PHY 113 A General Physics I
9-9:50 AM MWF Olin 101

Plan for Lecture 26:

Chapter 14: The physics of fluids

1. Density and pressure
2. Variation of pressure with height
3. Buoyant forces

22	10/29/2012	Kepler's laws and satellite motion	13.4-13.6	13.28, 13.34	10/31/2012
	10/31/2012	Review	10-13,15		
	11/02/2012	Exam	10-13,15		
23	11/05/2012	Fluid mechanics	14.1-14.4	14.8, 14.24	11/07/2012
24	11/07/2012	Fluid mechanics	14.5-14.7	14.39, 14.51	11/09/2012
25	11/09/2012	Temperature	19.1-19.5	19.1, 19.20	11/12/2012
26	11/12/2012	Heat	20.1-20.4		11/14/2012
27	11/14/2012	First law of thermodynamics	20.5-20.7		11/16/2012
28	11/16/2012	Ideal gases	21.1-21.5		11/19/2012
29	11/19/2012	Engines	22.1-22.8		11/26/2012
	11/21/2012	*Thanksgiving Holiday*			
	11/23/2012	*Thanksgiving Holiday*			
	11/26/2012	Review	14,19-22		
	11/28/2012	Exam	14,19-22		
30	11/30/2012	Wave motion	16.1-16.6		12/03/2012
31	12/03/2012	Sound & standing waves	17.1-18.8		12/05/2012
	12/05/2012	Review	1-22		
	12/13/2012	Final Exam -- 9 AM			

The physics of fluids.

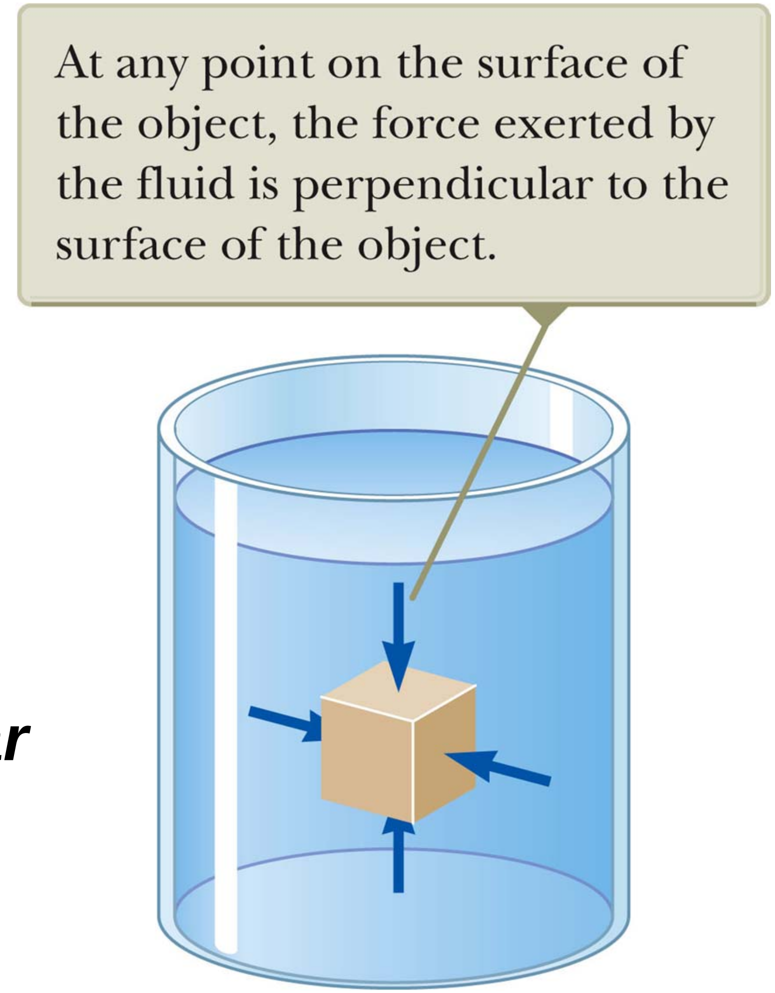
•Fluids include liquids (usually "incompressible) and gases (highly "compressible").

•**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

Note: In this chapter P≡pressure (NOT MOMENTUM)

Pressure $$P = \frac{|\mathbf{F}|}{A}$$



Note: since *P* exerted by a fluid acts in all directions, it is a *scalar* parameter

Example of pressure calculation

High heels

(http://www.flickr.com/photos/moffe6/3771468287/lightbox/)

$$P = \frac{|\mathbf{F}|}{A} \approx \frac{mg/4}{A_{heel}} \approx \frac{600/4N}{0.01 \times 0.01 m^2} = 1.5 \times 10^6 Pa$$

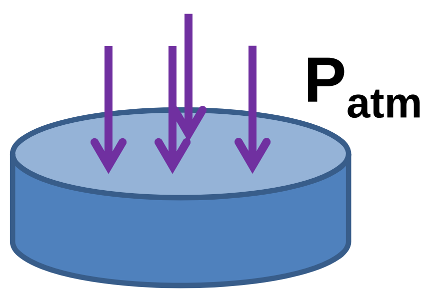
Pressure exerted by air at sea-level

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

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

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

$$= 2040 \text{ N}$$



Density = Mass/Volume

TABLE 14.1 *Densities of Some Common Substances at Standard Temperature (0°C) and Pressure (Atmospheric)*

Substance	ρ (kg/m^3)	Substance	ρ (kg/m^3)
Air	1.29	Iron	7.86×10^3
Air (at 20°C and atmospheric pressure)	1.20	Lead	11.3×10^3
Aluminum	2.70×10^3	Mercury	13.6×10^3
Benzene	0.879×10^3	Nitrogen gas	1.25
Brass	8.4×10^3	Oak	0.710×10^3
Copper	8.92×10^3	Osmium	22.6×10^3
Ethyl alcohol	0.806×10^3	Oxygen gas	1.43
Fresh water	1.00×10^3	Pine	0.373×10^3
Glycerin	1.26×10^3	Platinum	21.4×10^3
Gold	19.3×10^3	Seawater	1.03×10^3
Helium gas	1.79×10^{-1}	Silver	10.5×10^3
Hydrogen gas	8.99×10^{-2}	Tin	7.30×10^3
Ice	0.917×10^3	Uranium	19.1×10^3

Relationship between density and pressure in a fluid

Effects of the weight of a fluid:

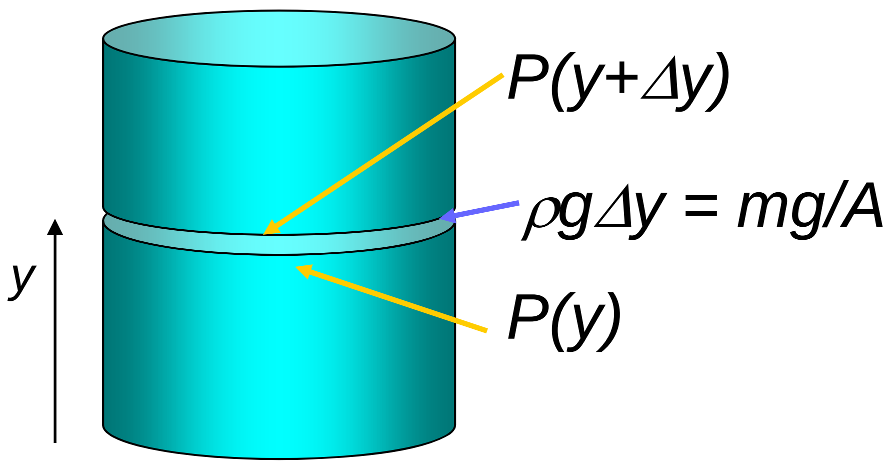
$$F(y) = F(y+\Delta y) + mg$$

$$\frac{F(y)}{A} = \frac{F(y+\Delta y)}{A} + \frac{mg}{A}$$

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

$$\lim_{\Delta y \to 0} \frac{P(y+\Delta y) - P(y)}{\Delta y} = \frac{dP}{dy}$$

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



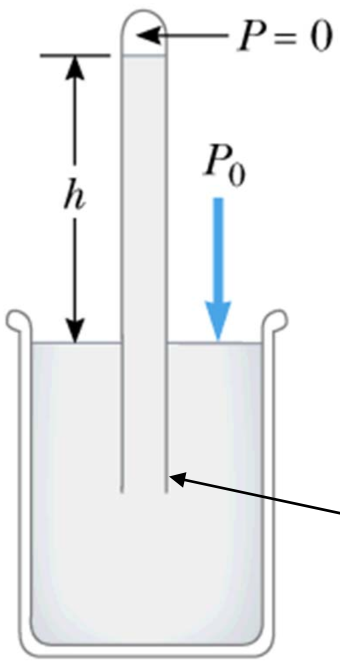
Note: In this formulation +y is defined to be in the up direction.

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

ρ = 13.585 x 10^3 kg/m^3 (constant)

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

Example:



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

$$= \frac{1.013\times10^5\ \text{Pa}}{13.595\times10^3\ \text{kg/m}^3 \cdot 9.8\ \text{m/s}^2}$$

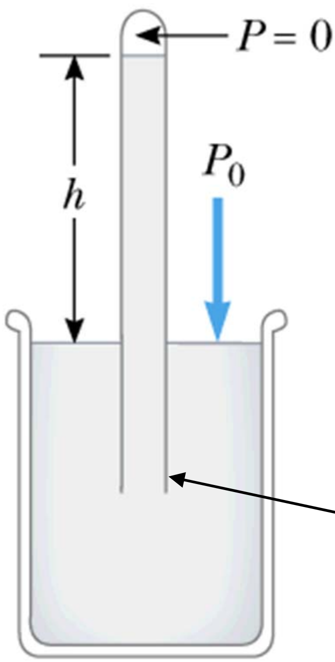
$$= 0.76\ \text{m}$$

$\rho = 13.595$ x 10^3 kg/m^3

Barometric pressure readings

Historically, pressure was measured in terms of inches of mercury in a barometer

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



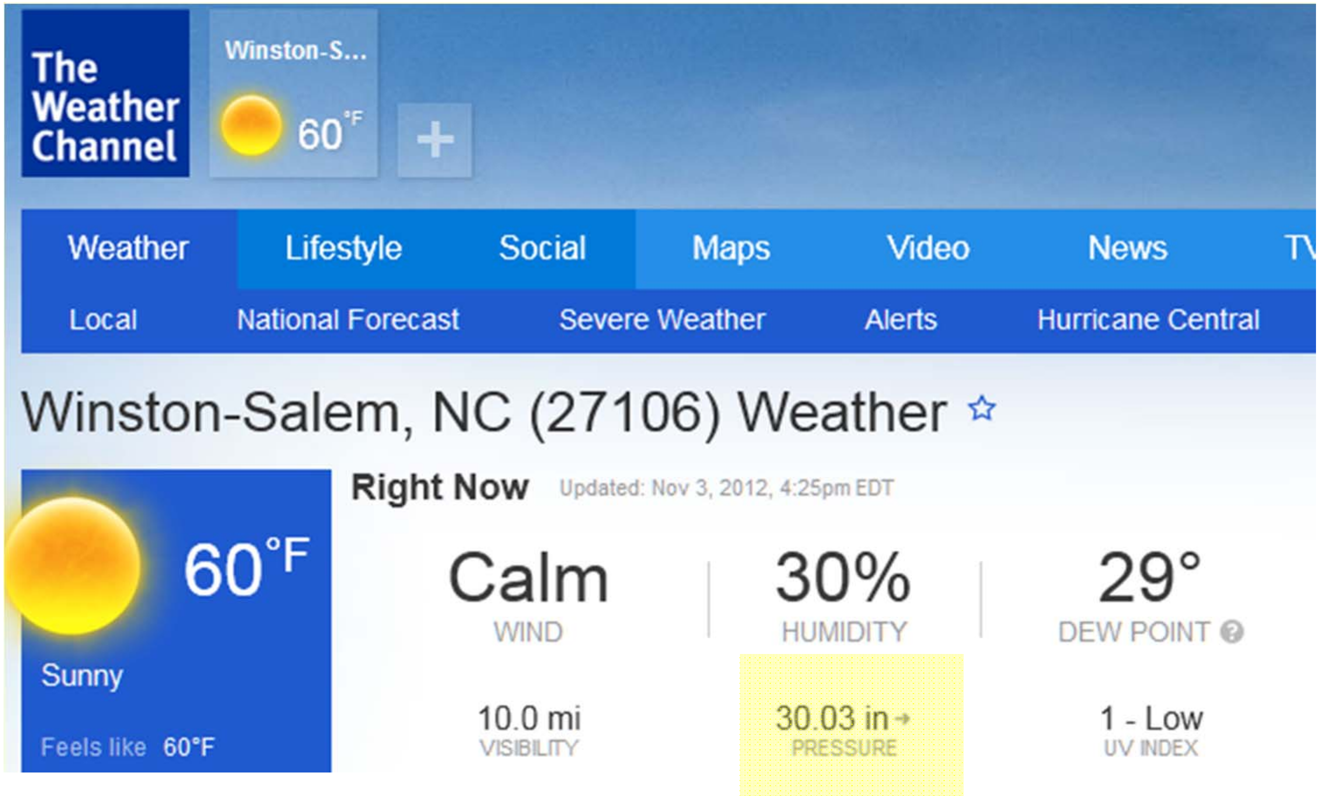
$$h = y - y_0 = \frac{P_0}{\rho g}$$

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

$$= 0.76 \text{ m} = 0.76\text{m} \times \left(\frac{1\text{in}}{0.0254\text{m}} \right) = 29.93\text{in}$$

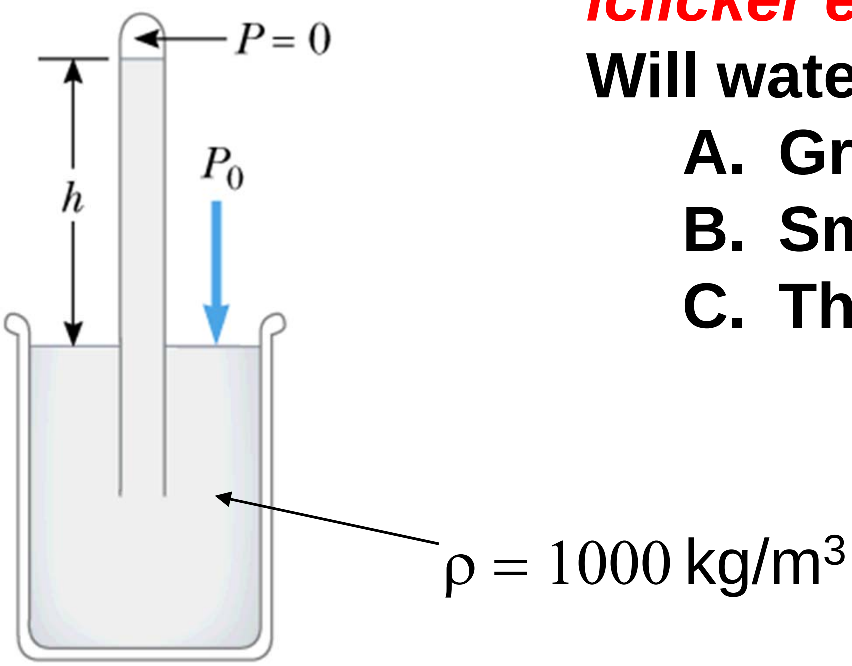
$\rho = 13.595 \times 10^3$ kg/m^3

Weather report:



$$30.03\text{in} = 30.03\text{in}\frac{0.0254\text{m}}{\text{in}} = 0.763\text{m}$$

Question: Consider the same setup, but replace fluid with water (ρ = 1000 kg/m^3). What is h?



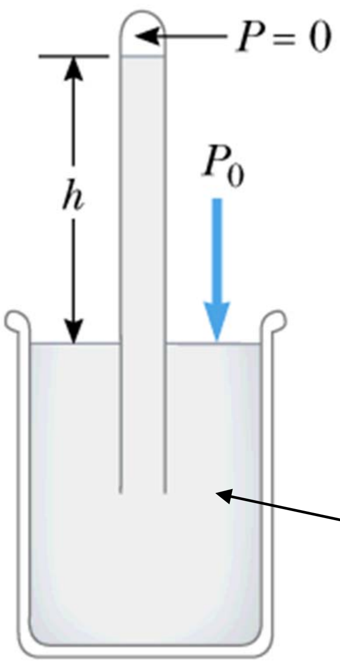
iclicker equation:

Will water barometer have *h*:

A. **Greater than mercury.**
B. **Smaller than mercury.**
C. **The same as mercury.**

Question: Consider the same setup, but replace fluid with water (ρ = 1000 kg/m^3). What is h?

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

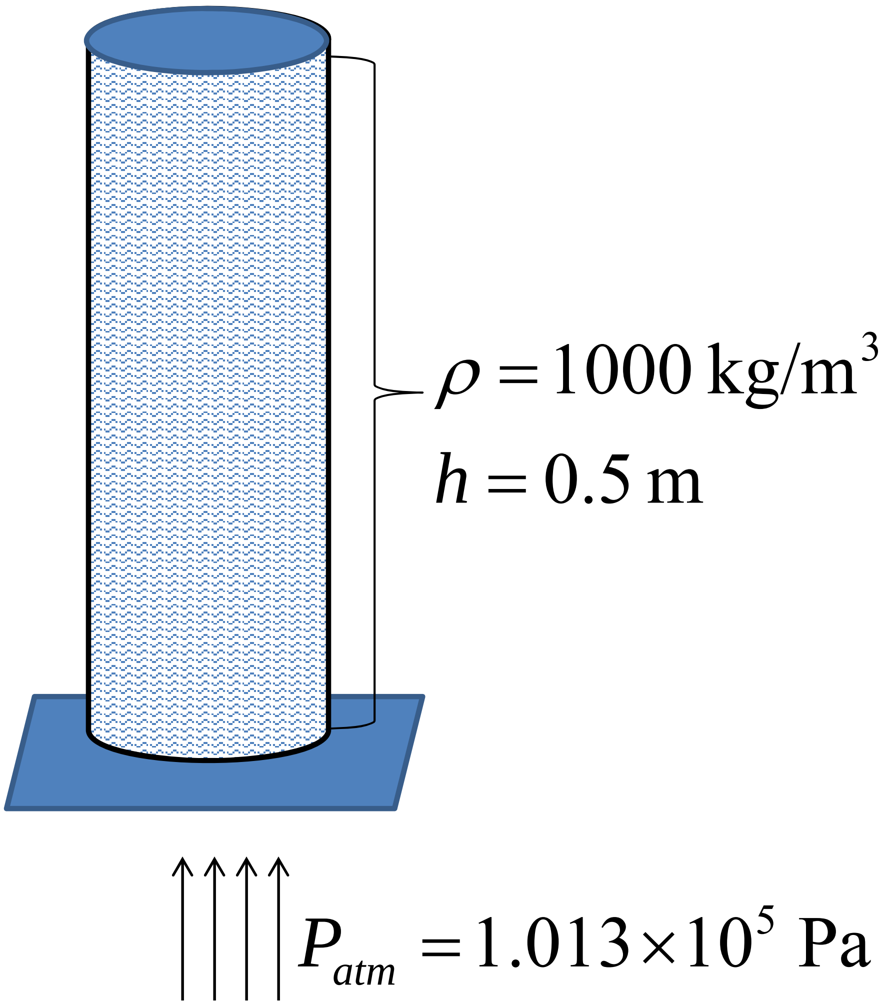


$$h = y - y_0 = \frac{P_0}{\rho g}$$

$$= \frac{1.013 \times 10^5 \text{ Pa}}{1000 \text{ kg/m}^3 \cdot 9.8 \text{ m/s}^2}$$

$$= 10.34 \text{m}$$

$\rho = 1000$ kg/m^3



iclicker question:

A 0.5 m cylinder of water is inverted over a piece of paper. What will happen

A. **The water will flow out of the cylinder and make a mess.**
B. **Air pressure will hold the water in the cylinder.**

General relationship between P and ρ:

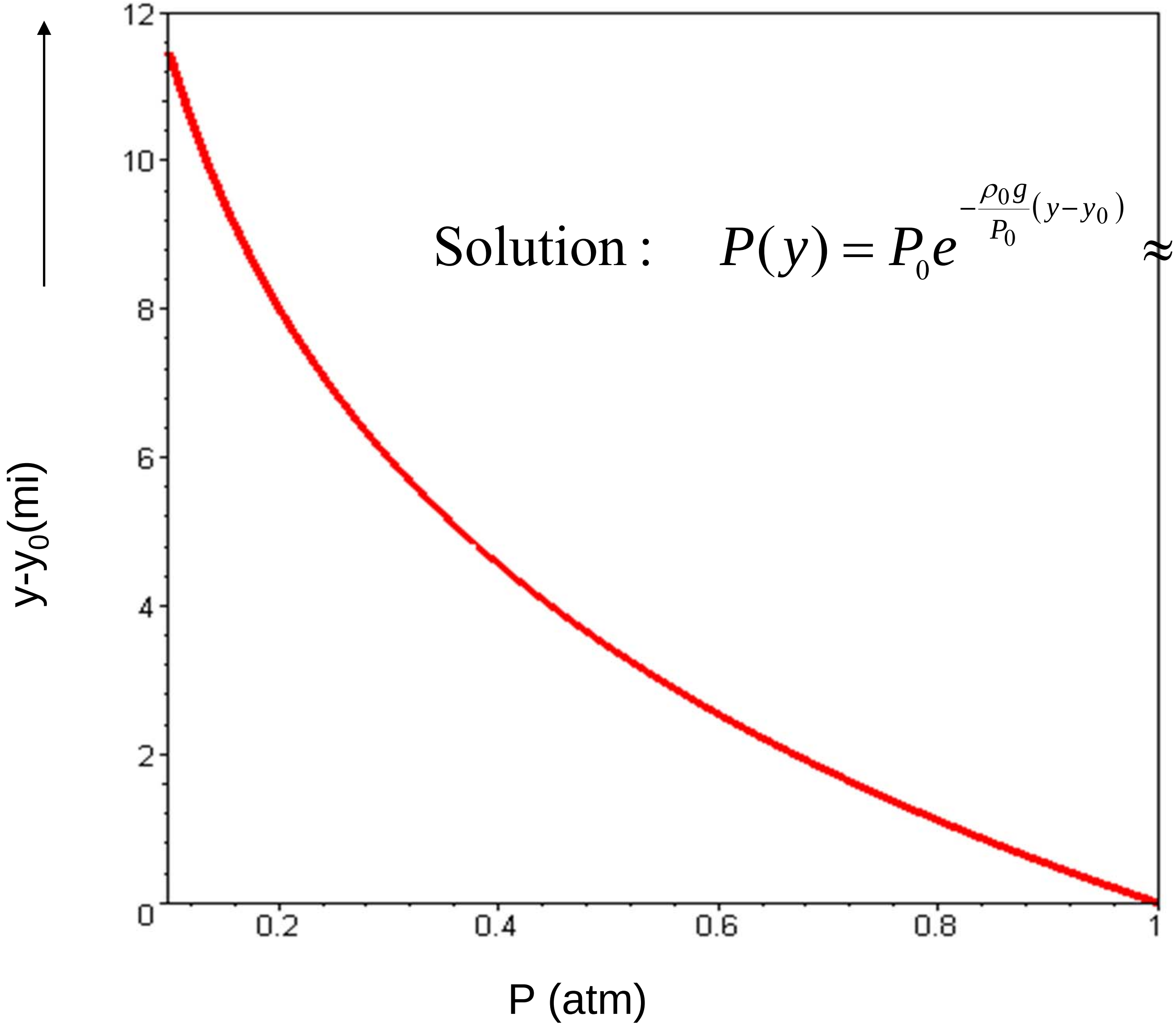
$$\text{For all fluids near Earth's surface: } \frac{dP}{dy} = -\rho g$$

$$\text{For water, mercury, etc: } \quad \rho \equiv (\text{constant}) \quad \Rightarrow P = P_0 - \rho g (y - y_0)$$

$$\text{For an ideal gas: } \rho = P \frac{\rho_0}{P_0} \qquad \Rightarrow \frac{dP}{dy} = -P \left(\frac{\rho_0 g}{P_0} \right)$$

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

Approximate relation of pressure to height above sea-level



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

iclicker question:

Have you personally experienced the effects of atmospheric pressure variations?

A. By flying in an airplane

B. By visiting a high-altitude location (such as Denver, CO etc.)

C. By visiting a low-altitude location (such as Death Valley, CA etc.)

D. All of the above.

E. None of the above.

Buoyant forces in fluids

(For simplicity we will assume that the fluid is incompressible.)

Image from the web of a floating iceberg.

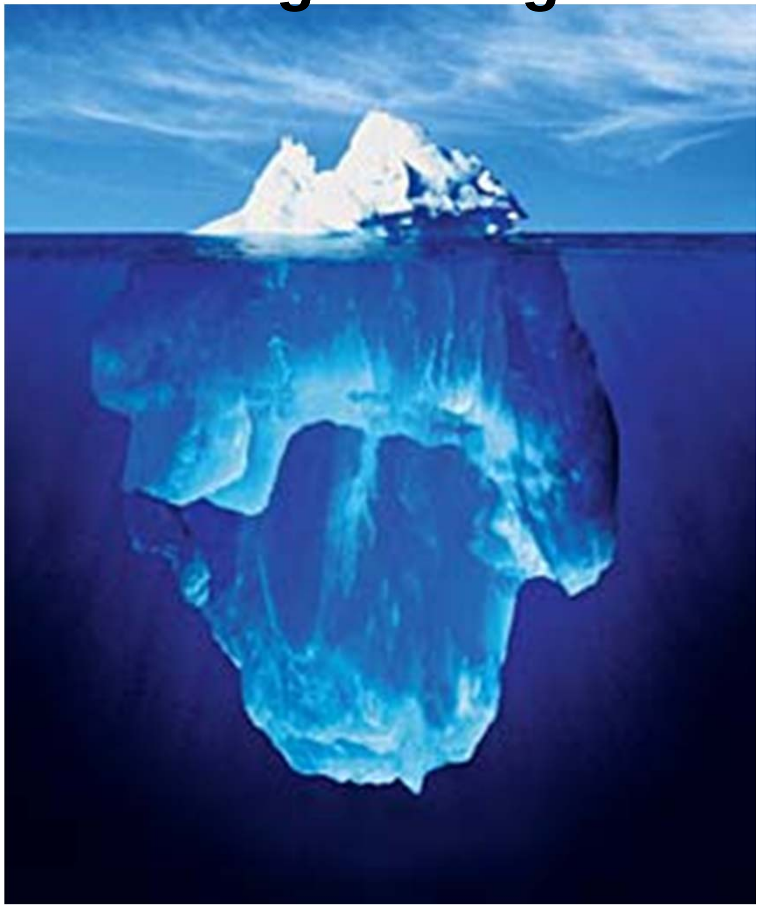


Image from the web of a glass of ice water

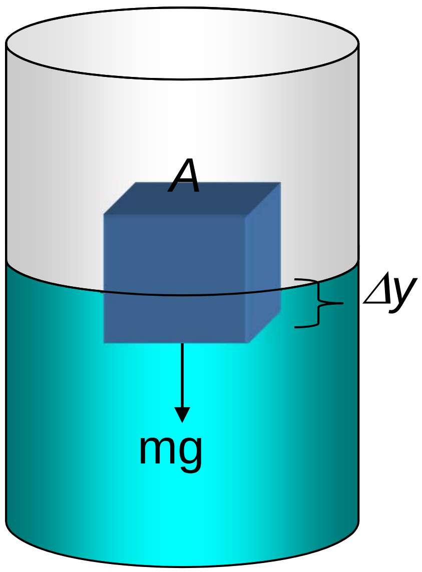
Buoyant force for fluid acting on a solid:

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

$$P(y) = P(y + \Delta y) + \rho_{\text{fluid}} g \Delta y$$

$$\text{Buoyant force:} \quad F_B = F_{bottom} - F_{top}$$

$$F_B = \{P(y) - P(y + \Delta y)\} A = \rho_{\text{fluid}} g \Delta y A = \rho_{\text{fluid}} g V_{submerged}$$



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

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

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

Summary:

$$\text{Buoyant force:} \quad F_B = \rho_{\text{fluid}} g V_{submerged}$$

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

Some densities:

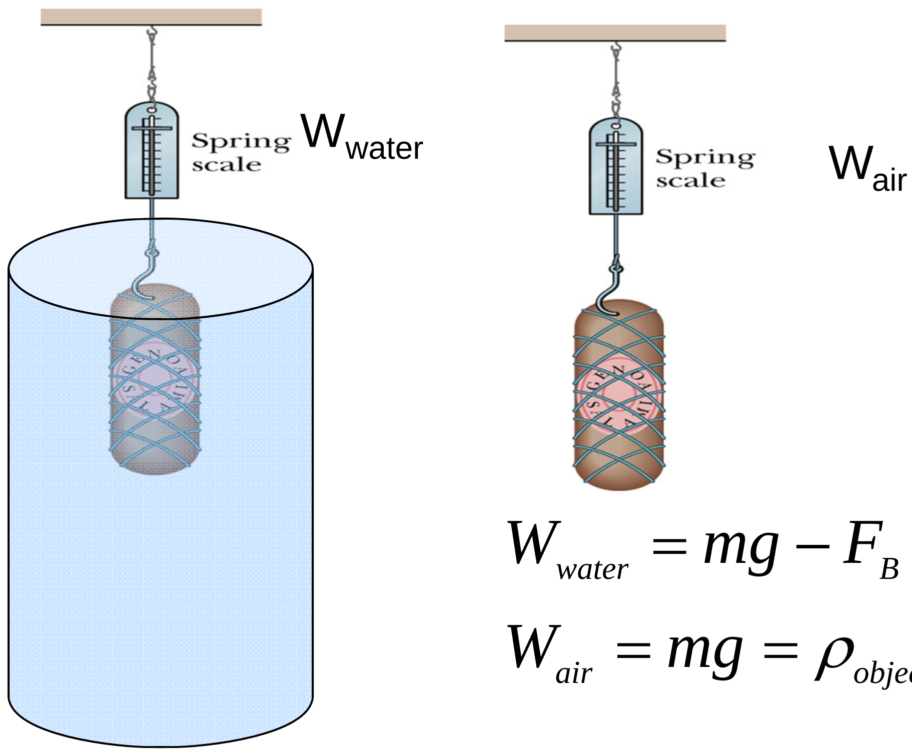
ice	**ρ = 917 kg/m^3**
fresh water	**ρ = 1000 kg/m^3**
salt water	**ρ = 1024 kg/m^3**

iclicker question:

Suppose you have a boat which floats in a fresh water lake, with 50% of it submerged below the water. If you float the same boat in salt water, which of the following would be true?

A. **More than 50% of the boat will be below the salt water.**
B. **Less than 50% of the boat will be below the salt water.**
C. **The submersion fraction depends upon the boat's total mass and volume.**
D. **The submersion fraction depends upon the barometric pressure.**

Archimede’s method of finding the density of the King’s “gold” crown



$$W_{water} = mg - F_B = \rho_{object} V_{object} g - \rho_{water} V_{object} g$$

$$W_{air} = mg = \rho_{object} V_{object} g$$

$$\rho_{object} = \rho_{water} \frac{W_{air}}{W_{air} - W_{water}}$$

Summary:

Application of Newton's second law to fluid (near Earth's surface)

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

$$\text{Incompressible fluid:} \quad P = P_0 - \rho g (y - y_0)$$

$$\text{example: } \rho = 1000 \text{kg/m}^3 \text{ (water)}$$

$$\text{Compressible fluid:} \quad P = P_0 e^{-\frac{\rho_0 g}{P_0}(y - y_0)}$$

$$\approx P_0 - \rho_0 g (y - y_0) \quad \left(\text{for } \frac{\rho_0 g}{P_0}(y - y_0) << 1\right)$$

$$\text{example: } \rho = 1.29 \text{kg/m}^3 \text{ (air)}$$

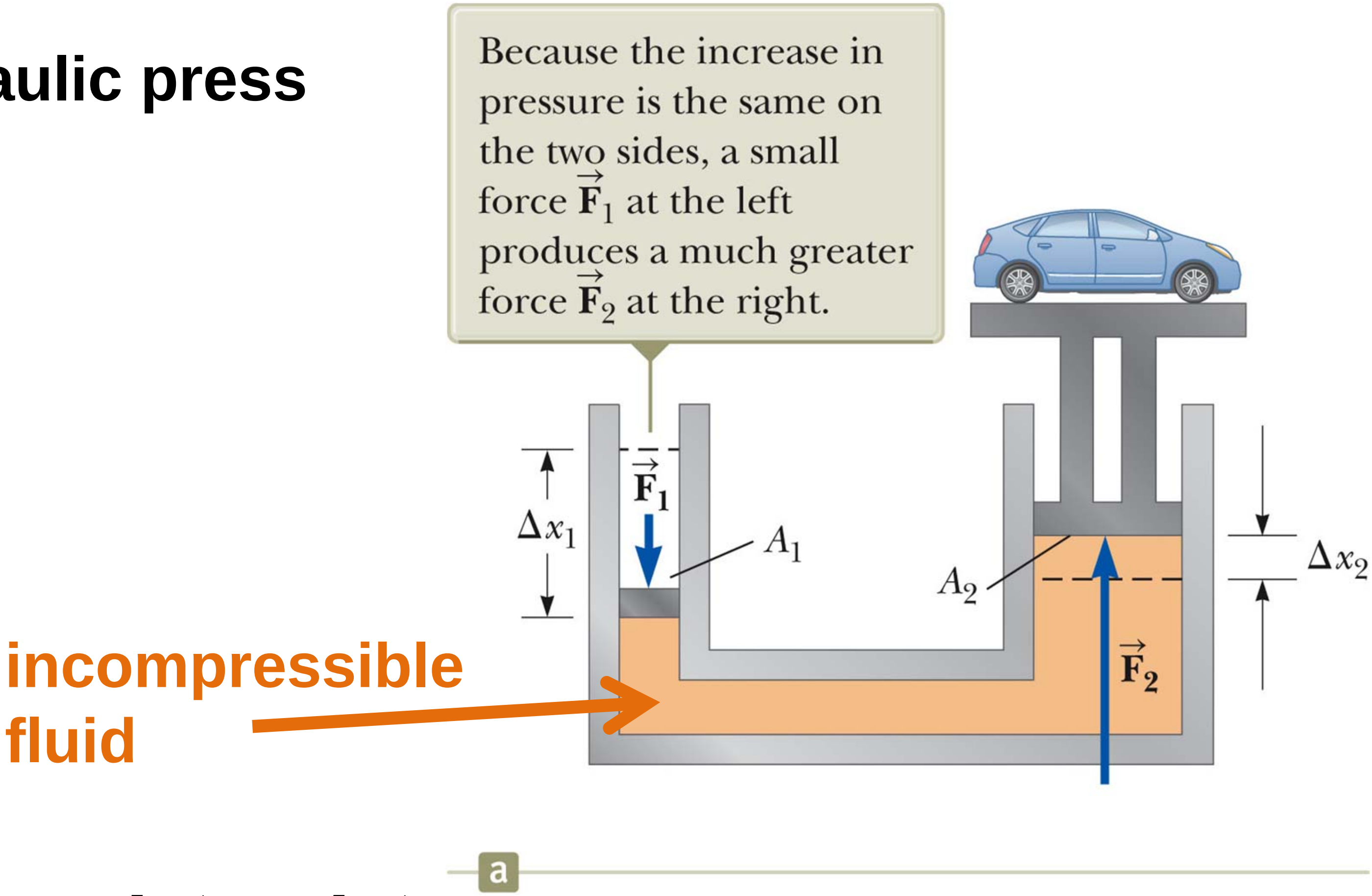
iclicker question:

Suppose that a caterer packed some food in an air tight container with a flexible top at sea-level. This food was loaded on to an airplane with a cruising altitude of ~6 mi above the earth's surface. Assuming that the airplane cabin is imperfectly pressurized, what do you expect the container to look like during the flight?

(A) **(B)** **(C)**

Example:

Hydraulic press



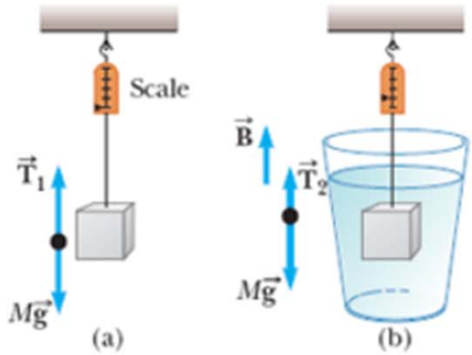
$$A_1 \Delta x_1 = A_2 \Delta x_2$$

$$F_1/A_1 = F_2/A_2$$

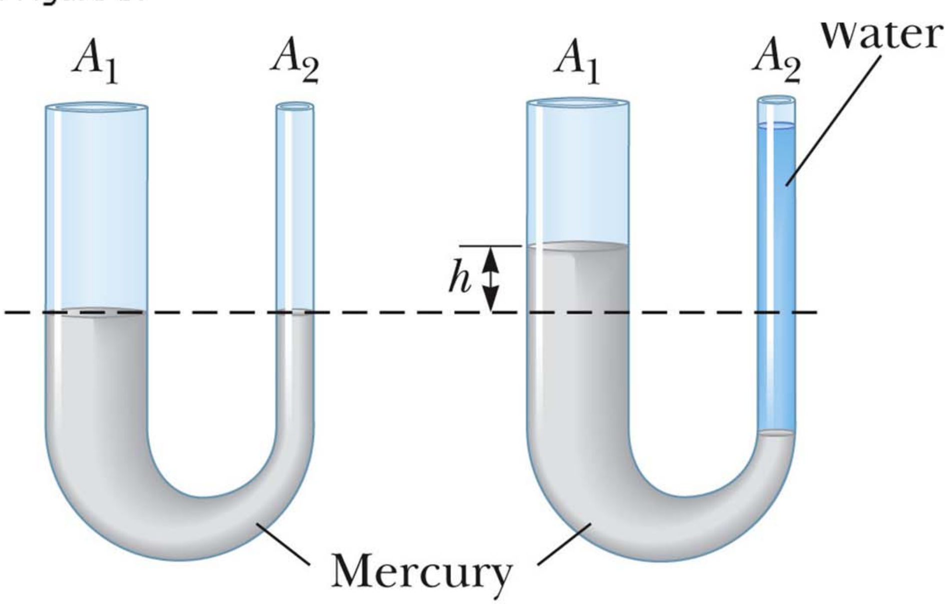
5. –/0.5 points | My Notes | SerPSE8

The gravitational force exerted on a solid object is 4.60 N. When the object is suspended from a spring scale and submerged in water, the scale reads 3.20 N as shown in the figure below. Find the density of the object.

[ ] kg/m^3



Mercury is poured into a U-tube as shown in Figure a. The left arm of the tube has cross-sectional area A_1 of 9.5 cm^2, and the right arm has a cross-sectional area A_2 of 5.30 cm^2. Four hundred grams of water are then poured into the right arm as shown in Figure b.



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

cm

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

cm