FLUID STATICS

Chapter 11

STATES OF MATTER

- Matter can come in a number of phases. Matter in a different phase is still the same stuff, but behaves very differently. The phase something will be in depends on its temperature and the pressure it is under.

- Solid (Crystalline Solid) - The basic definition of a solid is something that has a rigid shape. However, this is really only true for crystalline solids where the atoms and molecules are arranged in a specific ordered structure.

- Liquid Crystals (Deformable Solids, Glasses, Plastics) - These are solids that hold there shape for awhile but will flow over longer times or when heated. The line between solid and liquid is not as clear cut as you learn in middle school.

- Liquids - This is a state of matter that can easily flow to fill a container, but doesn't appreciably change its volume. The atoms/molecules in a liquid touch but aren't locked in place like in a crystalline solid.

- Gases - A gas can expand or shrink to fill any volume. The atoms/molecules in a gas aren't touching which is why the volume can change.

- Plasma - In a plasma not only do the atoms not touch, but the electrons have been knocked off the atoms so that you have a 'gas' of ions and electrons.

- Degenerate Matter - Under the extreme pressure only found in stars matter can reach a new phase where the interatomic forces are no longer electromagnetic, but instead quantum forces from trying to pack too many atoms too close together.

- Bose-Einstein Condensate - Some substances when very cold can form a new state of matter where the different molecules become linked together in one quantum state. The entire substance behaves like a single atom which leads to some very strange behavior.

FLUIDS

- In physics a fluid refers to a liquid or a gas. Liquids and gasses have many properties in common so we will often discuss them together, though of course there are some differences which we will also discuss.

- The language we have been using, mass, force, etc. doesn't really describe a fluid very well. We will have to use new terms to describe a fluid. In particular density and pressure.

DENSITY

- For fluids density replaces our concept of mass. Density is just mass per volume and since we've run out of letters it gets the Greek letter ρ.

$$\rho = \frac{M}{V}$$

- The above equation allows us to write mass in terms of fluid quantities, M =ρV. We can use this to connect fluids and mechanics. For example the weight of a fluid on the surface of the Earth is Mg = ρgV.

- The specific gravity of a fluid is its density divided by the density of water. This is a dimensionless measure of density and is often useful because water plays an important role in many situations.

EXAMPLE 11.1

- **Calculating the Mass of a Reservoir From Its Volume:**
A reservoir has a surface area of 50.0km² and an average depth of 40.0m. What mass of water is held behind the dam?

A = 50.0km² = 50km² (1000m / 1 km)² = 5 ×10⁷ m²
d = 40.0m
m = ?   ρ = 1000 kg /m³

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

$$m = \rho V = \rho A d = 1000 kg/m^2 (5 \times 10^7 m^2)(40m) = 2 \times 10^{12} kg$$

PRESSURE

- Just like density replaced mass for fluids, force is replaced by pressure. Pressure is force per area, or

$$P = \frac{F}{A}$$

- Although force is a vector, pressure is a scalar. The SI unit of pressure is the pascal (Pa). 1 Pa = 1 N/m^2.

- A fluid that is not moving must be in pressure equilibrium. In a fluid pressure is caused by the motion of the atoms/molecules that make up the fluid. The pressure is exerted against everything the fluid is in contact with.

EXAMPLE 11.2

- **Calculating Force Exerted by the Air: What Force Does a Pressure Exert?** An astronaut is working outside the International Space Station where the atmospheric pressure is essentially zero. The pressure gauge on her air tank reads 6.90×10^6 Pa. What force does the air inside the tank exert on the flat end of the cylindrical tank, a disk 0.150 m in diameter?

P = 6.90×10^6 Pa
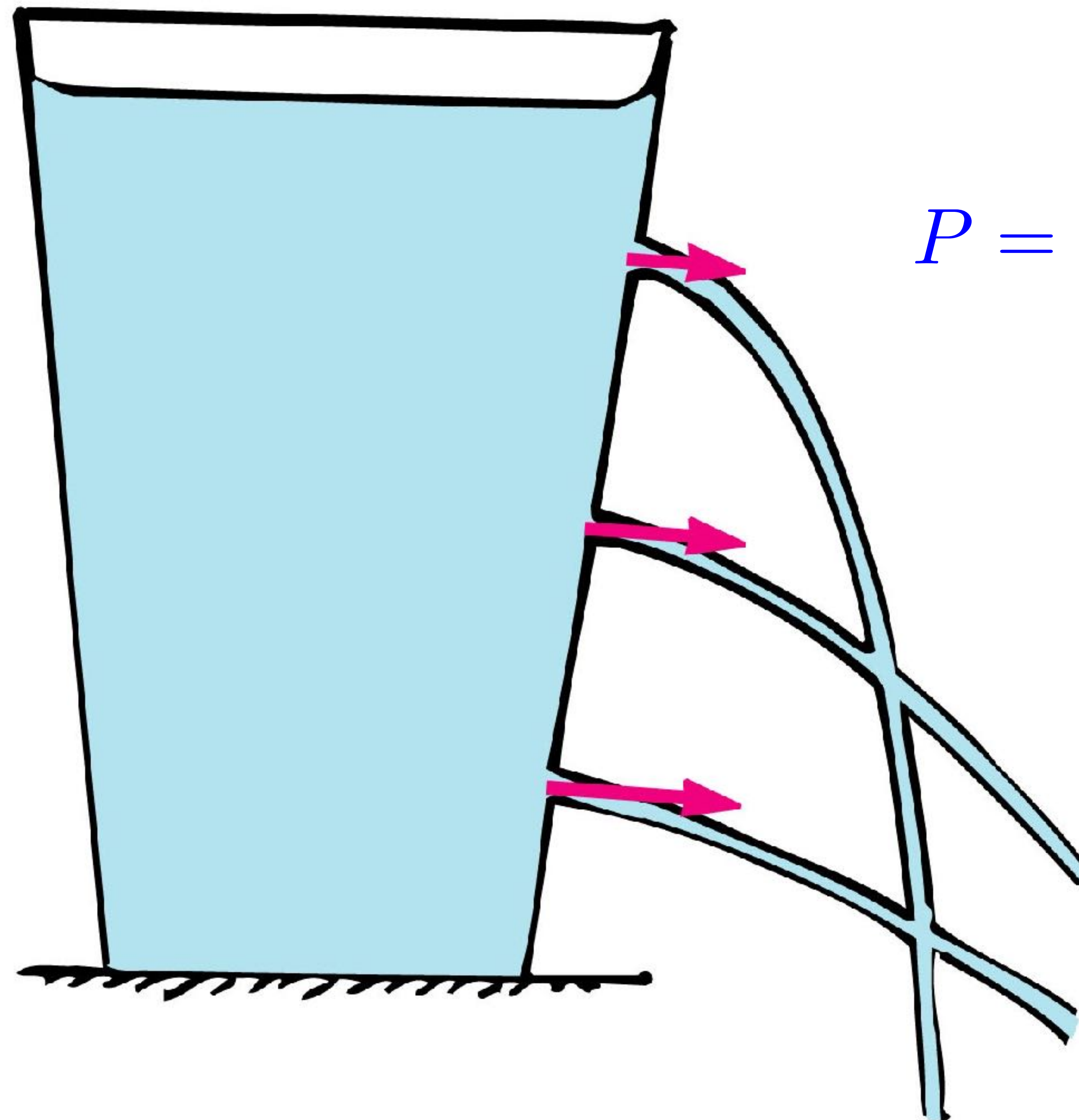
d = 0.150 m

F = ?

$$P = \frac{F}{A} \qquad\qquad F = PA$$

$$A = \pi r^2 = \pi(d/2)^2$$

$$F = P\pi(d/2)^2 \; = \pi(6.90 \times 10^6\, N/m^2)(0.075m)^2 = 1.22 \times 10^5\, N$$

PRESSURE AND GRAVITY

- The pressure is a fluid must be enough to support the weight of fluid above it (otherwise it wouldn't be in equilibrium).

- Thus the pressure must increase as you go down in a fluid. Since the weight of a uniform fluid is ρgV the pressure as a function of depth must be,

$$P = \frac{F}{A} = \frac{\rho g h A}{A} = \rho g h$$

$$P = \rho g h$$

Can this really happen?

The pressure inside a plane is different than the pressure outside a plane, to make it comfortable and breathable for passengers.

Outside the pressure decreases as an exponential with a scale height of 8km. So if the plane is flying at 6000m the pressure would be.

$$P(6000m) = P(0m)e^{(-6000m/8000m)} = 0.47P(0m)$$

The pressure at sea level is one atmosphere or 101,000 Pa. So the pressure outside the plane is

$$P(6000m) = (0.47)(1.01 \times 10^5 Pa) = 4.8 \times 10^4 Pa$$

$$\Delta P = 1.01 \times 10^5 Pa - 4.8 \times 10^4 Pa = 5.3 \times 10^4 Pa$$

Size of the window is about 30cm × 30cm, or A = 900cm² = 0.09 m².

$$F = PA = (5.3 \times 10^4 Pa)(0.09m^2) = 4,770N$$

Yes there is enough force to pull him through the window, however this pressure difference quickly decreases as the air in the plane escapes.

EXAMPLE 11.5

- **Calculating Depth Below the Surface of Water:** Calculate the depth below the surface of water at which the pressure due to the weight of the water equals 1.00 atm.
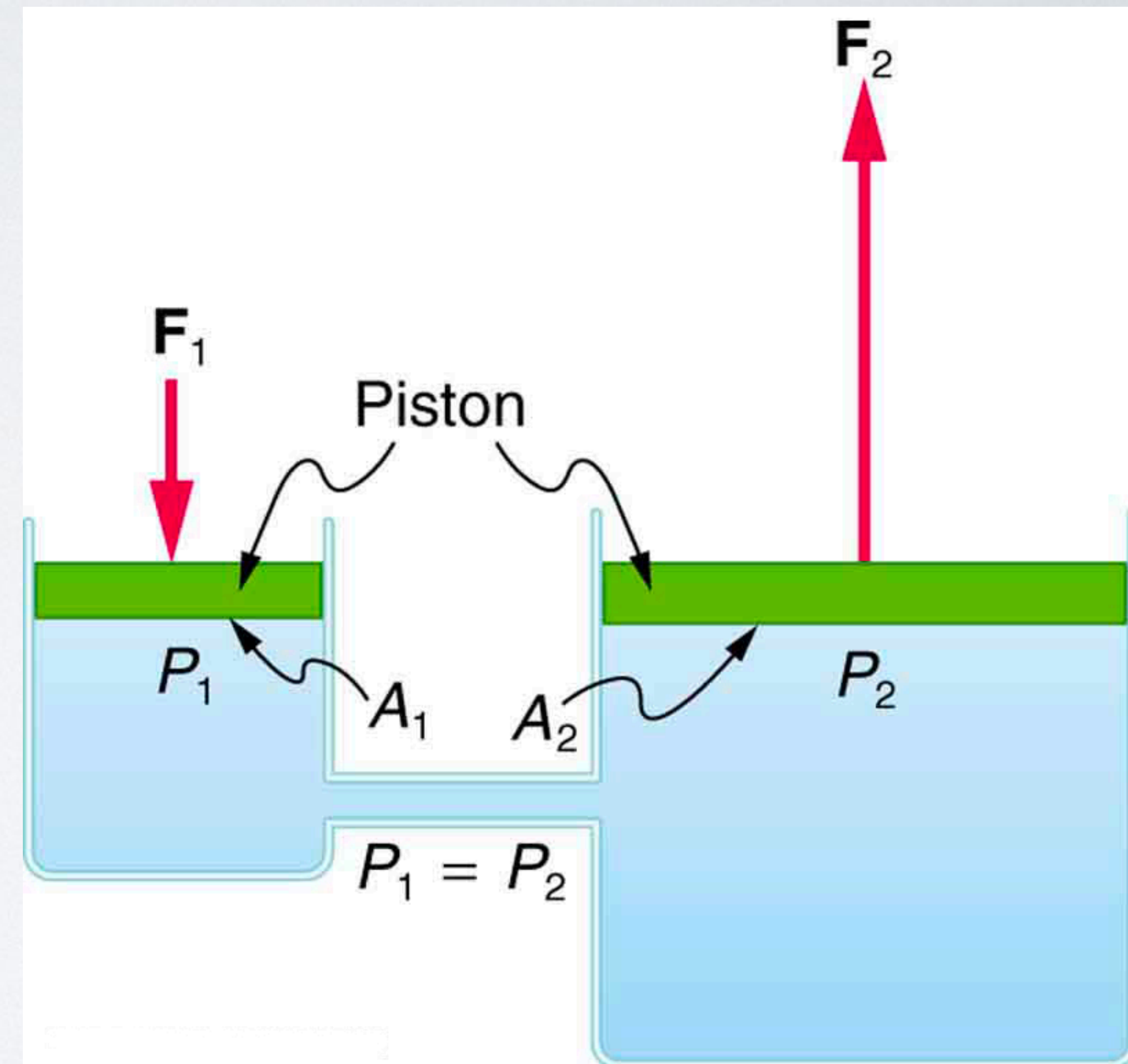
P = 1.00 atm = 101,000 Pa

ρ_w = 1000 kg/m³

$$P = h\rho g \quad \rightarrow h = \frac{P}{\rho g}$$

$$h = \frac{101,000 N/m^2}{(1000 kg/m^3)(9.8 m/s^2)} = 10.3m$$

At this depth in the water the pressure will be 2.00 atm, 1atm from the water and 1atm from the air above it.

PASCAL'S PRINCIPLE

- Pascal's principle is that any pressure applied on a static fluid is felt by all fluid it is in contact with.

- Thus in the figure to the right $P_1 = P_2$.

GAUGE PRESSURE

- Because most of us are on the surface of the Earth and experience 1 atm of pressure all the time, often pressure is only measured in excess of this amount. This is called gauge pressure.

$$P_{abs} = P_g + P_{atm}$$

- So if you measure the pressure in your tire, you measure gauge pressure. Zero means the tire doesn't have any pressure greater than the atmosphere. You just have to be careful when reading a pressure, which type is being specified.
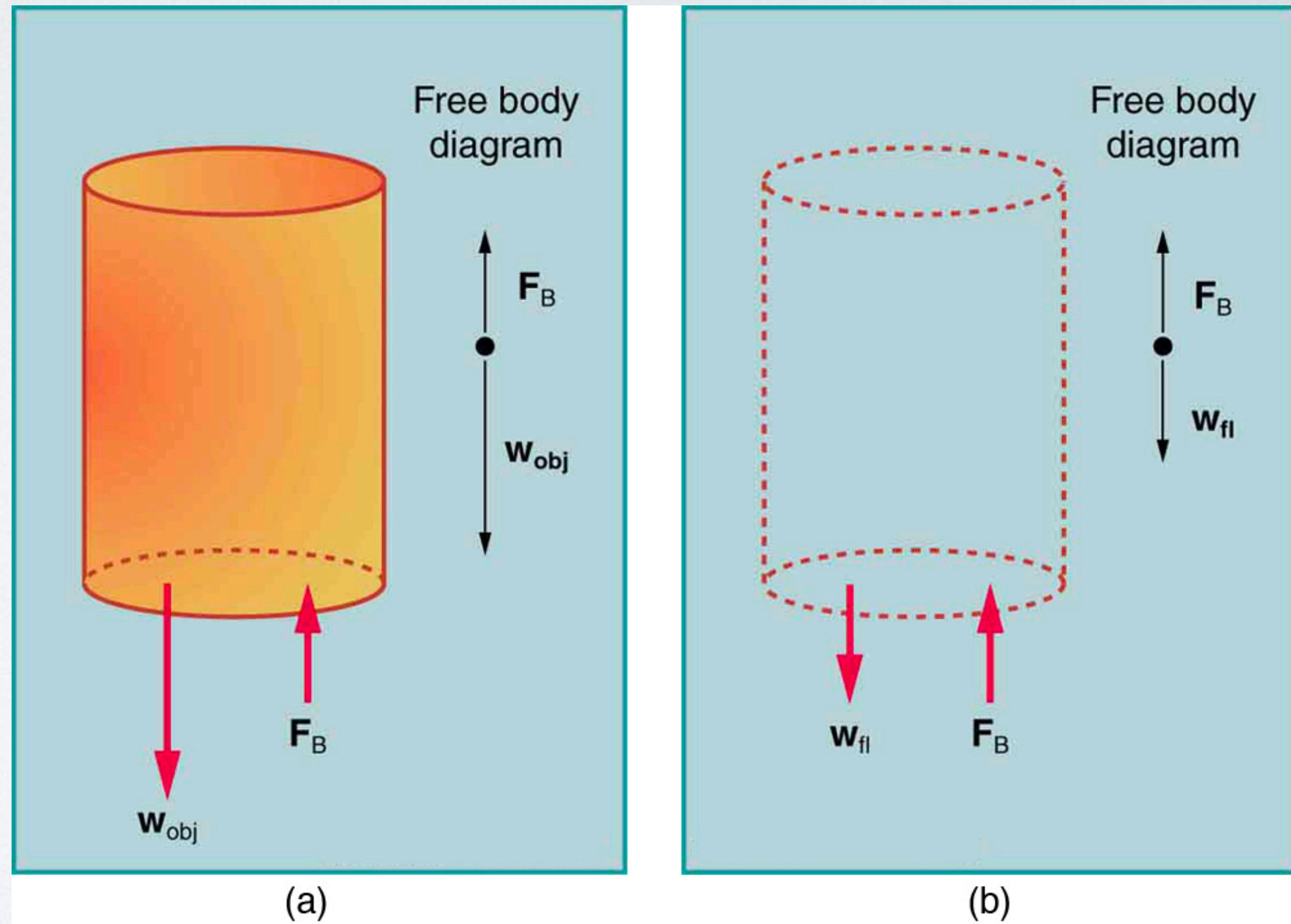
BUOYANT FORCE

- An object in a fluid will feel pressure on all sides.

- However, because the pressure is greater lower down this creates a net force pushing up on the object.

- This is called the buoyant force.
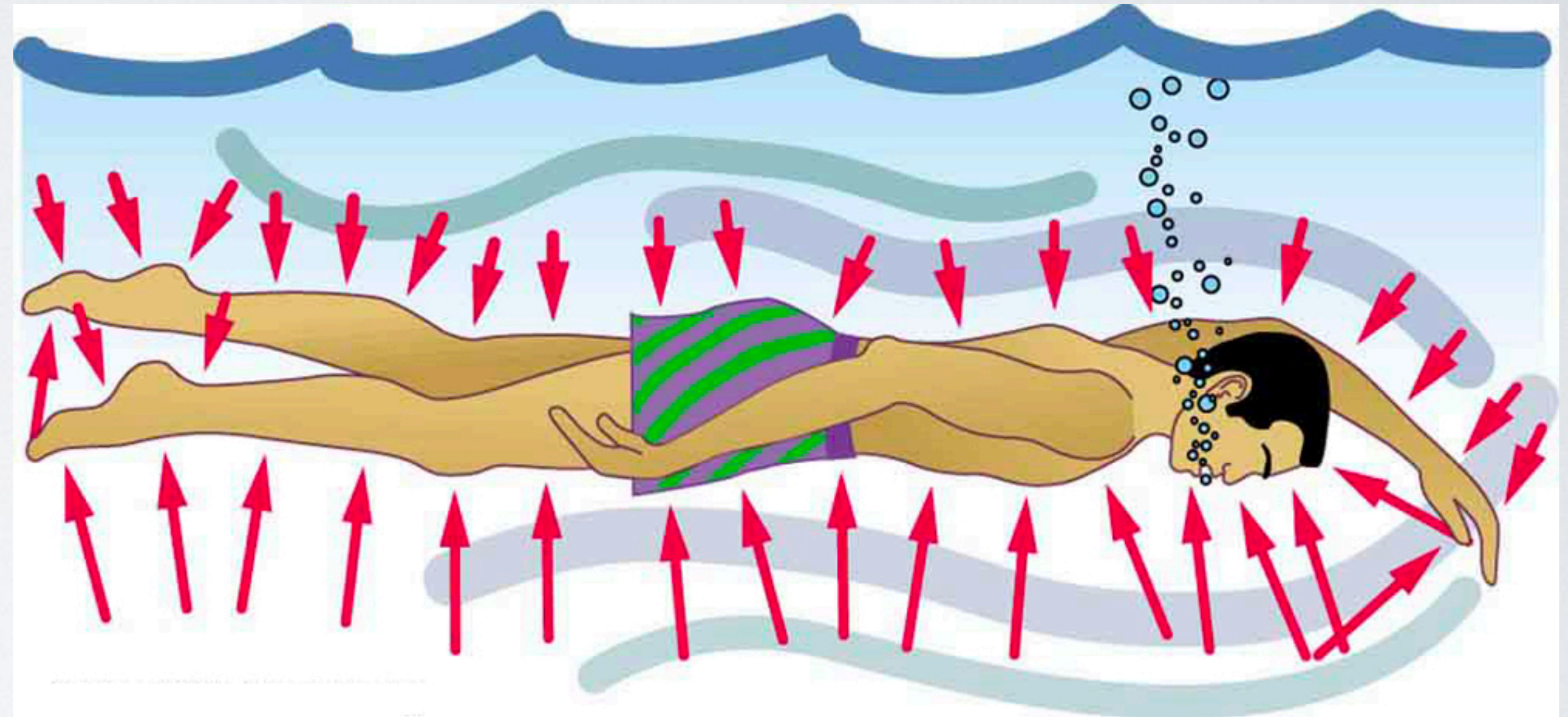
ARCHIMEDES'S PRINCIPLE

- Archimedes figured out the buoyant force in 2nd century BC.

- He realized that you could imagine the object in the water was the water itself.

- Then we know the buoyant force must be exactly the objects weight.

$$F_b = \rho g V_{displaced}$$

(a)　(b)

EXAMPLE 11.8

- Calculating buoyant force: dependency on shape (a) Calculate the buoyant force on 10,000 metric tons (1.00×10⁷kg) of solid steel completely submerged in water, and compare this with the steel's weight. (b) What is the maximum buoyant force that water could exert on this same steel if it were shaped into a boat that could displace 1.00×10⁵m³ of water?

$m_{st} = 1 \times 10^7$ kg

$\rho_{st} = 7.8 \times 10^3$ kg/m³

$\rho_w = 1 \times 10^3$ kg/m³

$$\rho = \frac{M}{V} \qquad \to V = \frac{M}{\rho} \qquad V_{st} = \frac{m_{st}}{\rho_{st}}$$

$$F_b = \rho g V_d \quad = \rho_w g \frac{m_{st}}{\rho_{st}} \quad = \frac{\rho_w}{\rho_{st}} g m_{st} \quad = \frac{1}{7.8}(9.8 m/s^2 1 \times 10^7 kg = 1.3 \times 10^7 N$$

$$F_w = m_{st} g = (1 \times 10^7 kg)(9.8 m/s^2) = 9.8 \times 10^7 N$$

HOME WORK

- Chap 11 - 5, 10, 12, 15, 39, 43