Fluid Statics

AP Physics 2

States of Matter

Before we begin to understand the nature of a Fluid we must understand the nature of all the states of matter:

The 3 primary states of matter

- - **solid** - Definite shape and volume.
- - **liquid** -Takes the shape of its container, yet has a definite volume.
- - **gas** - Takes the shape and volume of its container.

Special "states”

- - **Plasma, Bose-Einstein Condensate**

Density

The 3 primary states have a distinct **density**, which is defined as ***mass per unit of volume.***

Density is represented by the Greek letter, "RHO", ρ

$$\rho_{(density)} = \frac{M}{V} = \frac{kg}{m^3}$$

$$\rho_{(units)} = {}^{kg}\!/_{m^3}$$

Specific Gravity

- Ratio of a substance's density to the density of water
  - Sp. gr. = ρ_{subs} / ρ_{water}
  - ρwater = 1000 kg/m^3
  - Can be used to determine the percentage of an object that will be submerged/floating in water.

Example

- A piece of plastic has a density of 600 kg/m^3. Find the plastic's specific gravity. Calculate the % of the plastic that will be submerged in water.
- The specific gravity of the plastic is 0.600
- 60% of the plastic will be submerged. See the connection?

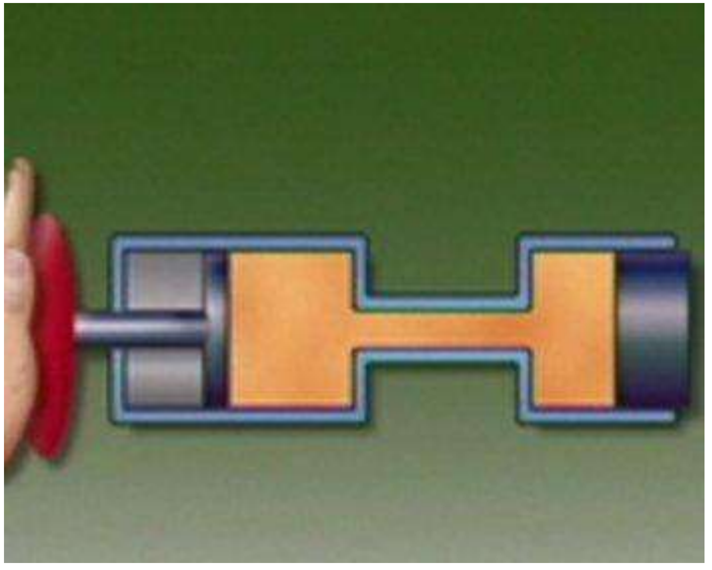
What is a Fluid?

By definition, a **fluid** is any material that is unable to withstand a static shear stress. Unlike an elastic solid which responds to a shear stress with a recoverable deformation, a fluid responds with an irrecoverable flow.

Examples of fluids include gases and liquids.

Why fluids are useful in physics?

Typically, liquids are considered to be **incompressible**. That is once you place a liquid in a sealed container you can DO WORK on the FLUID as if it were an object. The **PRESSURE** you apply is transmitted throughout the liquid and over the entire length of the fluid itself.



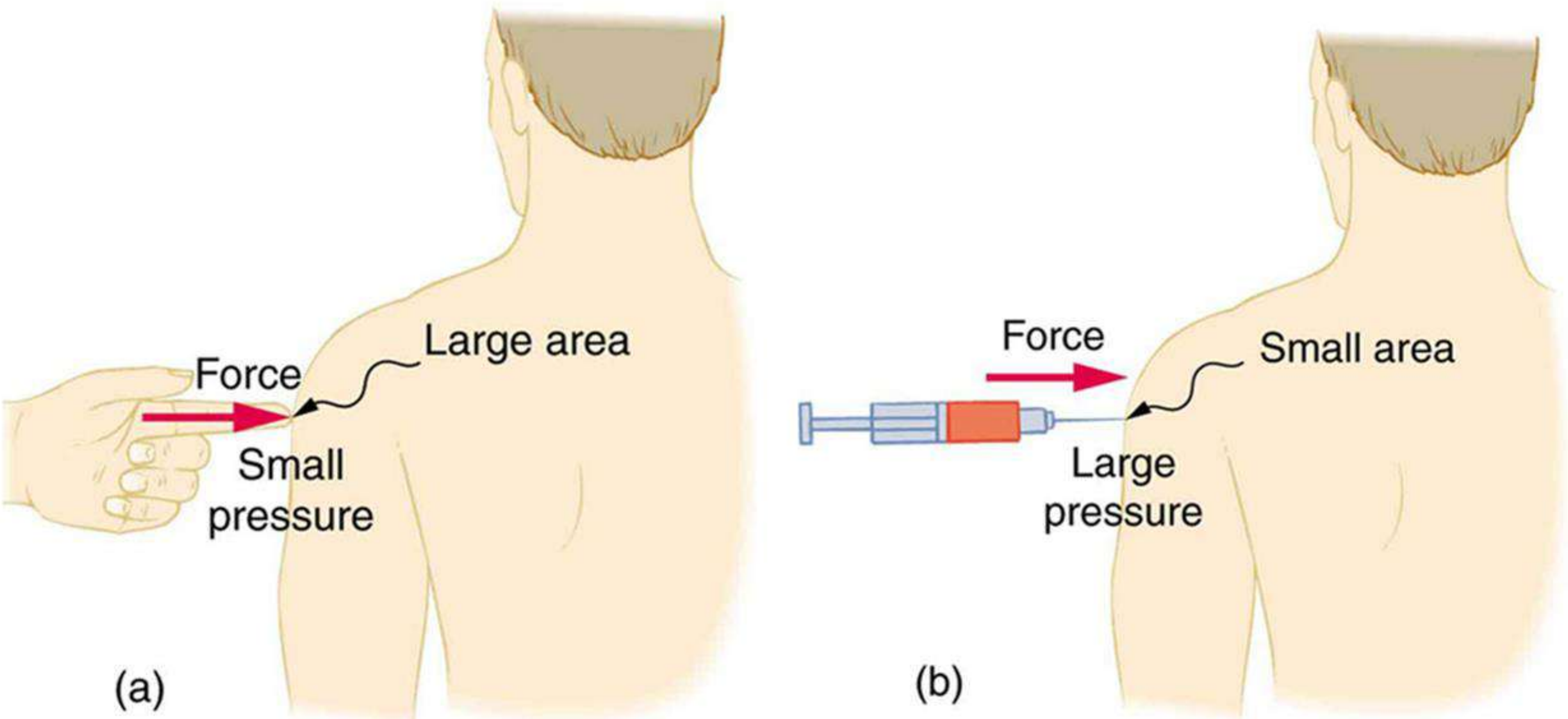
Pressure

- One of most important applications of a fluid is it's **pressure- defined as a Force per unit Area**

$$P = \frac{F}{A} = \frac{N}{m^2}$$

$$P_{(units)} = N/m^2$$

Force and Area affect pressure



(a) While the person being poked with the finger might be irritated, the force has little lasting effect.
(b) In contrast, the same force applied to an area the size of the sharp end of a needle is great enough to break the skin.

Example

A water bed is 2.0 m on a side an 30.0 cm deep.

(a) Find its weight if the density of water is 1000 kg/m3.

(b) Find the pressure the that the water bed exerts on the floor. Assume that the entire lower surface of the bed makes contact with the floor.

$$a) \quad V = 2 * 2 * 0.30 = \text{1.2 m}^3$$

$$\rho = \frac{m}{V} \rightarrow 1000 = \frac{m}{V} = \text{1200 kg}$$

$$W = mg = \text{11760 N}$$

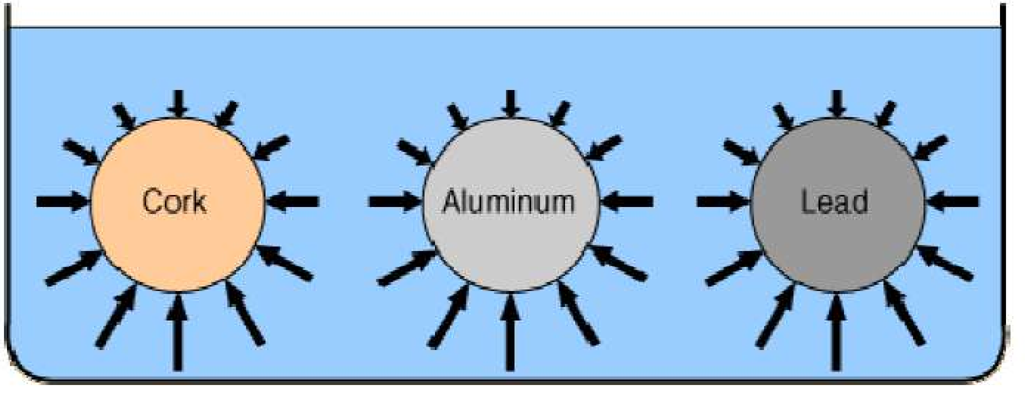
$$b) \; P = \frac{F}{A} = \frac{mg}{A} = \frac{11760\,N}{4\,m^2} = \text{2940 N/m}^2$$

Hydrostatic Pressure

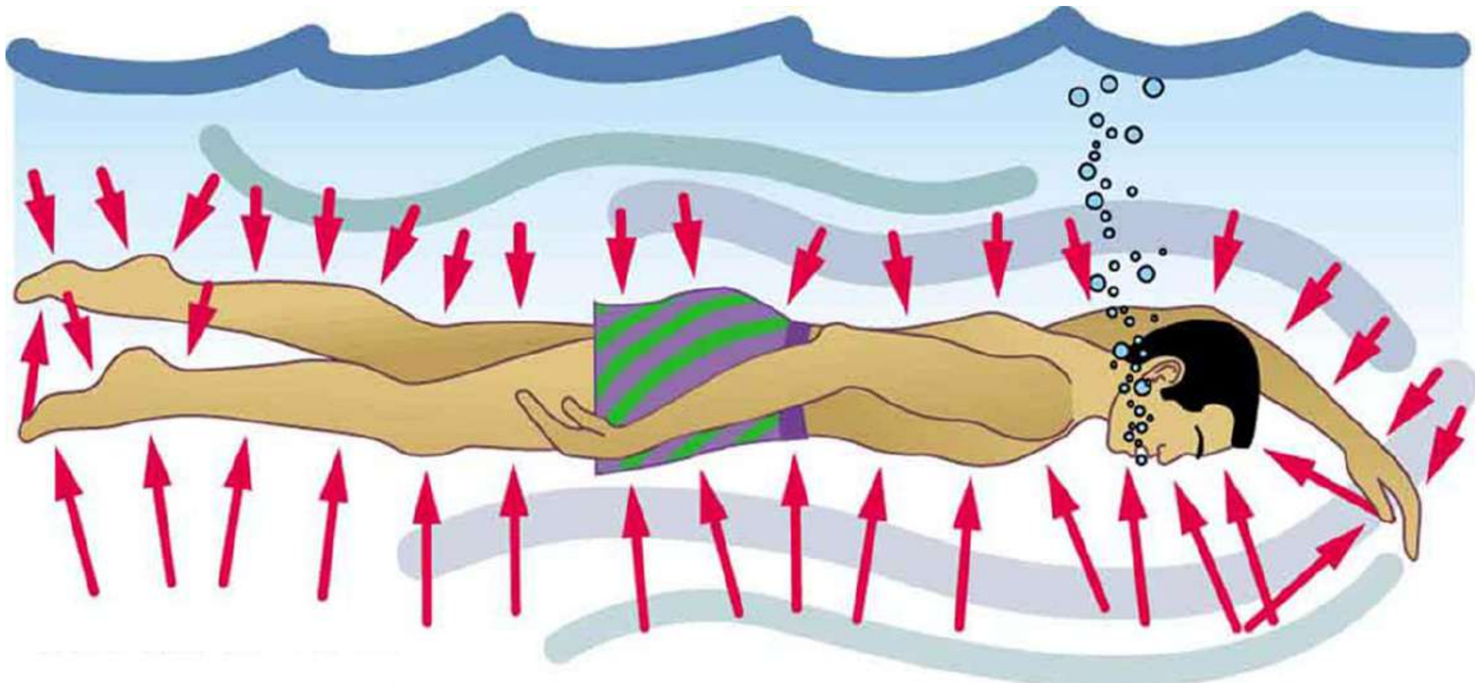
Suppose a Fluid (such as a liquid) is at REST, we call this
HYDROSTATIC PRESSURE

Two important points

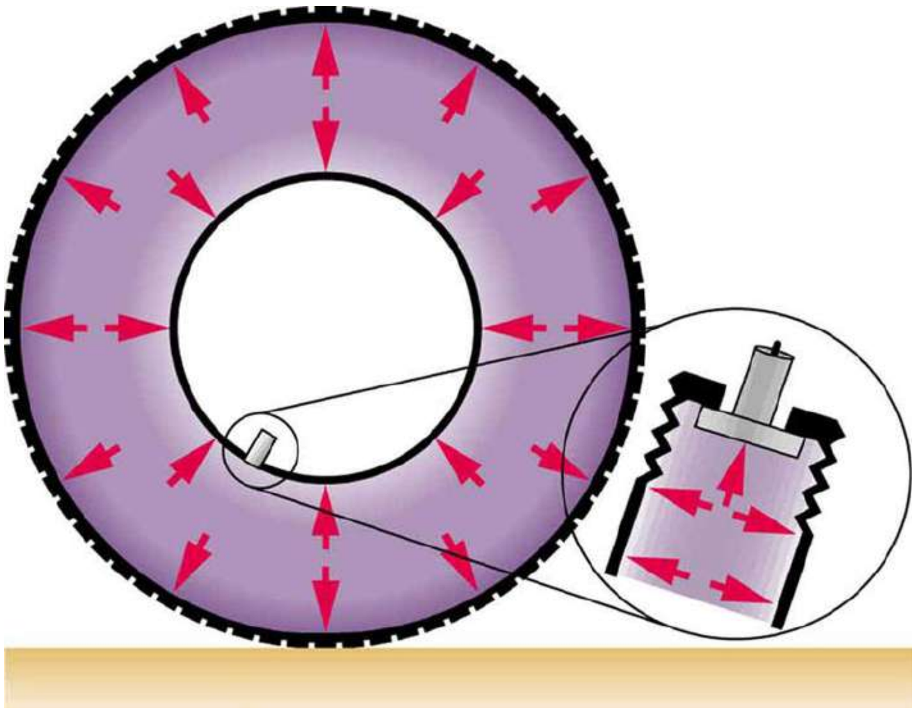
- A fluid will exert a pressure in all directions
- A fluid will exert a pressure perpendicular to any surface it compacts



Notice that the arrows on TOP of the objects are smaller than at the BOTTOM. This is because pressure is greatly affected by the DEPTH of the object. Since the bottom of each object is deeper than the top the pressure is greater at the bottom.

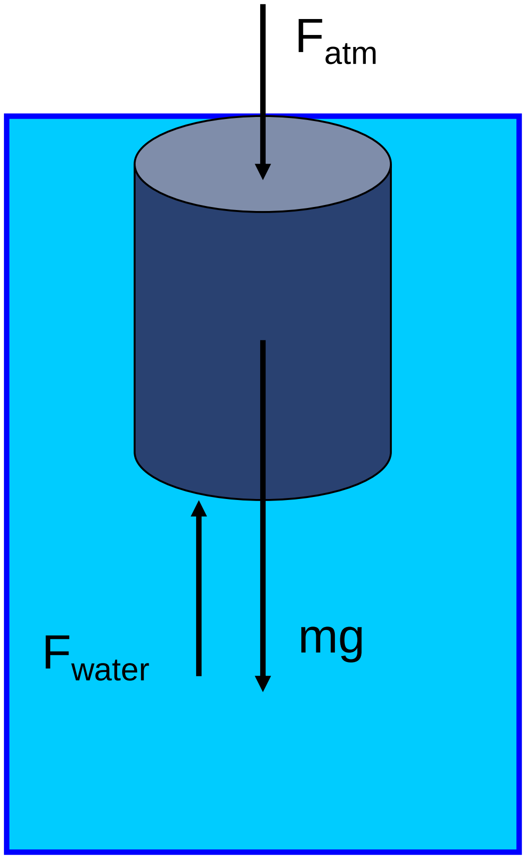


Pressure is exerted on all sides of this swimmer, since the water would flow into the space he occupies if he were not there. The arrows represent the directions and magnitudes of the forces exerted at various points on the swimmer. Note that the forces are larger underneath, due to greater depth, giving a net upward or buoyant force that is balanced by the weight of the swimmer.



Pressure inside this tire exerts forces perpendicular to all surfaces it contacts. The arrows give representative directions and magnitudes of the forces exerted at various points. Note that static fluids do not exert shearing forces.

Pressure vs. Depth



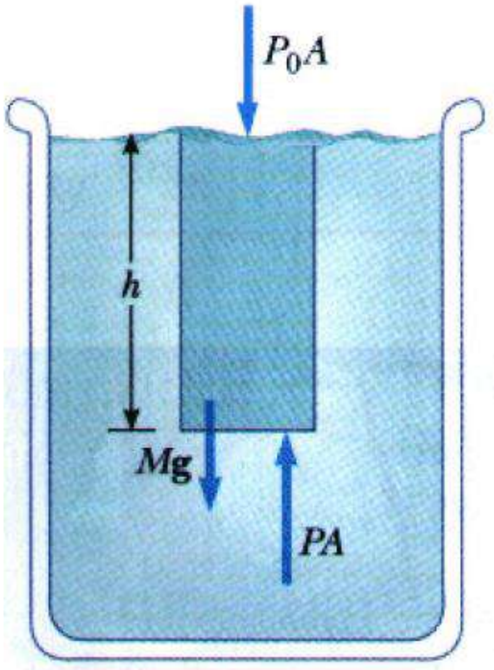
Suppose we had an object submerged in water with the top part touching the atmosphere. If we were to draw an FBD for this object we would have three forces

1. The weight of the object
2. The force of the atmosphere pressing down
3. The force of the water pressing up

$$F_{water} = F_{atm} + mg$$

Pressure vs. Depth

But recall, pressure is force per unit area. So if we solve for force we can insert our new equation in.



$$P = \frac{F}{A} \quad F_{water} = F_{atm} + mg$$

$$PA = P_o A + mg$$

$$\rho = \frac{m}{V} \rightarrow m = \rho V$$

$$PA = P_o A + \rho V g$$

$$V = Ah$$

$$PA = P_o A + \rho A h g$$

$$P = P_o + \rho g h$$

Note: The initial pressure in this case is atmospheric pressure, which is a CONSTANT.

$P_o = 1 \times 10^5$ N/m^2

A closer look at Pressure vs. Depth

$$P = P_o + \rho g h$$

Depth below surface

Initial Pressure – May or MAY NOT be atmospheric pressure

ABSOLUTE PRESSURE

$$\Delta P = \rho g h$$

Gauge Pressure = CHANGE in pressure or the DIFFERENCE in the initial and absolute pressure

Atmospheric Pressures

- 1.01×10^5 Pa
- 1.01×10^5 N/m^2
- 1 atm
- 101.3 kPa

Example

a) Calculate the absolute pressure at an ocean depth of 1000 m. Assume that the density of water is 1000 kg/m^3 and that P_o= 1.01 x 10^5 Pa (N/m^2).

b) Calculate the total force exerted on the outside of a 30.0 cm diameter circular submarine window at this depth.

$$P = P_o + \rho g h$$

$$P = 1x10^5 + (1000)(9.8)(1000)$$

$P =$ **$9.9x10^6\ N/m^2$**

$$P = \frac{F}{A} = \frac{F}{\pi r^2} = \frac{F}{\pi (0.15)^2} =$$

7.0×10^5 N

A closed system Pascal's Principle

If you take a liquid and place it in a system that is CLOSED like plumbing for example or a car's brake line, the PRESSURE is the same everywhere.

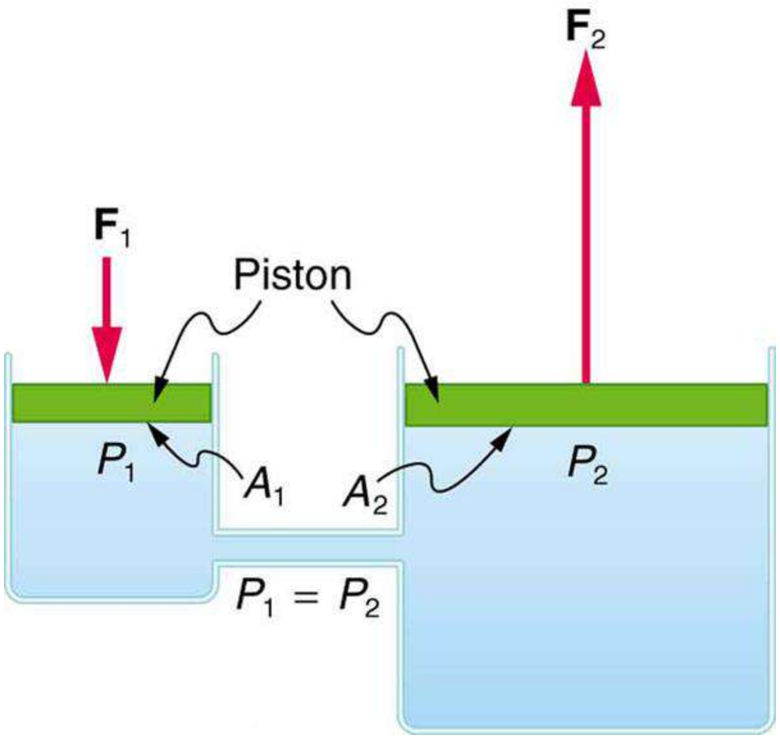
Since this is true, if you apply a force at one part of the system the pressure is the same at the other end of the system. The force, on the other hand MAY or MAY NOT equal the initial force applied. It depends on the AREA.

You can take advantage of the fact that the pressure is the same in a closed system as it has MANY applications.

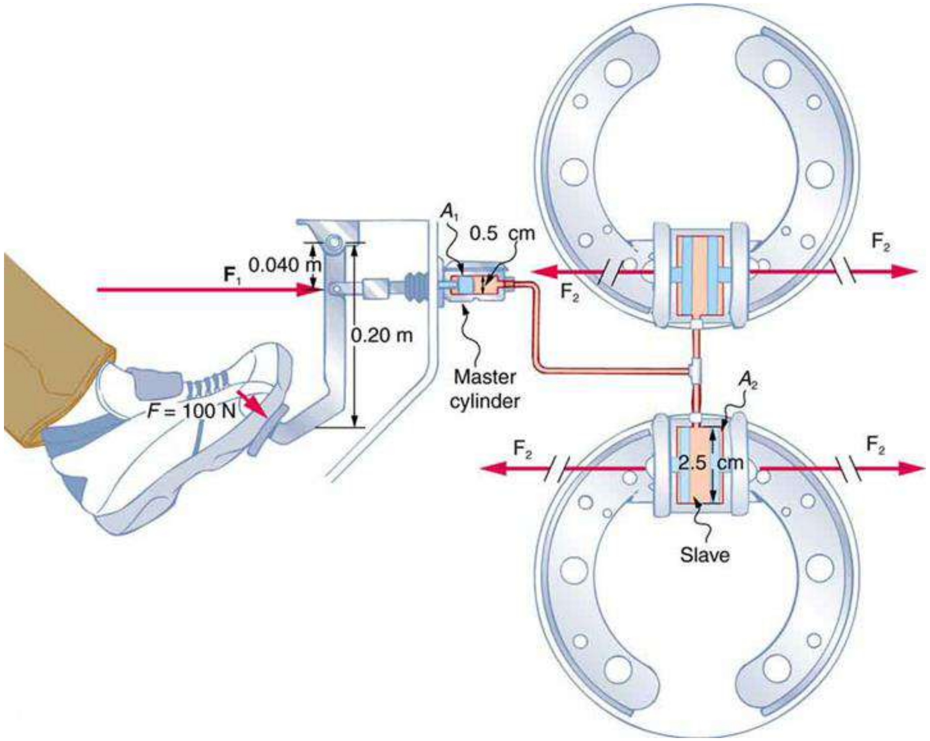
The idea behind this is called PASCAL'S PRINCIPLE

$$P_1 = P_2$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$



A typical hydraulic system with two fluid-filled cylinders, capped with pistons and connected by a tube called a hydraulic line. A downward force $\mathbf{F}_1$ on the left piston creates a pressure that is transmitted undiminished to all parts of the enclosed fluid. This results in an upward force $\mathbf{F}_2$ on the right piston that is larger than $\mathbf{F}_1$ because the right piston has a larger area.

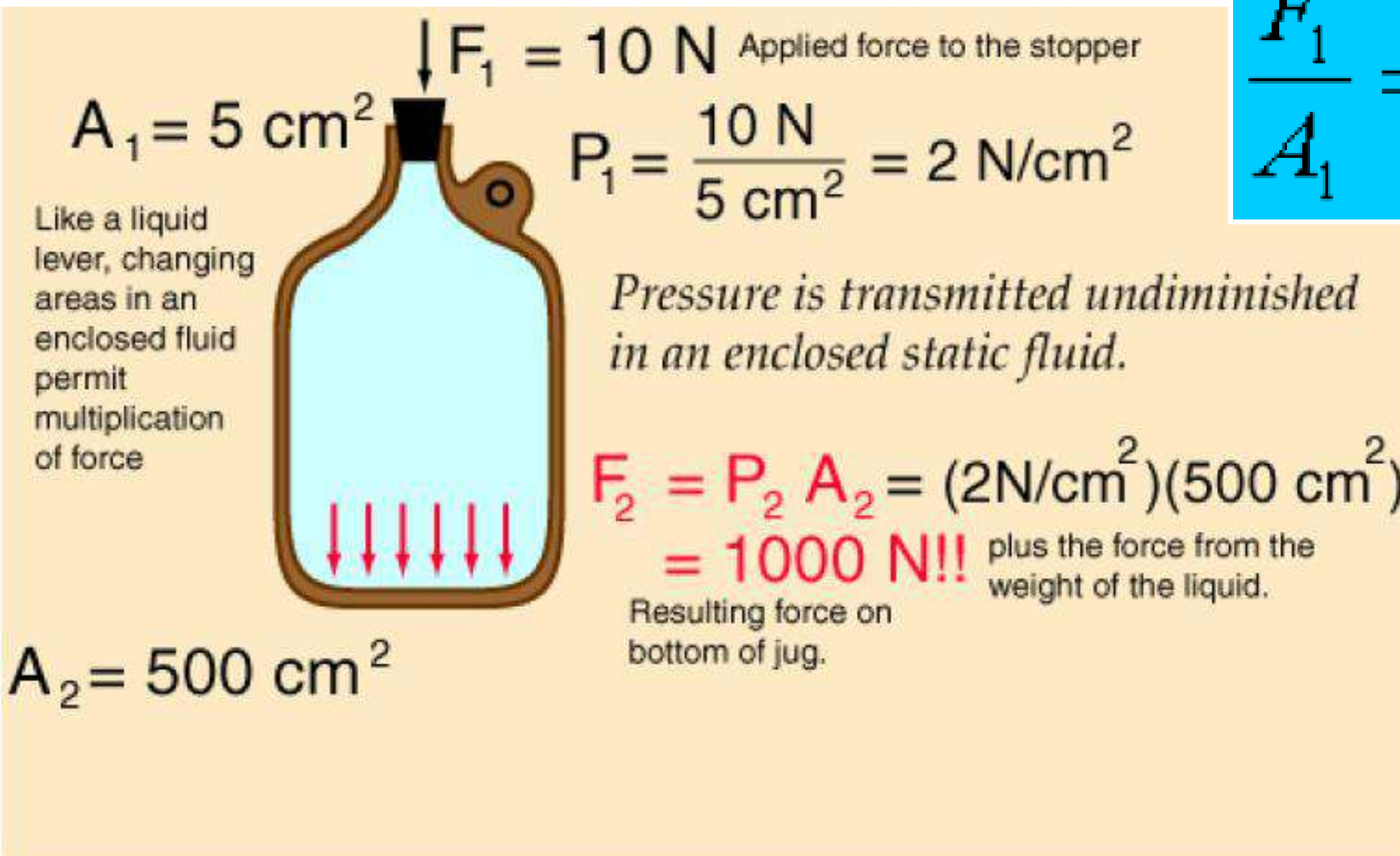


Hydraulic brakes use Pascal's principle. The driver exerts a force of 100 N on the brake pedal. This force is increased by the simple lever and again by the hydraulic system. Each of the identical slave cylinders receives the same pressure and, therefore, creates the same force output F_2 . The circular cross-sectional areas of the master and slave cylinders are represented by A_1 and A_2 , respectively

Pascal's Principle

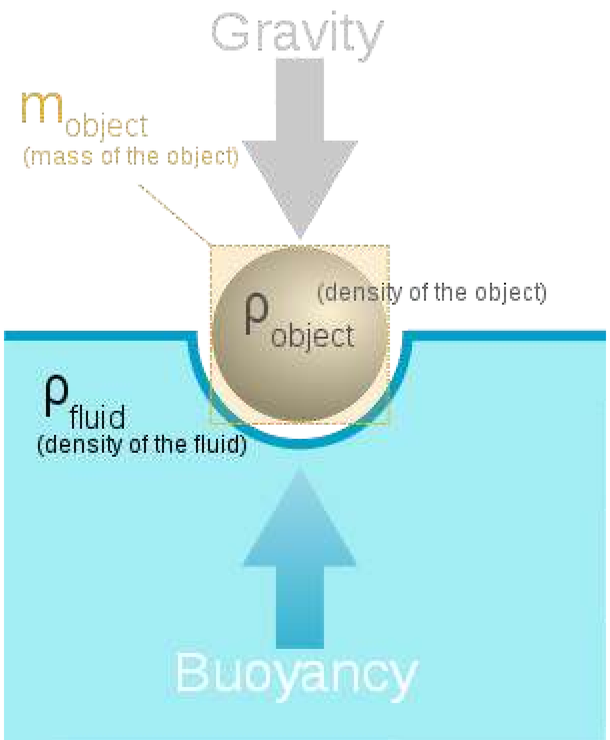
$$P_1 = P_2$$

$$\frac{F_1}{A_1} = \frac{F_2}{A_2}$$

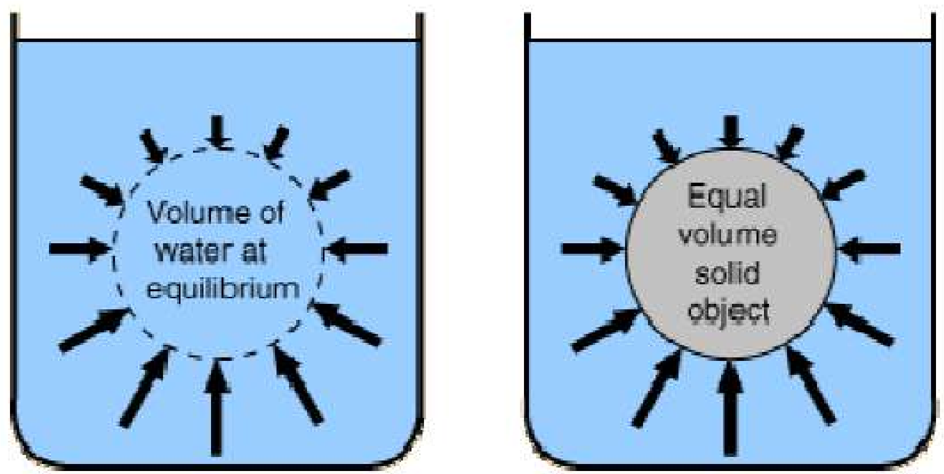


Buoyancy

When an object is immersed in a fluid, such as a liquid, it is buoyed UPWARD by a force called the BUOYANT FORCE.

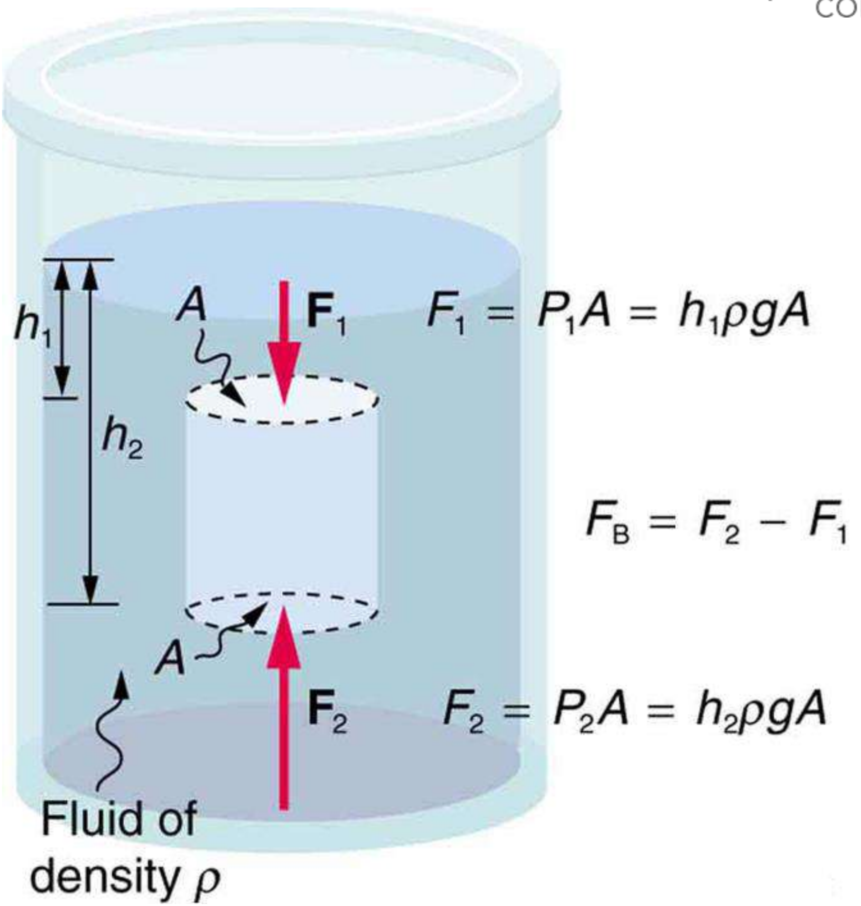


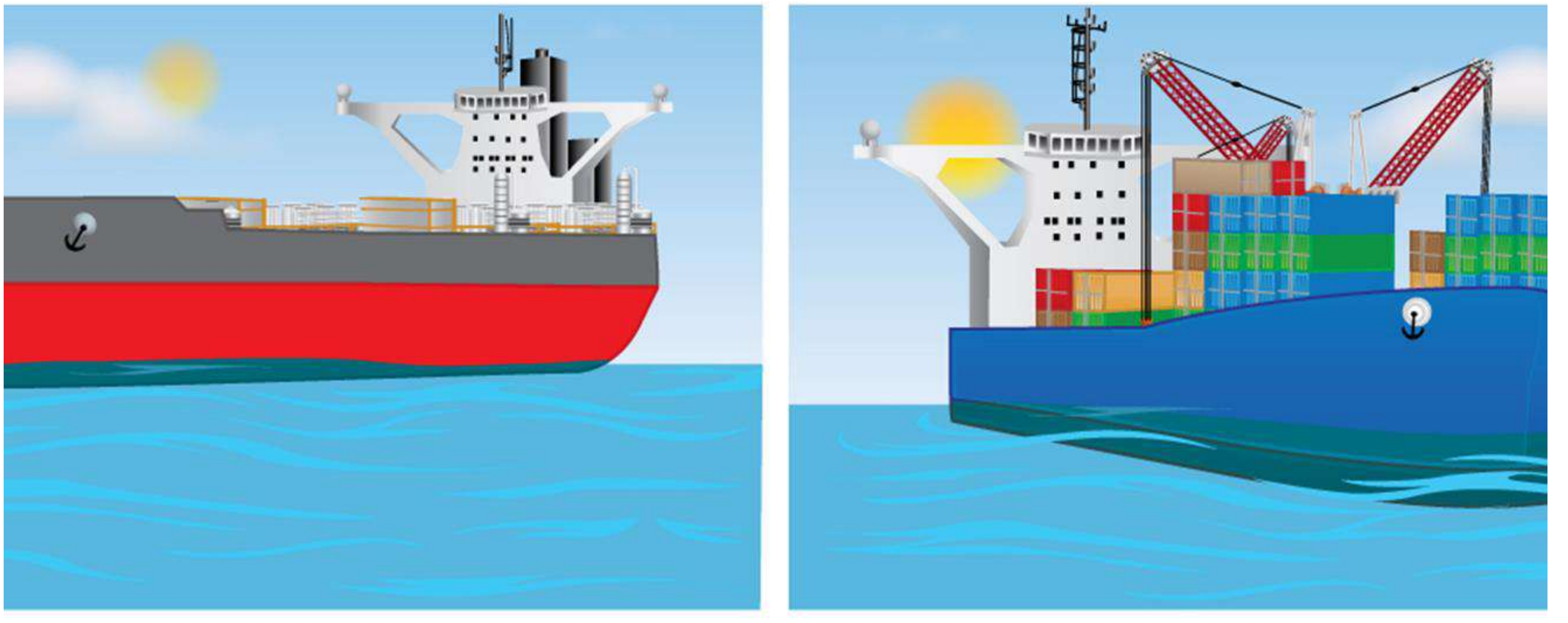
When the object is placed in fluid it DISPLACES a certain amount of fluid. If the object is completely submerged, the VOLUME of the OBJECT is EQUAL to the VOLUME of FLUID it displaces.



Where does the buoyant force come from?

Pressure due to the weight of a fluid increases with depth since $P = \rho h g$. This pressure and associated upward force on the bottom of the cylinder are greater than the downward force on the top of the cylinder. Their difference is the buoyant force **F**B . (Horizontal forces cancel.)



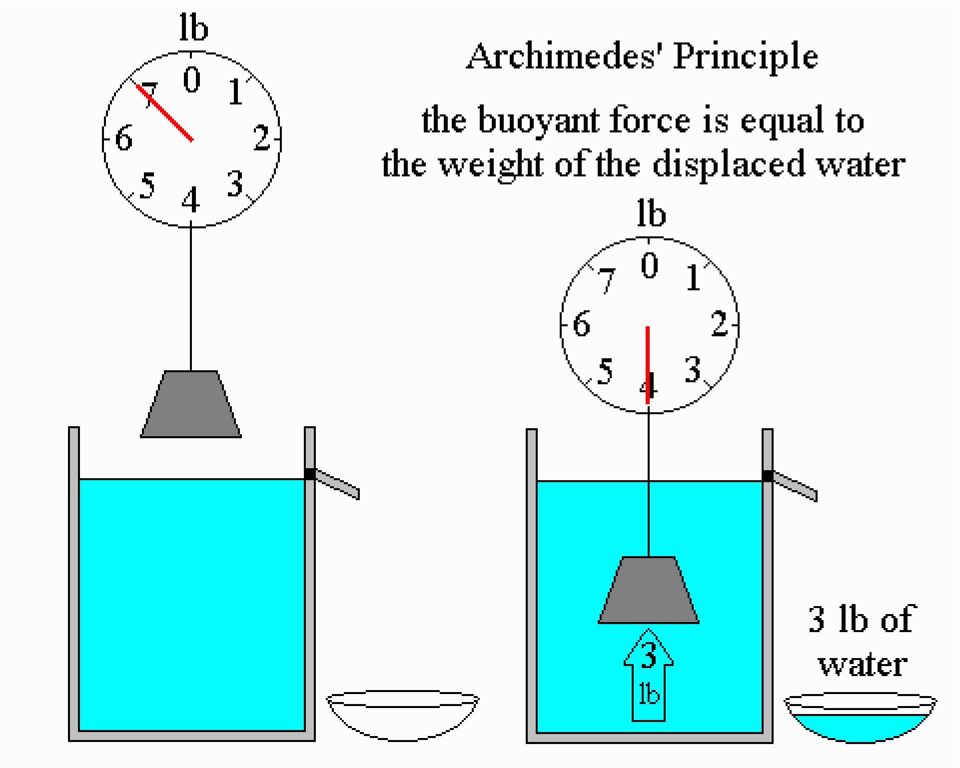


(a) (b)

Why does the empty ship (a) float higher than the loaded ship (b)?

Archimedes's Principle

" An object is buoyed up by a force equal to the weight of the fluid displaced."



In the figure, we see that the difference between the weight in AIR and the weight in WATER is 3 lbs. This is the buoyant force that acts upward to cancel out part of the force. If you were to weigh the water displaced it also would weigh 3 lbs.

Archimedes's Principle

$$F_B = (mg)_{FLUID} \quad m = \rho V$$

$$F_B = (\rho V g)_{Fluid}$$

$$V_{object} = V_{Fluid}$$

** The volume of the object is the volume that is submerged. If the object is partially submerged, then the specific gravity may be needed to determine the volume that is submerged.

Example

A bargain hunter purchases a "gold" crown at a flea market. After she gets home, she hangs it from a scale and finds its weight in air to be 7.84 N. She then weighs the crown while it is immersed in water (density of water is 1000 kg/m^3) and now the scale reads 6.86 N. Is the crown made of pure gold if the density of gold is 19.3 x 10^3 kg/m^3?

$$F_{object(air)} - F_{object(water)} = F_{buoyant}$$

$$7.84 - 6.86 = F_B =$$ 0.98 N

$$F_B = (mg)_{Fluid} = \rho_{fluid} V_{fluid} g$$

NO! This is NOT gold as 8000<19300

$$V_{fluid} =$$ **0.0001 m^3**

$$V_{object} =$$ **0.0001 m^3**

$$mass_{object} =$$ **0.80 kg**

$$\rho_{object} = \frac{m_{object}}{V_{object}} =$$ **8000 kg/m^3**