Announcements

1. Summarize results on gravitational force law and satellite motion
2. Fluid mechanics

Satellites orbiting earth (approximately circular orbits):

$$T = 2\pi\sqrt{\frac{R_E^3}{GM_E}}\left(1 + h/R_E\right)^{3/2} = 5058\left(1 + h/R_E\right)^{3/2} s$$

$R_E \sim 6370$ km

Examples:

Satellite	h (km)	T (hours)	v (mi/h)
Geosynchronous	35790	~24	6900
NOAA polar orbitor	800	~1.7	16700
Hubble	600	~1.6	16900
Inter. space station*	390	~1.5	17200

*Link: http://liftoff.msfc.nasa.gov/temp/StationLoc.html

Sample question:

Suppose that the space shuttle ($m=10^5$kg) was initially in the same orbit as the International space station (h_i=390km) and the engines are fired to give it exactly the amount of energy ΔW to raise it to the same orbit as the Hubble space telescope (h_f= 600km). What is the energy ΔW?

You can show that the energy of a satellite of mass m in a circular orbit of height h above the Earth's surface is given by:

$$E_{mech} = K + U = -\frac{GM_E m}{2(R_E + h)}$$

$$\Delta W = -\frac{GM_E m}{2R_E}\left(\frac{1}{\left(1+{h_f}/{R_E}\right)} - \frac{1}{\left(1+{h_i}/{R_E}\right)}\right) = 89{,}000J$$

The physics of fluids.

•Fluids include liquids (usually "incompressible) and gases (highly "compressible").

•Fluids obey Newton's equations of motion, but because they move within their containers, the application of Newton's laws to fluids introduces some new forms.

- Pressure: P=force/area 1 (N/m^2) = 1 Pascal
- Density: ρ =mass/volume 1 kg/m^3 = 0.001 gm/ml

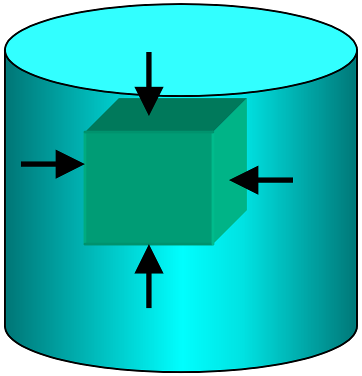
Pressure exerted by air at sea-level

$1 \text{ atm} = 1.013\text{x}10^5 \text{ Pa}$

Example: What is the force exerted by 1 atm of air pressure on a circular area of radius 0.08m?

$$F = PA = 1.013\text{x}10^5 \text{ Pa x } \pi(0.08\text{m})^2$$

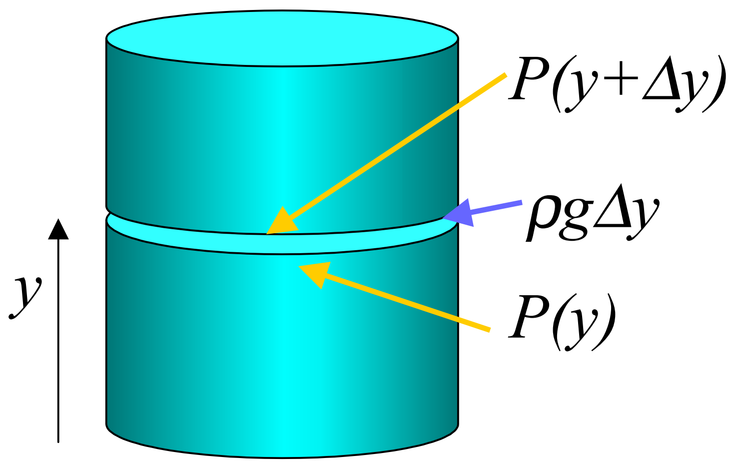
$$= 2040 \text{ N}$$



Pressure exerted by a fluid acts in all directions.

Density: ρ =mass/volume

Effects of the weight of a fluid on pressure.



$$P(y) = P(y+\Delta y) + \rho g \Delta y$$

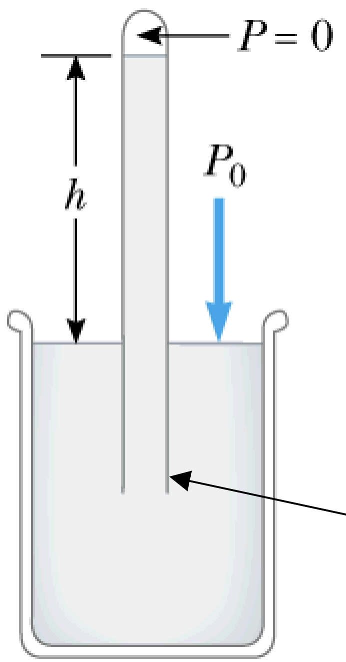
$$\Rightarrow \frac{dP}{dy} = -\rho g$$

Note: In this formulation +y is defined to be in the up direction.

For an "incompressible" fluid (such as water):

$$\frac{dP}{dy} = -\rho g \quad \Rightarrow P = P_0 - \rho g(y - y_0)$$

Example:



$$h = y - y_0 = \frac{P_0}{\rho g}$$

$$= \frac{1.013\times 10^5 \text{ Pa}}{13.595\times 10^3 \text{ kg/m}^3 \cdot 9.8 \text{ m/s}^2}$$

$$= 0.76 \text{ m}$$

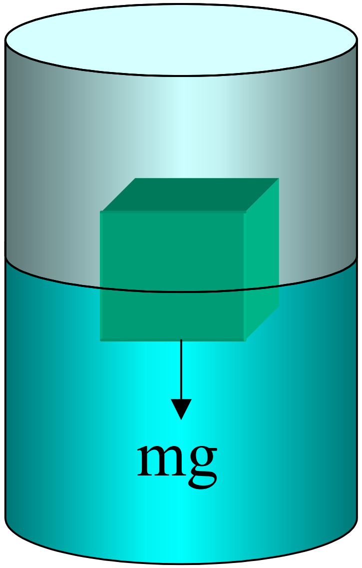
$\rho = 13.595 \times 10^3 \text{ kg/m}^3$

Buoyant force for fluid acting on a solid:

$F_B=\rho_{fluid}V_{displaced}g$

$$P(y+\Delta y)=P(y)-\rho g\Delta y$$

$$F_B=\{P(y)-P(y+\Delta y)\}A=\rho g\Delta yA=\rho gV$$



$$F_B \quad - \quad mg \quad = 0$$

$$\rho_{fluid}V_{submerged}g - \rho_{solid}V_{solid}g = 0$$

$$\frac{V_{submerged}}{V_{solid}}=\frac{\rho_{solid}}{\rho_{fluid}}$$

Peer instruction question

Suppose that a ball floats in water (ρ_w=1000kg/m^3) with 90% of it submerged. What will happen if we pour oil (ρ_o=800kg/m^3) on top of the ball and water?

(A) The ball will sink in the water so that more than 90% of it is submerged in the water.

(B) The ball will be raised toward the oil so that less than 90% of it is submerged in the water.

(C) The ball will not be effected by the oil.

(D) Not enough information is given.

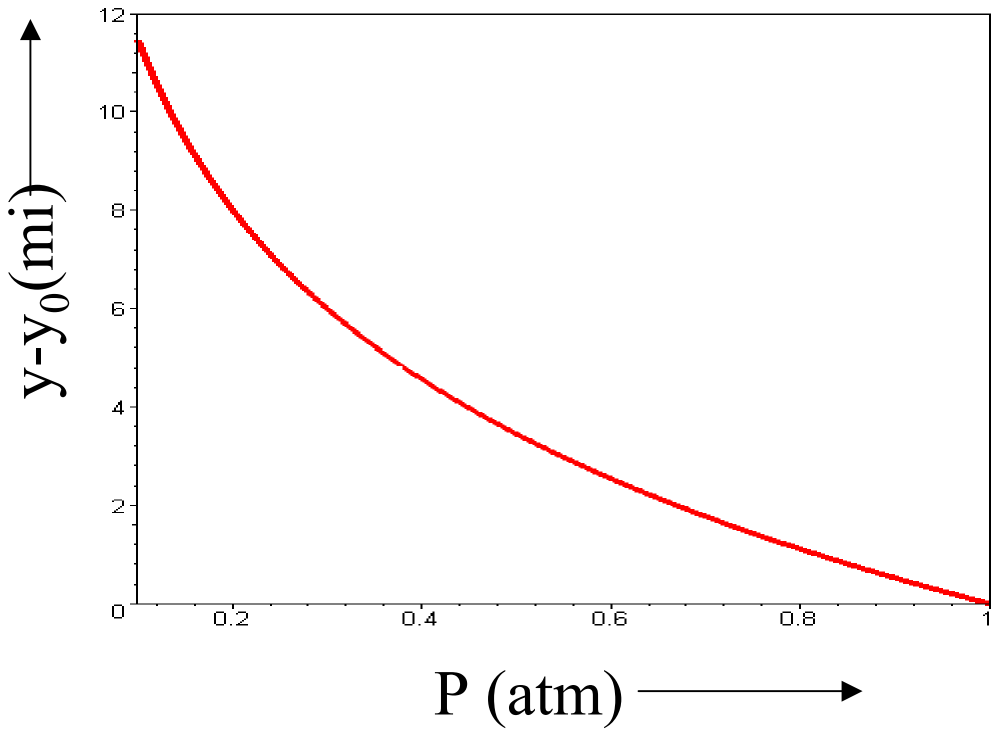
Effects of the weight of a "compressible" fluid on pressure.

$$\frac{dP}{dy} = -\rho g$$

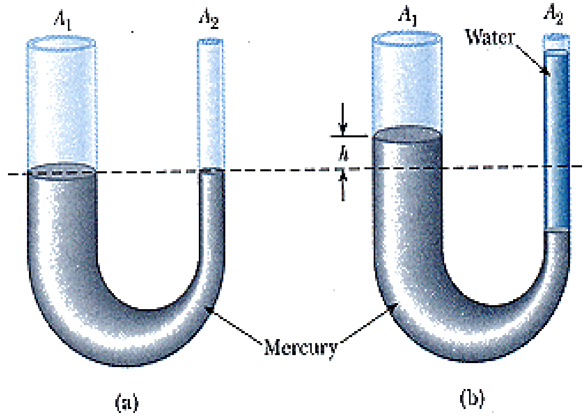
Solution :

For a gas, $\rho = P\frac{\rho_0}{P_0}$

$$P(y) = P_0 e^{-\frac{\rho_0 g}{P_0}(y-y_0)} \approx P_0 e^{-\frac{y-y_0}{8000m}} \approx P_0 e^{-\frac{y-y_0}{5mi}}$$



Mercury is poured into a U-tube as in Figure P15.18a. The left arm of the tube has a cross-sectional area A_1 of 93.0 cm^2, and the right arm has a cross-sectional area A_2 of 5.50 cm^2. One hundred grams of water are then poured into the right arm, as in Figure P15.18b.



(a) Determine the length of the water column in the right arm of the U-tube.

(b) Given that the density of mercury is 13.6 g/cm^3, what distance, h does the mercury rise in the left arm?