PASCAL'S PRINCIPLE, ARCHIMEDES' PRINCIPLE & BUOYANCY

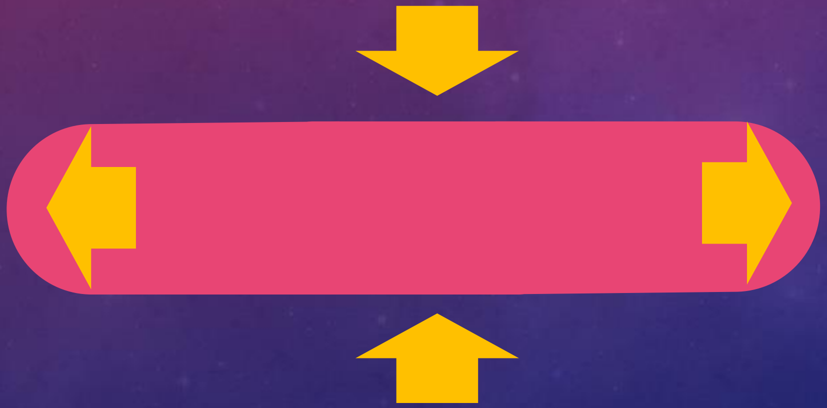
PES 1000 – PHYSICS IN EVERYDAY LIFE

THREE PRINCIPLES DESCRIBING FLUID BEHAVIOR

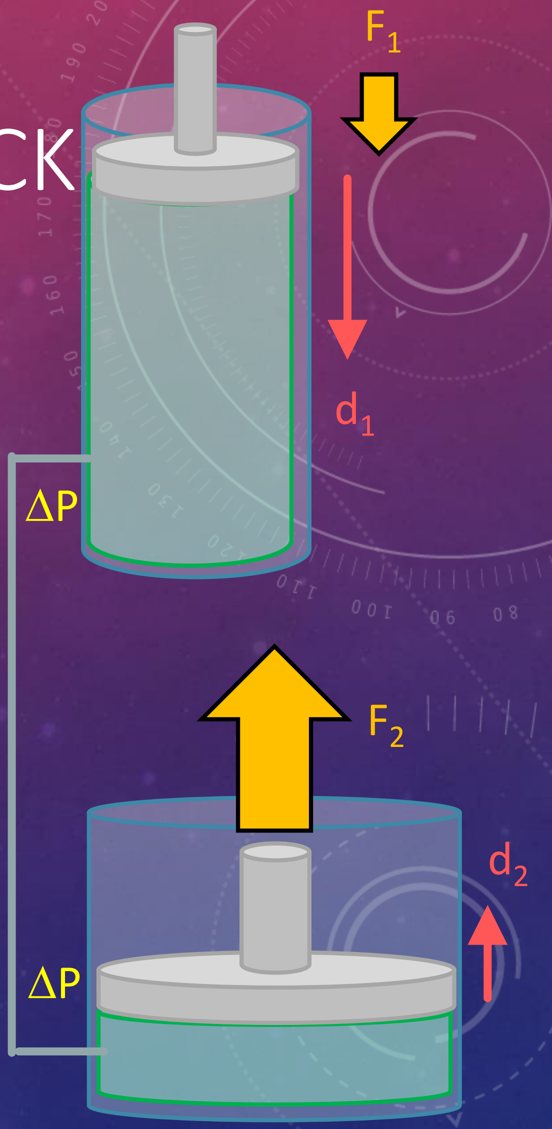
- There are three fundamental principles that describe the macroscopic behavior of static and dynamic fluids.
- Pascal's Principle and Archimedes' Principle apply to static fluid. Even though the fluid particles are in constant motion, the bulk of the fluid stays in place.
- Bernoulli's Principle applies to fluid that is moving in bulk (like flowing wind or water).

PASCAL'S PRINCIPLE

- Blaise Pascal (1623-1662) formulated a law about pressure changes in a fluid.
  - A pressure change in one part of a fluid is transmitted equally throughout the fluid.
- Example: If we squeeze one part of a balloon, all the air in the balloon increases in pressure, pushing it out in all directions.



PASCAL'S PRINCIPLE: EXAMPLE – HYDRAULIC JACK



- A hydraulic jack consists of two pistons filled with oil with their reservoirs connected by a tube.
- If we increase the force on the smaller piston, the force acting over the area of the piston increases the pressure in its reservoir.
- The change in pressure is transmitted through the oil to the larger piston.
- The larger area of the piston means that, for the same pressure increase, the force must also be larger: $\Delta P = {F_1}/{A_1} = {F_2}/{A_2}$, or, stated another way, $F_2 = \frac{A_2}{A_1} F_1$
- A small force translates into a large force. The price we pay is that the larger force must move through a smaller distance (energy/work conservation): $W = F_1 * d_1 = F_2 * d_2$

$$d_2 = \frac{A_1}{A_2} d_1$$

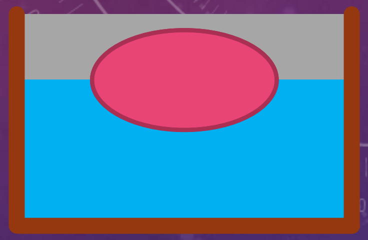
CROWN PROBLEM

- Archimedes of Syracuse (287 – 212 BC) was tasked with the following problem by King Hiero II:
  - A crown had been made by a goldsmith from a quantity of gold given to him. King Hiero suspected that a less valuable metal could have been substituted for part of the gold. The problem was to determine if this had happened without melting down the crown.
  - Restating, how can the volume of an oddly-shaped object be determined?
- Legend has it that Archimedes contemplated the problem while bathing at the public bath. As he lowered himself into the water, he observed the water level rising. He realized that the submerged part of his body displaced an amount of water, the volume of which could be easily measured.
- He was so excited by his discovery that he ran through the streets shouting 'Eureka' ("I've found it"), forgetting to dress himself first.
- Supposedly, the crown was then submerged and the displaced water was measured, confirming that, indeed, the goldsmith had substituted silver for some of the gold and selling the excess for extra profit.



ARCHIMEDES' PRINCIPLE

- Archimedes' Principle describes the idea of buoyancy
  - *A body that is fully or partially submerged in a fluid experiences an upward buoyant force equal to the weight of the fluid displaced.*
- Explanation:
  - The object pushes the fluid away from the volume it occupies.
  - The fluid level rises by the volume of fluid displaced.
  - The displaced fluid seeks to refill the original volume, and its weight increases the pressure around the submerged part of the object.
  - The pressure results in a net upward (buoyant) force on the object.



BUOYANCY

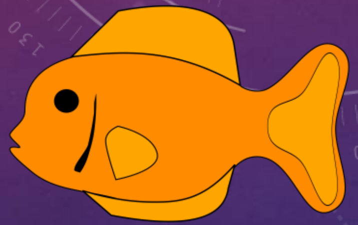
- Floating a boat
  - As long as the weight of the boat is more than the buoyancy (due to the weight of the water displaced), then the boat will sink lower until the weight of the water displaced equals the weight of the boat.
  - As the boat takes on cargo, it sinks lower until the additional displaced water weight equals the added cargo weight.
  - The size of a ship is often stated as its *displacement*.
  - Steel boats can float because they also displace a large amount of air. If the average steel/air density is equal to water density, it floats. If it leaks, some air is replaced with water, and the boat begins to sink.

BUOYANCY

- *Neutral buoyancy* occurs when the weight of the boat exactly equals the upward buoyancy.
- So, if the average density is …
  - … equal to water, the object will float.
  - … greater than water, the object will sink.
  - … less than water, the object will rise.

MORE EXAMPLES

- Submarine: A submarine has ballast tanks with air and water in them. For neutral buoyancy, the average density of steel, air, and water in the submarine is equal to the water density. To rise, air is pumped into the tanks, lowering the submarine's average density. To dive, air is pumped out.



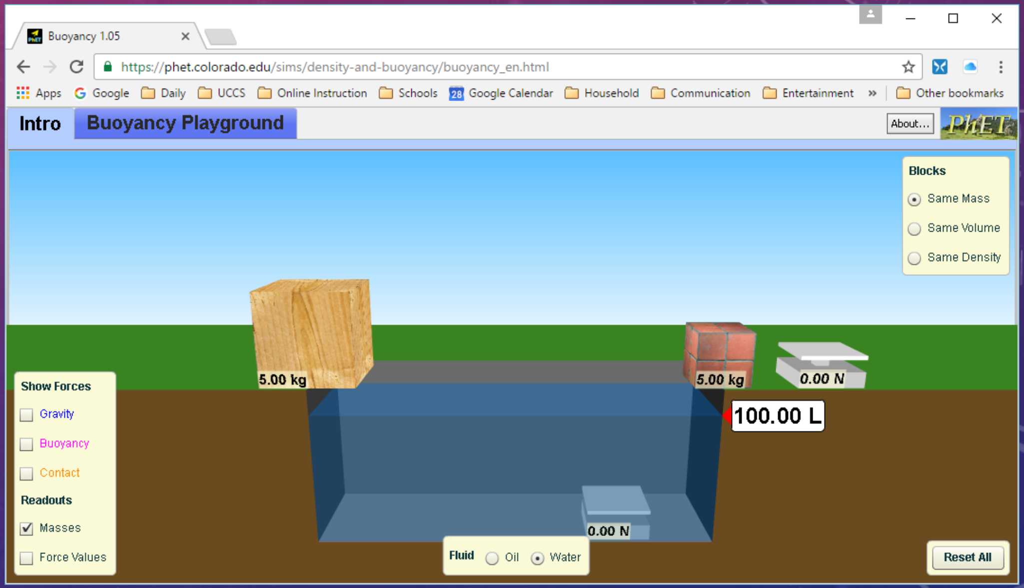
- Fish: Fish have a gas-filled swim bladder, which contracts or expands, compressing or uncompressing the gas, changing the fish's average density and letting it float, rise, or sink.

- Helium balloon: The average density of the balloon plus the helium (which is less dense than air) must be equal to the density of air for the balloon to float.

- Hot air balloon: The average density of the balloon plus the hot air (which is less dense than cold air) must be equal to the density of the cold air for the balloon to float. This is why most balloon flights occur during the pre-dawn, when the outside air is coldest, and why the balloons sink as the sun heats the atmosphere.

BUOYANCY SIMULATION

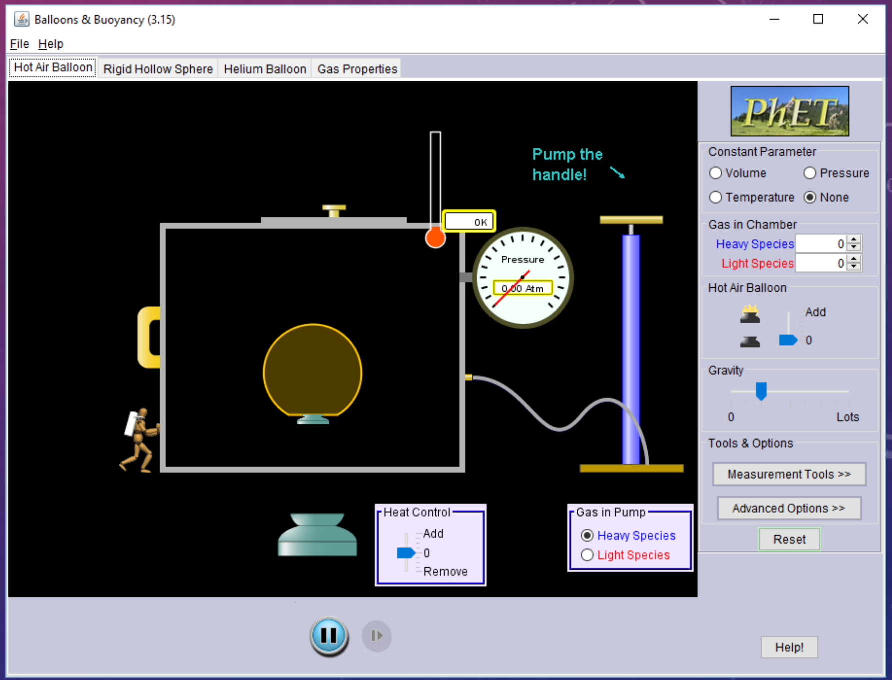
- Link to simulation: https://phet.colorado.edu/en/simulation/buoyancy
- Things to do:
    - Bottom left check boxes: select all of them
    - Drop the block into the water. Observe the upward buoyance fluctuating until it floats.
    - Place the bricks on the above-water scale. What does it weigh? Then place it on the underwater scale. Why is there a weight difference?
    - Experiment with the different types of blocks (upper right selection box)



BALLOON SIMULATION

- Link to simulation: https://phet.colorado.edu/en/simulation/legacy/balloons-and-buoyancy

- Things to do:
  - Hot Air Balloon tab
    - Pump some gas into the chamber. Does the balloon inside rise, sink, or float?
    - Add heat to the air inside the balloon (this control is on the strip on the right margin.) Add heat until the balloon rises. Can you see a difference in the density of air inside the balloon and outside?
    - Add heat to the air outside (control at the bottom) until the balloon sinks.
  - Helium Balloon tab
    - Using the text boxes on the right, add 100 atoms of blue gas to the chamber, and 25 atoms of the red gas to the inside of the balloon. Does the helium balloon float or sink?
    - Change the 100 atoms of the blue gas in the chamber to 100 atoms of red gas. What happens to the balloon now?



CONCLUSION

- Pascal's Principle states that *a pressure change in one part of a fluid is transmitted uniformly throughout the fluid.*
- Archimedes' Principle states that *a body that is fully or partially submerged in a fluid experiences an upward buoyant force equal to the weight of the fluid displaced.*
- If the average density is …
  - … equal to the fluid around it, the object will float.
  - … greater than the fluid around it, the object will sink.
  - … less than the fluid around it, the object will rise.
- Buoyancy explains the behavior of boats, submarines, fish, and balloons.