UNIT 2 FLUIDS

PHYS:1200 LECTURE 12 – FLUIDS (1)

Lecture 12 is the first lecture on the new topic of **fluids.** Thus far we have been discussing the physics of *ideal* solid objects that do not change their shape, and cannot be bent, stretched, or compressed. Fluids can be compressed and expanded. Liquids possess definite volumes in the same sense as solids, but have no definite shapes, but take on the shape of their containers. Gases exhibit neither definite volumes nor shapes: they expand to fill large containers, may be compressed to fit into small ones, and escape from open ones**. Fluids are materials that can flow readily from one place to another**. Fluids include liquids and gases, but also granular materials like sand or grain. Although fluids are more complicated than solids, fluid motion can still be analyzed using Newton's laws of motion.

12-1. States of Matter.—Before we discuss the properties and behavior of fluids such as water and air, it is important to get some basic understanding of the differences between the three states of matter – **solid, liquid, and gas**. The differences are best described in terms of the basic constituents of all matter --- atoms. The idea is that if we start with a piece of matter and begin to break it down into smaller and smaller pieces, we eventually arrive at the smallest object out of which the big piece is made --- the atom. For example, if we have a block of aluminum and divide it into smaller and smaller pieces, eventually we get to a single atom of aluminum. This is known as the atomic hypothesis, which has been accepted for a little more than a hundred years. A typical atom has a size of about 10^{-10} m.

The difference between the various states of matter – ice, water, and steam for example, is the **distance between the atoms**. The atoms are held together by attractive forces between the individual atoms and these forces depend on how far apart the atoms are--- the closer they are, the stronger the forces. As described on slide 4, the atoms are closest in the solid state, and farthest apart in the gaseous state. The attractive forces then are strongest in the solid state which gives solids their characteristic properties of being dense and hard. The atoms in a solid are fixed in place, they might vibrate a bit, but they cannot move around inside the solid. The atoms in a liquid or gas are free to move around – that's why these substances can flow.

a. Mass density.—The **mass density**, designated by the Greek letter ρ (rho), is one of the parameters that is used to characterize materials. Mass density is the **mass of a unit volume of the substance** – typically measured in kg/m^3 or g/cm^3. Clearly, the density of a substance depends on how close together the atoms are, so that a substance typically has its highest density when in the solid state (Interestingly, water is an exception to this rule, and we will discuss this later. By the way, it is the reason that ice floats in water.) **Slide 6** gives a table showing the mass densities of various substances.

b. Pressure.—A liquid contained in a vessel exerts forces against the walls of the vessel. To discuss the interaction between a liquid and walls, it is convenient to introduce the concept of **pressure**. Pressure is also a useful concept in dealing with gases. For example, a balloon is maintained by the force that the air inside exerts on the inner surface of the balloon. **Pressure is defined as the force per unit area** on which it acts and is measured in Newtons per square

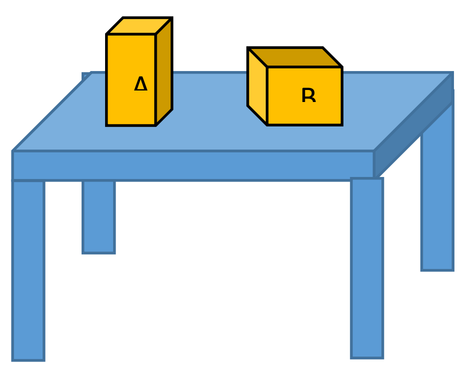
PRESSURE

$$P = \frac{F}{A} \quad [1]$$

meter, N/m^2. One N/m^2 is also called one **Pascal (Pa).** The pressure of the air in your tires is (in the US) is measured in pounds per square inch or psi. Alternately, if pressure is applied to an area A, the resulting force on that area is

$$F = PA. \quad [2]$$

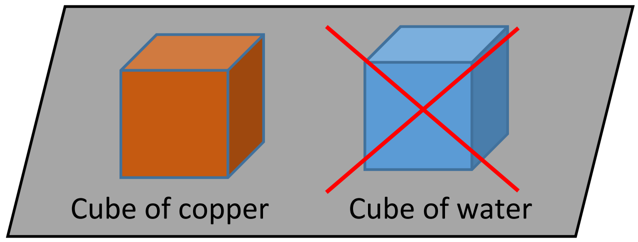
The concept of pressure can be illustrated by considering a block that has a weight W. The block can rest on a table on any of its 6 sides; two possibilities, A and B are shown. In both cases, the block exerts a force = W on the table. In case A, the smaller side of the box is in contact with the table than in case B, so in case A, the block exerts a *greater* pressure on the table than in case B, where the weight is distributed over a larger area. This is also why it hurts more when a sharp object is applied to you rather than a blunt object. The sharp object produces a larger pressure than the blunt object.



12-2. The Pressure in a Gas.—Suppose we have a box filled with air. If we could look inside and see what the air molecules were doing, we would see that they **are in constant random motion and are constantly colliding with the walls of the box. Every time a molecule hits a wall, it exerts a force on it** – not a big force because the mass of a molecule is small (~ 10^{-26} kg). However, there are a lot of molecules in the box and the net average effect of these hitting the wall produces a large force. (A one cubic meter box contains about 10^{25} air molecules.) The force per unit area of the walls is the pressure due to the air molecules. The pressure of the gas molecules on its container depends on how many gas molecules are in the container and their temperature (This is quantified in the ideal gas law.). As the temperature of a gas rises, each molecule moves with a higher speed and is thus able to produce a larger effect on the walls – higher pressure.

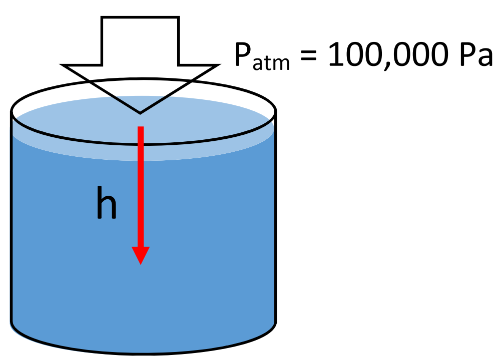
*Atmospheric pressure.—*Atmospheric pressure is the pressure exerted on the Earth's surface (and us) by the air molecules in the atmosphere. The atmosphere is a relatively thin layer of mostly oxygen and nitrogen molecules surrounding the Earth up to an altitude of about 6 miles. The Earth's atmosphere is held in place by the Earth's gravity. There is no atmosphere on the moon because the moon's gravity is too weak to hold on to one. The value of the atmospheric pressure at the Earth's surface is roughly 100,000 N/m^2 or 10^5 Pa. In the US this is expressed as 15 pounds per square inch (psi). Atmospheric pressure varies from day to day, but the largest deviation of atmospheric pressure from its nominal value was 17% in the center of a typhoon. Day to day variations in atmospheric pressure are typically just a few percent. If you think about it, atmospheric pressure produces a fairly large force on us and everything else on the earth – 15 pounds of force on every square inch, yet we don't seem to notice this – why? We don't notice atmospheric pressure typically, because it is usually very well balanced on both sides of objects. For example, there is 15 psi on both the inside and outside of a glass window, so the net effect cancels out. We might notice atmospheric pressure on our ear drums when we are going up a tall mountain. This is because it may take some time for the air pressure on the inside of our eardrums to equalize (this is what our Eustachian tubes do for us) with the pressure on the outside. Several dramatic demonstrations of the effects of air pressure will be performed in class; a few of these are illustrated on slides 13 and 14.

12-3 Pressure in a Liquid.—Liquids are very different than solids in the sense that a liquid cannot support itself as a solid can. The diagram shows a block of copper and a block of water resting on a surface. The copper can support itself, but the cube of water cannot support itself, so this is not a real situation. Water must be in a container to be able to rest on a surface like shown. Every layer of water pushes against the layers below it which then slip horizontally until we are left with a puddle.



The technical explanation for this is that **liquids cannot exert shear forces** (sidewise forces) to prevent slipping. A container is necessary to provide the sidewise forces to keep the liquid in a particular shape.

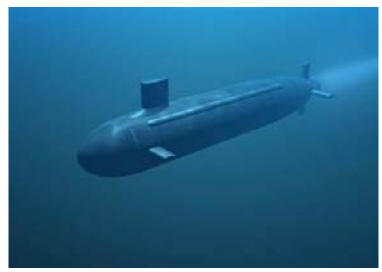
A liquid exerts forces on the walls of its containing vessel. **The force per unit area on the walls is the liquid pressure.** If you have ever dove into a deep pool or lake, you can feel the water pressure pressing against your body. In fact the deeper you go into a body of water, the greater is the water pressure that you will experience. This is simply because at any point in a liquid, the force of the weight of all the liquid above that point is acting and the deeper you go, the more liquid is above you. The increasing water pressure with depth places a limit on how deep a submarine can submerge. How does the pressure in a liquid increase with depth? We are looking for a simple formula that provides a value for the pressure of any liquid, not just water. Every liquid is characterized by it mass density in kilograms per cubic meter; the Greek letter rho, ρ is used to designate this parameter. Consider a container filled with some liquid, you can imagine it to be water for simplicity. Since the upper surface is open to the atmosphere, the atmosphere presses down on the liquid with 100,000 Pa, this is the starting pressure at the surface. We want **the pressure at a depth h** below the surface, call this P(h). This pressure is simply the pressure at the surface, P_{atm} plus the pressure of all the water from the surface to the point h below the surface. Suppose the cross sectional area of the container is A. The force on the surface



due to the atmosphere is P_{atm} A, and the force of all the water down to a depth h is just the weight of that water W which is just W = M g, where M is the mass of all the water in the container of length h. In terms of the density M = ρ(Ah), where Ah is the volume of the water, so that W = ρ(Ah) g. The total force at the depth h is then $P_{atm}A+\rho\left(hA\right)g$, and the pressure is force per unit area, so if we divide out A we get

PRESSURE VARIATION WITH DEPTH $P(h)=P_{atm}+\rho gh.$ [3

Example 12-1: The US Seawolf-class submarines were designed to withstand a maximum hull pressure of about 7000 kPa (1 kPa = 1000 Pa). What is the approximate maximum depth (referred to as the crush-depth) to which a Seawolf-class sub can submerge? Assume the density of sea water is about 1000 kg/m^3.



Solution: The maximum pressure is 7x10^6 Pa.

$P(h)=P_{atm}+\rho gh=1\times10^{5}\,Pa+(1000\,kg/m^{3})(10\,m/s^{2})h.$ At what depth h is P = 7x10^6 Pa? Since this pressure is 70 times larger than atmospheric pressure, we can neglect atmospheric pressure at crush depth for this rough calculation. Then we must have that:

$\rho gh\approx7\times10^{6}\ Pa\rightarrow(1000)(10)h=7\times10^{6}\rightarrow10^{4}h\approx7\times10^{6}\rightarrow h\approx700\ m\approx2300\ ft.$

The USS Thresher with its crew of 129 was lost in April 1963 during deep-sea diving drills when it lost propulsion power and sank in the Atlantic Ocean, 200 miles off the coast of Boston, MA.

Another example of the use of this formula is given on **slide 18. Slide 19** gives a picture of how the increase in pressure comes about. **Slide 17** shows a hypothetical volume inside a liquid and shows that for this volume is at rest the pressure must increase with depth. This is all based on the fact that all parts of a fluid are at rest. When a liquid is first poured into a container, there is a lot of motion of various parts of the liquid with respect to other parts, but eventually the liquid settles down and every part of it is at rest – we refer to this situation as **fluid statics**.