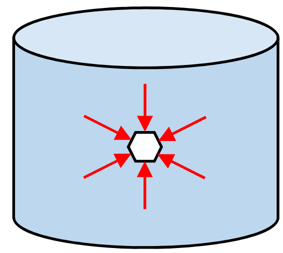
PHYS:1200 LECTURE 13 – FLUIDS (2)

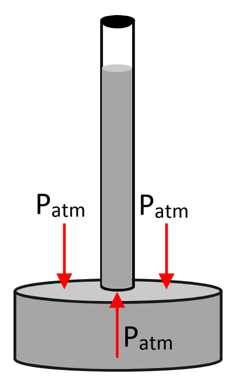
Lecture 13 deals with the properties of fluids at rest or fluid statics. We will be discussing mostly liquids and will introduce two important principles of fluid statics: **Pascal's principle and Archimedes principle of buoyancy**, which will be used to understand why some objects float.



First we will review some of the important facts about fluid pressure. The first important fact **about fluid pressure is that it always produces a force that is perpendicular to surfaces**. The figure shows a *very small* hexagonal object immersed in a container of water. Water pressure is exerted on every surface of the object in a direction that is perpendicular to that surface. The water on top of the object pushes down on it and the water below the object pushes up on it, etc. Since the object is very small, the value of the pressure is roughly the same on all of its sides.

The second important fact about liquid pressure is that it increases with depth below the surface. This is illustrated by the demonstration shown in slide 3. Also liquid pressure does not depend on the shape of the container that it is in, only on the depth – this is illustrated on **slide 5. Slide 7** shows a demonstration of this effect known as **Pascal's vases.**

Slides 14, and 15 illustrate some consequences of the increase in pressure with depth. Because the pressure is higher at the bottom of a dam, the dam must be thicker at its base to handle the pressure there. Also, the pressure on the dam does not depend on how far back the water extends. The increase in pressure with depth also applies to the blood in our arteries and vessels. When we are standing, our blood pressure is higher at feet level than at heart level. Blood pressure is usually measured in our upper arm which is roughly at the same level as our heart.



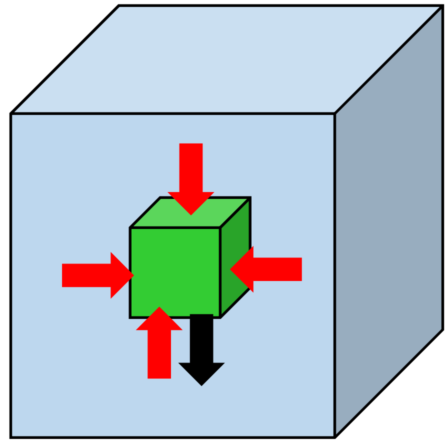
13-1. The Barometer and Atmospheric Pressure.—The effect of atmospheric pressure on a column of liquid provides a method for measuring this atmospheric pressure in a device known as a **barometer**. It is a common experience that if you have a drinking straw in a glass, if you put your finger over the top of the straw, you can lift it out of the glass and the liquid remains suspended in the straw even though the bottom of the straw is open. It is atmospheric pressure pushing up on the liquid at the bottom of the straw that keeps the liquid from falling**. In fact atmospheric pressure is sufficient to support a column of water that is about 10 m (30 feet) high! Atmospheric pressure is sufficient to support a column of mercury Hg (a metal that is a liquid at room temperature) that is roughly 0.76 m high**, because the density of Hg is 13.6 times higher than the density of water. A barometer is an inverted tube of Hg, closed at the top and open at the bottom, immersed in an open pool of Hg, as shown on **slide 9**. Atmospheric pressure pushing down on the Hg pool is transmitted to the bottom of the Hg column and suspends it against gravity. The height of the Hg column is then a sensitive indication of atmospheric pressure, and this height varies as the atmospheric pressure varies from day to day. This is the reason why on weather reports, atmospheric pressure is quoted in inches (or mm or cm) of Hg. Nominal atmospheric pressure will support a Hg column that is roughly 29.9 inches high. A pressure of 29.92 inches of Hg is then equivalent to 10^5 Pa. **Slide 13** discusses how atmospheric pressure allows us to drink using a straw and how water pumps work.

13-2. Pascal's Principle.—This is one of the basic principles of fluid statics and is illustrated by the figure on slide 10:

A change in pressure in an enclosed fluid at rest is transmitted undiminished to all points in a fluid.

This means that if you exert extra pressure on a fluid, that extra pressure appears at every point in the fluid. This will be demonstrated in class using the Cartesian diver. So in the figure **in slide 10**, if enough weight is placed on the piston, the increased pressure on the liquid also appears on the walls of the vessel, and the vessel can break. All hydraulic devices, like a car lift or earth movers, operate on Pascal's principle as illustrated in slides 11 and 12.

13-3. Buoyancy (Archimedes' Principle).—We will now take up the question of why some objects float (and other do not). **The buoyant force is a direct consequence of the fact that the pressure in a liquid increases with depth**. Think about an object completely submerged in a tank say of water. Suppose the object is just a cube of some material and the sides of the cube have

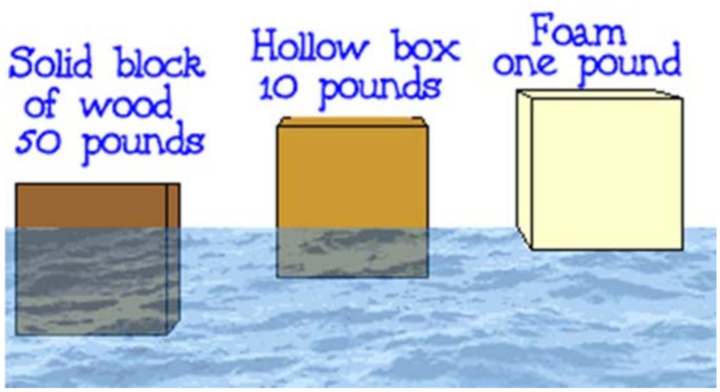


an area A and the volume of the cube is V**. What forces act on this object?** First, of course, the weight W of the object (black arrow). The surrounding liquid exerts pressure forces on all six sides (red arrows) of the object also, a given pressure P produces a force F = PA on that particular side. How do all these forces add up? The forces on the 4 horizontal sides of the cube cancel each other in pairs—the force on the left face is canceled by the force on the right face, and the force on the back face cancels the force on the front face. What about the liquid forces on the top and bottom faces? Here we must take into account that since pressure increases with depth, the upward pressure on the bottom of the object will be larger than the downward pressure on the top of the object. If we call these pressures P_{TOP} and P_{BOTTOM}, then the forces on the top and bottom surfaces due to these pressures are: $F_{TOP} = P_{TOP}$ A and $F_{BOTTOM} = P_{BOTTOM}$ A. Since P_{BOTTOM} is larger than P_{TOP}, F_{BOTTOM} is larger than F_{TOP}. The net force on the object is then: $F_{NET} = F_{BOTTOM} - F_{TOP} - W$. The difference between the upward and downward liquid forces is called the buoyant force, $F_B = F_{BOTTOM} - F_{TOP}$, and since $F_{BOTTOM} > F_{TOP,}$ the buoyant force is always up**. A buoyant force is always exerted on a submerged object regardless of whether or not it floats.** If an object is attached to a spring scale and submerged, the measurement on the scale will be less than the weight of the object by an amount equal to the buoyant force (this will be demonstrated in class). *Now, if the buoyant force is larger than the weight of the object, the object will float*. If this analysis is carried further, we find that the buoyant force is given by the weight of the liquid which the object displaces. This is Archimedes' principle. The physics is simple—a submerged object pushes the liquid out of its volume; the liquid attempts to refill this volume and thus squeezes the object upward.

Archimedes' principle can be stated in a way that allows us to determine if a given object will float in water.

The weight of water is 10 N per liter of volume 10 N/liter

For every liter of water that is displaced by an object, the buoyant force is 10 N. Now objects that have the same total volume but are made of materials of different mass densities, e.g., a dense wood like maple, compared to a less dense wood like pine, float with different amounts of their volume submerged. The denser material weighs more, so it floats with more of its volume submerged than a less dense material **(slide 21).** As a practical matter, any material that is less dense than water will float in water (ice floats because ice is less dense than water). If an object is completely submerged, it displaces the maximum volume of water. If the weight of this submerged object is greater than the weight of the displaced water, it will sink. So a chunk of aluminum, which is denser than water, will sink unless it is formed into a shape that allows it to displace enough water (this will be demonstrated in class).

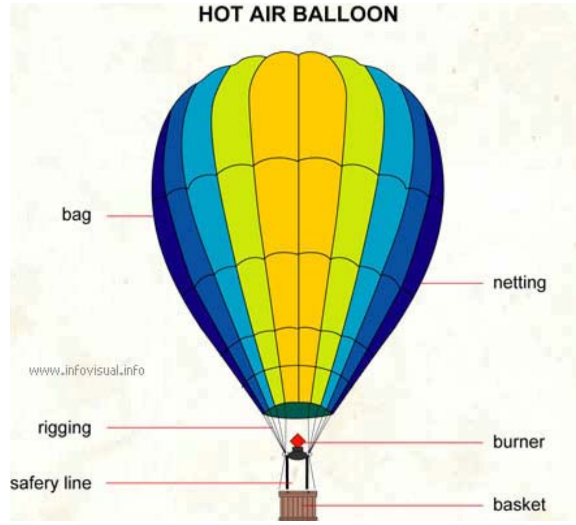


Note that in any situation, if the maximum possible buoyant force is less than the weight of an object, the object will sink to the bottom

Example 13-1: An object weighing 3000 N has a total volume of 500 liters. What will happen if this object were placed in a tank of water?

Solution- The largest possible buoyant force on this object would occur if it were completely submerged, in which case the maximum buoyant force is $F_{B,\ MAX}$ = 500 liters x 10 N/liter = 5000 N. Since the maximum buoyant force is greater than the weight of the object, it will float. Since only 3000 N of buoyant force are needed for floatation, only 3/5 (60%) of the object's volume will be submerged. So, the object will float with 60% of its volume submerged.

Buoyancy is not limited to liquids, it also occurs in gases. A hot air balloon is held aloft because the density of the hot air inside the balloon is lower than the density of the cooler air outside the balloon, giving rise to an upward buoyant force. The same idea holds for balloons filled with helium which is considerably less dense than air.



Buoyancy can be demonstrated by weighing an object while it is under water as shown on the right. Out of water, the object weighs 7 lb. However, when held underwater, it weighs 4 pounds because it displaces 3 lb of water which provides an upward buoyant force of 3 lb. The scale reads the difference between the actual weight and the buoyant force.