? If not, explain why you think so and if there is a pressure, explain why you think there is and what is causing it.

2. Obtain a pan from your instructor and fill it with water. Submerge a small graduated cylinder in the water remove all air bubbles and then, leaving the
open end of the cylinder under water, lift the closed end as high as you can. Describe what you see.

3. Consider a tube filled with mercury. When the tube is turned over, into a container of mercury, the mercury in the tube flows out and then stops, as in the picture below.

If the atmosphere is exerting a pressure on the surface of the mercury, and the pressure in the container is the same at a particular level, then at a line drawn at the level where the atmosphere meets the mercury, as in the diagram below, the upward pressure due to the mercury below the line must equal the downward pressure due to the mercury in the tube above the line and this must equal the pressure of the atmosphere downwards. Since we can calculate the pressure due to the mercury in the tube, we can use this instrument to measure atmospheric pressure. It is called a barometer.

4. Suppose the height of the mercury in the tube above the level where the atmosphere meets the mercury is 760mm high. The density of mercury is $13.6 \times 10^3 \text{ kg/m}^3$. Calculate the atmospheric pressure. Convert your number to Pascals.

Show your calculation to an instructor.
When measuring pressure, people sometimes report only the height of the mercury in the tube. To get the pressure in standard units, the pressure must still be calculated as above.

5. Another instrument similar to a barometer is a manometer. It simply consists of a U-shaped tube filled with liquid, as in the diagram below.

(i) If both ends of the tube are open to the atmosphere, how would the level of the liquid in each side of the tube compare? Explain. What if one side is larger than the other?

(ii) If one end of the tube is open to the atmosphere and a syringe with the piston all the way out is attached to the other end of the tube and then the piston is compressed, how would the level of the liquid in each side of the tube compare? Explain.

(iii) If one end of the tube is open to the atmosphere and a syringe with the piston all the way in is attached to the other end of the tube and then the piston is pulled all the way out, how would the level of the liquid in each side of the tube compare? Explain.

(iv) Now for a tough question: We know that air (in fact, fluids in general) can push on an object, but can air pull on an object as well? If so, by what mechanism can it pull on an object?