Objectives

These lab activities will focus on the concept of buoyancy and how pressure and density affect the motion of fluids. You should read all the steps in each part before you start. Work in your assigned groups and maintain a collaborative and communicative team.

For the following activities, you will use a physics simulation program. Visit: https://uglabs.physics.ucr.edu/ for lab downloads and links.

Introduction

Last week we dealt with static fluids, this week we will deal with fluids in motion. We will be dealing with ideal fluids. An ideal fluid assumes that there is no internal friction when it moves and that the fluid is incompressible. These are both reasonable assumptions to make.

Consider this ideal fluid moving through a pipe which is non-uniform in radius (such as the one shown below):
Fluid Flow

As the fluid moves with steady flow it will cross through different points in the pipe with different cross-sectional areas. Let’s focus on two different points in the pipe: point 1 with cross-sectional area \( A_1 \) and point 2 with cross-sectional area \( A_2 \). The mass of fluid that crosses \( A_1 \) in some time interval is the same mass of fluid that crosses \( A_2 \) in the same time interval. Since this ideal fluid is incompressible, its volume is constant. This leads us to find that:

\[
A_1 v_1 = A_2 v_2
\]

We call this the continuity equation. It is another way of saying that the product of the area and the fluid speed at all points along a pipe is constant for an incompressible fluid.

In a static fluid, the pressure of the fluid will change as you go deeper into the fluid. But, in a fluid that is moving you will have to also consider the speed of the fluid in addition to the depth to find the pressure at a given point. This is encapsulated in Bernoulli’s Equation for two points in a connected fluid:

\[
p_1 + \frac{1}{2} \rho v_1^2 + \rho g h_1 = p_2 + \frac{1}{2} \rho v_2^2 + \rho g h_2
\]

where \( \rho \) is the density of the fluid, \( g \) is the acceleration due to gravity, \( p_1 \) is the pressure at point 1, \( h_1 \) is the depth of the fluid to point 1, and \( v_1 \) is the velocity of the fluid at point 1, \( p_2 \) is the pressure at point 2, \( h_2 \) is the depth of the fluid to point 2, and \( v_2 \) is the velocity of the fluid at point 2. Many times the fluid will be water, where \( \rho_{\text{water}} = 1,000 \text{ kg/m}^3 \).

The water tower in the second section of the lab, will be very similar to shooting a cannonball from a cannon. Fluids that are flowing will follow the same rules of motion as a point mass. The kinematics equations from mechanics will still be valid in this fluid environment:

\[
x - x_0 = v_{0x} t
\]

\[
y - y_0 = v_{0y} t - \frac{1}{2} g t^2
\]

\[
v_y^2 = v_{0y}^2 + 2a \Delta y
\]
Experimental Apparatus:

This simulation contains three activities (Pressure, Flow, and Water Tower). For the purposes of our experiment, we will use the two tabs entitled “Flow” and “Water Tower.” An image of the Colorado PhET for the first section of this week’s lab is shown below:

![Simulation Image]

Summary:

This lab is divided into two sections. In the first you will measure the velocity and pressure of the fluid for different cross-sectional areas. In the second section, you will predict the motion of water leaving a tower under constant water pressure.
1. Fluid Flow

1.1: Open the PhET and choose the Flow tab. You should see a pipe with water flowing through with a constant cross-sectional area. You should also see handles that allow you to change the radius of the pipe. On the top left, adjust the flow rate to 10,000 L/s.

1.2: We are going to create three sections of pipe that have different cross-sectional areas. Section 1 will be on the left and have a larger cross-sectional area. Section 2 will be in the middle and stay unaltered. Section 3 will be on the right and have a smaller cross-sectional area. You can take to handles to adjust the radius of the pipe (do it equally from the top and bottom so that the middle point is the same in all three sections. The image below shows what the sections should look like:

![Image of PhET Flow simulation](image.png)

1.3 Place the speed meter at the center of Section 1 pipe and measure the speed of the water flow (as shown to the right). Note: if the speed is below 1.0 m/s in this section then you will get inaccurate readings which will affect your results; you can decrease your radius a little to increase the speed appropriately.
1.4: Using the ruler found in the top right, measure the diameter of Section 1. Then divide this measurement by 2 to find the radius for Section 1. Calculate the cross-sectional area for Section 1. Note: it is a circular pipe.

1.5: Now, measure the diameter of Section 2. Then divide this measurement by 2 to find the radius for Section 2. Calculate the cross-sectional area for Section 2. Note: it is a circular pipe.

1.6: Using the Continuity Equation, predict the velocity of the water going through the center of Section 2 pipe based upon your calculations in 1.3-1.5.

1.7: Place the second speed meter in the center of Section 2 of pipe. Does the measurement of the fluid speed match your prediction from 1.6? If not, is it within measurement uncertainty?

1.8: Using Bernoulli’s Equation, calculate the pressure difference between the center of Section 1 pipe and the center of Section 2 pipe. Which point (1 or 2) do you expect to have greater pressure?

1.9: Take the pressure meters from the top right and put them at the center of Section 1 pipe and the center of Section 2 pipe (as shown to the right). Does the measurement of the pressure difference match your prediction from 1.8? If not, is it within measurement uncertainty?

1.10: Repeat parts 1.5 through 1.9 but replace Section 2 with Section 3 (the part of the pipe that is narrowest to the far right).

1.11: What do you think would happen to the speed at the center of Section 1 pipe if you were to increase the fluid density from 1,000 kg/m³ to 1,250 kg/m³? Explain your reasoning.
Fluid Flow

1.12: Actually alter the density of the fluid to 1,250 kg/m$^3$ with the button the bottom right. Discuss whether the results match your prediction from step 1.11.

1.13: What do you think would happen to the pressure difference between center points in Section 1 pipe and Section 2 pipe if you were to decrease the fluid density from 1,000 kg/m$^3$ to 750 kg/m$^3$? Explain your reasoning.

1.14: Actually alter the density of the fluid to 750 kg/m$^3$ with the button the bottom right. Discuss whether the results match your prediction from step 1.13.

2. Water Tower

2.1: In this part of the lab, you will choose the Water Tower tab. You should see a mostly filled water tower. On the faucet above the tower click on the Match Leakage button (as shown below). Next, hit the Fill button to the left of the Water Tower. Both of these items make sure that your tower remains full of water throughout this process. Note that the tower is open to the atmosphere at the top which allows the water to flow in.
**Fluid Flow**

**2.2:** Click on the ruler on the top right. Use it to measure the height of water in the tower. Use this height to calculate the pressure difference between point 1 (inside the water tower) and point 2 (outside the water tower) where both points are at the same height. The image below shows these two points in relation to the water tower.

2.3: Put pressure meters at point 1 and point 2 to find the pressure at each point. Is the pressure difference that you find the same as step 2.2? If not, is it within measurement uncertainty? Explain.

2.4 Based upon this pressure difference, calculate the velocity of the fluid leaving the water tower if a hole was created at point 2.

2.5 Lift the opening at the bottom of the tower (on the bottom right of the tower). Make sure to hit the Fill button again to make sure the water level in the tower is full. You will notice the water leaving the water tower and striking the ground.

2.6 Place a speed meter at the opening to measure the velocity of fluid as it leaves the water tower. Is the velocity that you find the same as step 2.4? If not, is it within measurement uncertainty? Explain.

2.7 With the ruler, measure the height of hole in the tower with respect to the ground. Use this height in addition to the velocity and kinematics to
Fluid Flow

calculate the magnitude of the velocity of the fluid when it reaches the ground.

2.8 Place a second speed meter at the point where the water hits the ground. Is the velocity that you find the same as step 2.7? If not, is it within measurement uncertainty? Explain.

2.9 Use the height in addition to the velocity and kinematics to calculate the location from the tower where the water will hit the ground.

2.10 Click on the tape measure in the upper right corner. Use this tape measure to find the horizontal distance from the tower that the water hits the ground. Is the horizontal location that you find the same as step 2.9? If not, is it within measurement uncertainty? Explain.

2.11: What do you think would happen to the speed at point 2 if you were to increase the fluid density from 1,000 kg/m$^3$ to 1,250 kg/m$^3$? Explain your reasoning.

2.12: Actually alter the density of the fluid to 1,250 kg/m$^3$ with the button the bottom right. Discuss whether the results match your prediction from step 2.11.

2.13: What do you think would happen to the location where the fluid strikes the ground if the fluid density was altered from 1,000 kg/m$^3$ to 750 kg/m$^3$? Explain your reasoning.

2.14: Actually alter the density of the fluid to 750 kg/m$^3$ with the button the bottom right. Discuss whether the results match your prediction from step 2.13.
1. Water flows from left to right through a horizontal pipe that has different diameters in three different sections, as shown below. Assume that the transitions between the sections have a negligible effect on the frictionless flow of water here.

   a. Rank the speeds ($v_1$, $v_2$, $v_3$) at these three points, from slowest to fastest, and give a logical explanation for your ranking.

   b. Rank the water pressures ($P_1$, $P_2$, $P_3$) at these three points, from least to greatest pressure, and give a logical explanation for your ranking.