Chapter 11 - Fluids

- Fluids flow – conform to shape of container
  - **liquids OR gas**
- Mass: mass density,   Forces: Pressure
- Statics:
  - **pressure, buoyant force**
- Dynamics: motion
  - **speed, energy**
  - **friction: viscosity**
- Human body 50-75% water, live in a fluid (air)

Density

- Defined as: $$\boxed{\rho = \frac{M}{V}}$$

- Or: $$\boxed{M = \rho V}$$

Typical densities:

Solids:

ρ_{Lead}=11 300 kg/m^3

ρ_{Iron}=7 860 kg/m^3

Liquids:

$\rho_{Mercury}$=13 600 kg/m^3

ρ_{water}=1000 kg/m^3

ρ_{Oil}=700-800 kg/m^3

Gases:

ρ_{air}=1.29 kg/m^3

- Specific gravity = $\rho / \rho_{\text{water at 4°C}}$
  - **$\rho_{\text{water at 4°C}}$ = 1.0 g/cm^3 = 1000 kg/m^3**
  - **Specific gravity has no units**

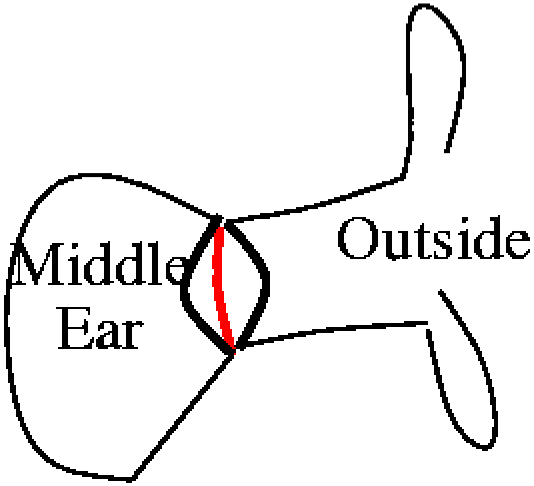
Pressure

- Fluid pressure arises from molecules of fluid colliding with:
  - **Walls of container**
  - **Objects in gas or liquid**
- If no molecules, pressure is zero (e.g. in vacuum of space)
- *Pressure = (Mag Force) / Area* ($P = F/A$) (a *scalar*)
  - **units: SI: *Pascals* (N/m^2). Other units: atm, lb/in^2 (psi)**

    $1atm = 1.013 \times 10^5$ Pa = 14.7 lb/in^2 = 1.013 bar
  - **In equilibrium, Force *perpendicular* to the surface.**

- Thumbtack, pop bottle, spheres

As you travel up a mountain, your ears pop. The figure below is a pitiful attempt to show the ear drum (in red). As you travel up a mountain, what will the ear drum do between 'pops'?



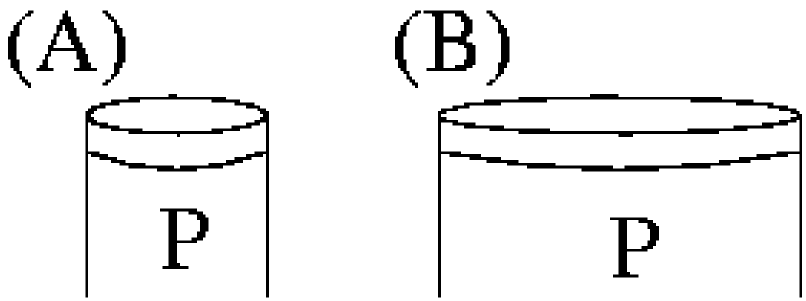
(1) Bow towards the middle ear

(2) Hold its shape

(3) Bow towards the outside

Pressure outside decreases.

Two pistons each have the same in the fluid just beneath them, and each fluid is at the same pressure just below the piston. Piston B has four times the surface area as piston A. Which piston can support the most weight? (consider the piston itself as part of the weight supported)



(1) Piston A

(2) Piston B

(3) Both the same

F=P*A: Same pressure, larger area, larger force

Reminders

- **Watch out for the final sprint!**

- **RQ#10,11 due Monday 07/16 10am**
- **RQ#12,13 due Tuesday 07/17 10am**

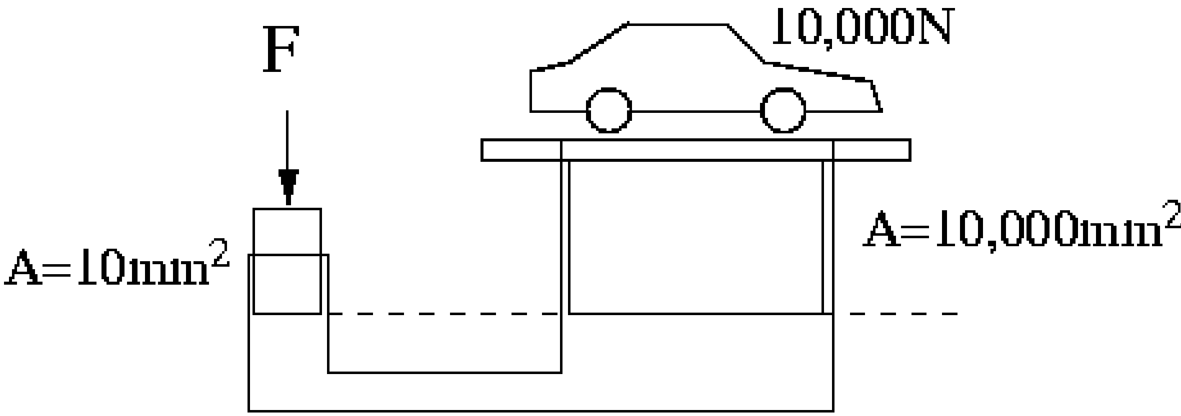
- **HW#7 due Sunday 7/15, 11:59pm**
- **HW#8 due Mon 7/16, 11:59pm**
- **HW#9 due Tue 7/17, 11:59pm**

- **FINAL EXAM: Next Thursday (07/19).**

  Topics:
  - Intro (Chapter 1)
  - 1D and 2D Kinematics (Chapters 2 and 3).
  - Newton' s Law and Forces (Chapter 4)
  - Torques and equilibrium (Chapters 9, secs 1-3),
  - Uniform Circular motion (chapter 5)
  - Work and Energy (chapter 6)
  - Momentum (Chapter 7)
  - Fluids (Chapter 11) (today and Monday)
  - Rotational Kinematics and Dynamics (Chapter 8) (Tuesday)

  (including Lab-related material).

A container is filled with oil and fitted on both ends with pistons. The are of the left piston is 10mm^2. The area of the right piston is 10,000mm^2. What force must be exerted on the left piston to keep the 10,000-N car on the right at the same height?



(1) 10N

(2) 100N

(3) 10,000N

(4) 10^6N

(5) 10^8N

$$P = F_1/A_1 = F_2/A_2$$
$$F_1 = (A_1/A_2)\, F_2$$
$$F_1 = (10\ mm^2 \ /\ 10{,}000\ mm^2) * 10{,}000N$$

Pressure as Function of Depth

Static Fluid

(Fluid at rest)

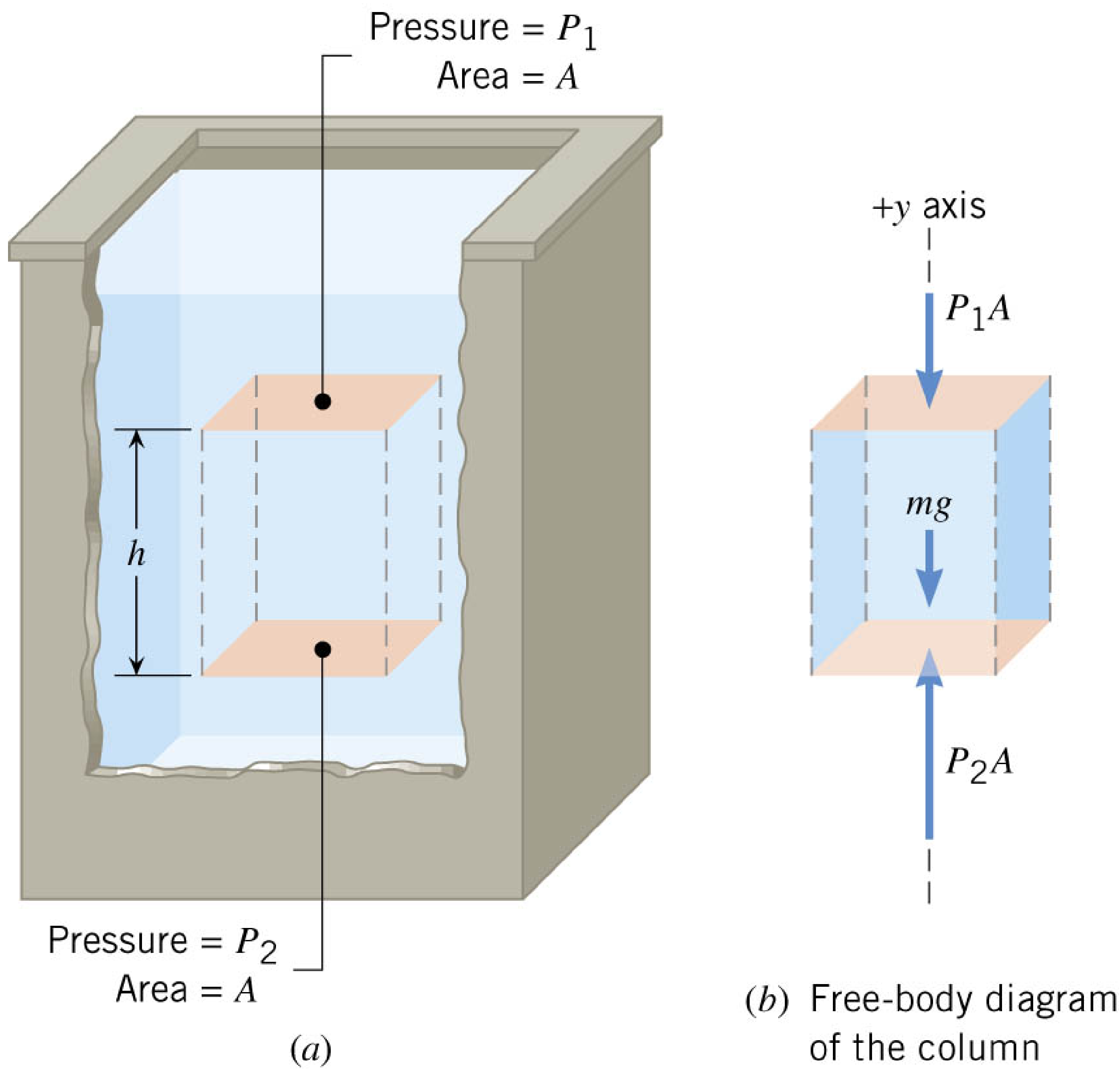
$P_2A = P_1A + mg$

$P_2 = P_1 + \rho g h$

Densities vary from fluid to fluid.

$\rho_{water} = 1000\ kg/m^3$

$\rho_{air} = 1.3\ kg/m^3$



(b) Free-body diagram of the column

Deepest Fish

Deepest fish ever sighted was on the floor of the Mariana's trench at 11,500m depth. What is the pressure here?

$P \quad = \quad P_0 \quad + \quad \rho g h$

$= \quad 1.013 \times 10^5 \text{ Pa} + (1000 \text{ kg/m}^3)(9.8 \text{m/s}^2)(11{,}500\text{m})$

$= \quad 1.013 \times 10^5 \text{ Pa} + 1.127 \times 10^8 \text{ Pa}$

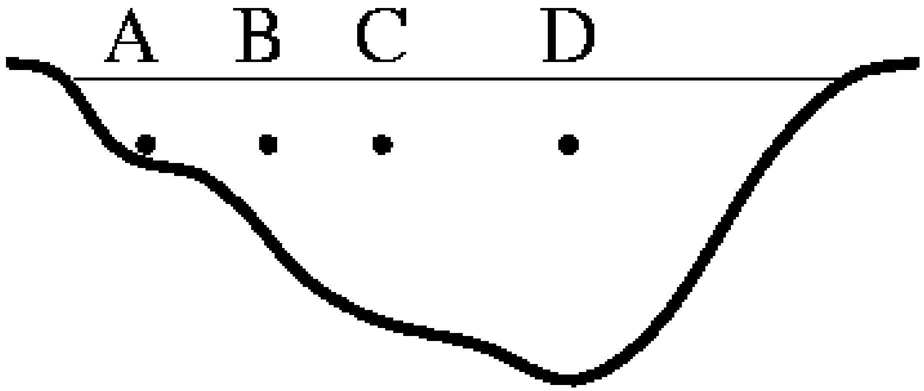
$= \quad 1.128 \times 10^8 \text{ Pa}$

What would be the inward force on a 20cm diameter circular window on a sub?

$F = P*A = 1.128 \times 10^8 \text{ Pa} * \pi (0.10)^2$

$= 3.54 \times 10^6 \text{ N} \qquad (8 \times 10^5 \text{ lbs or } 400 \text{ tons})$

Consider the four points in the lake. The points are all at the same depth below the surface, but the depth of the bottom of the lake underneath the points varies. At which point is the pressure the greatest?



(1) A

(2) B

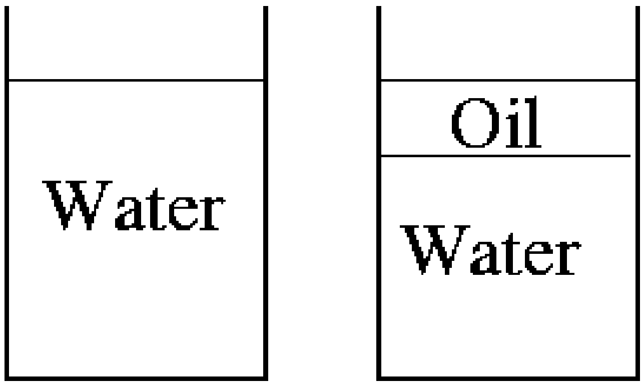
(3) C

(4) D

(5) All the same

Pressure only depends on depth of point where pressure is measured.

Two beakers are filled with fluid. One is filled with water. The other is filled with a mixture of oil (specific gravity 0.8) and water to the same level. Which beaker has the greatest pressure at the bottom of the beaker.



(1) The Water beaker

(2) The Oil and Water beaker

(3) Both the same

Pressure at depth where oil and water meet is lower in the oil and water mixture (oil less dense).

Increase in pressure from this level is same, since water in both columns.

Measuring Pressure

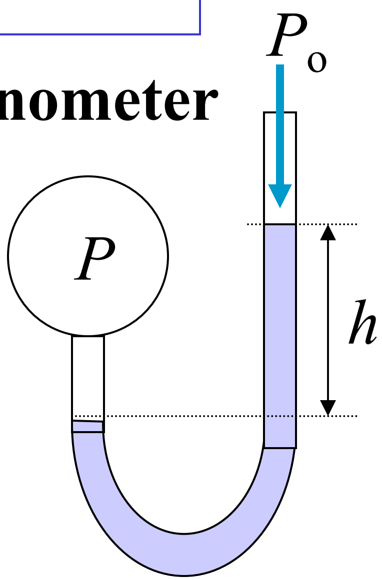
P = Force/Area

- Absolute Pressure, P
- Gauge Pressure = $P - P_o$
- P_o = Atmospheric Pressure

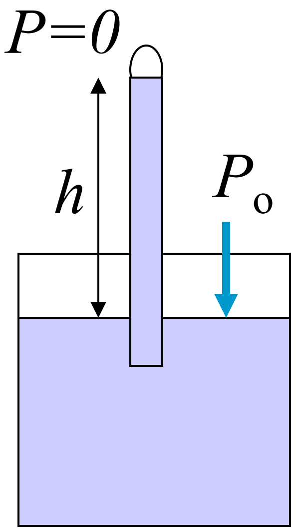
  $= 1.01 \times 10^5$ Pa = 1 atm = 760 mm of Hg

$$\boxed{P = P_o + \rho g h}$$

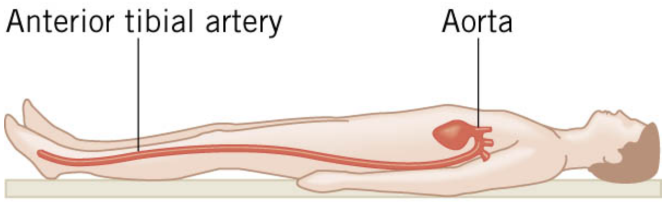
Manometer



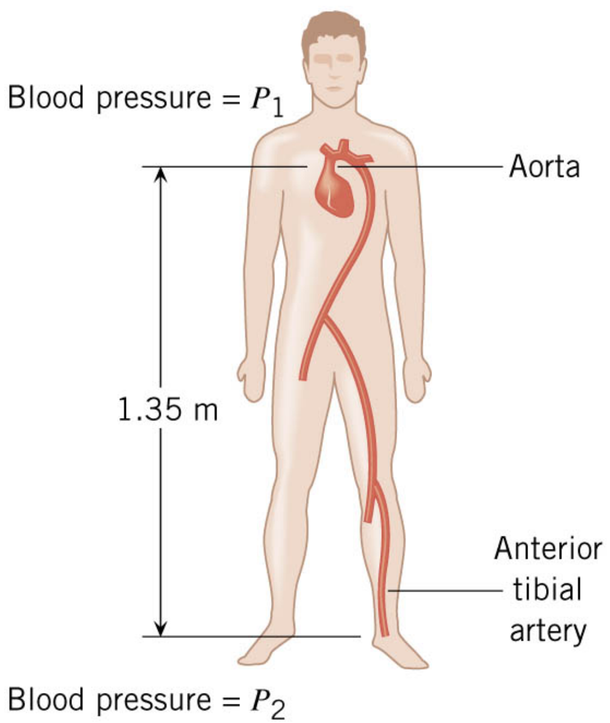
Barometer



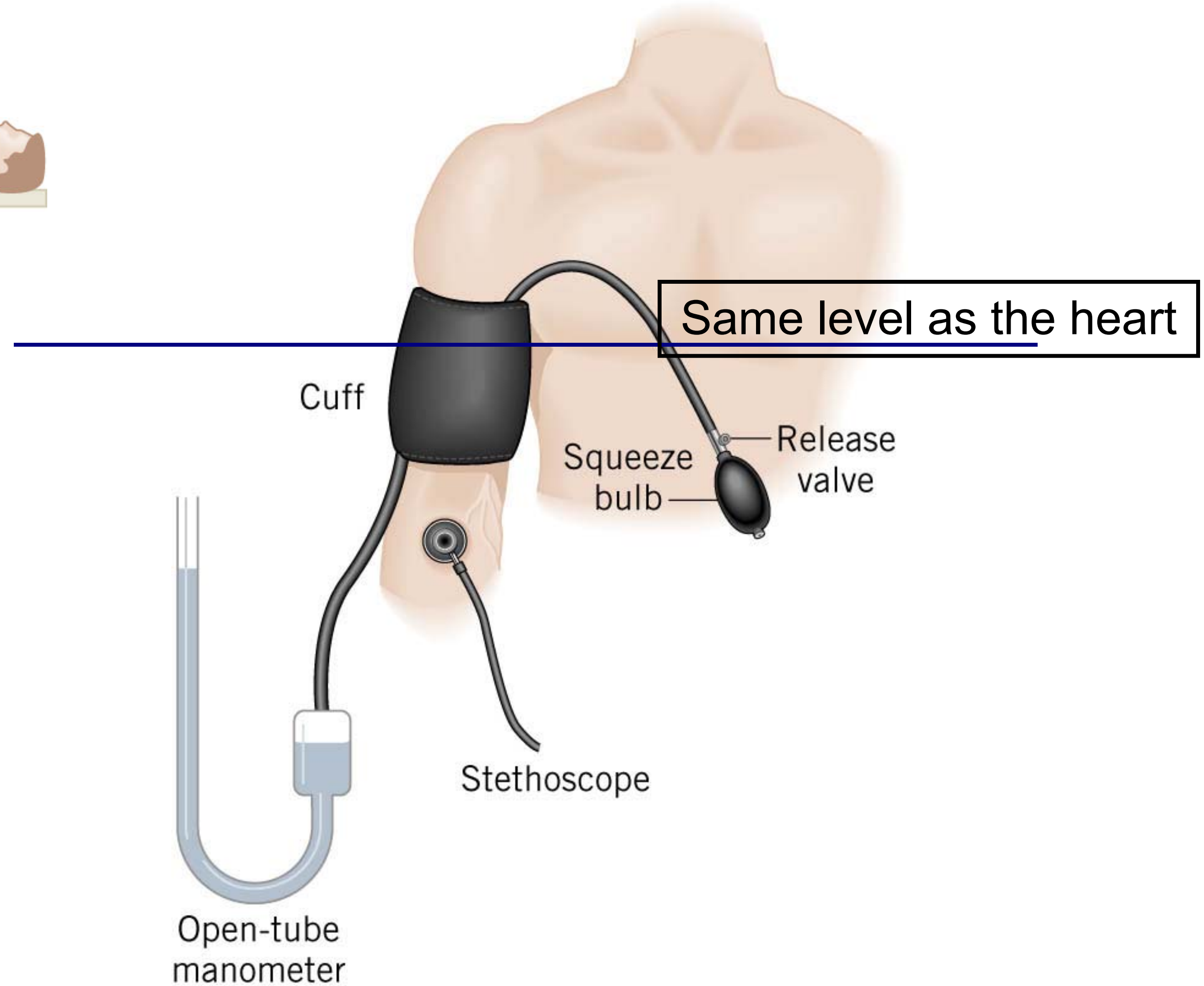
Blood Pressure



(a)



(b)



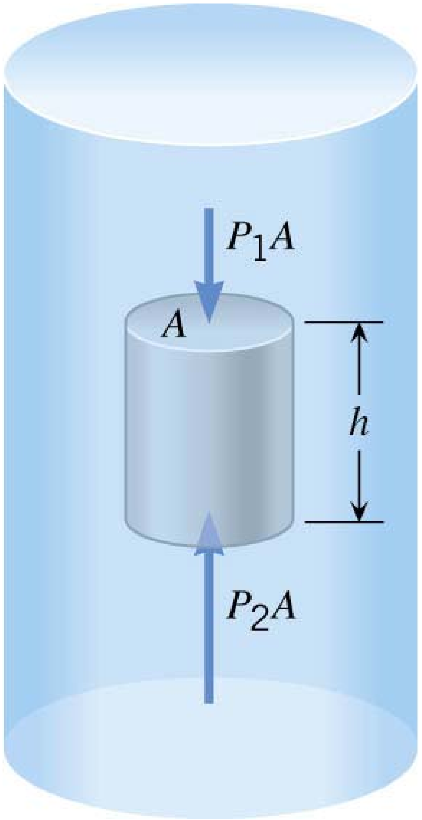
120 mm of Mercury/80mm of Mercury
Systolic (peak)/Diastolic (bottom)
Gauge pressure (relative to atmosphere)

$P_2 > P_1$ standing

Archimedes' Principle - Buoyancy

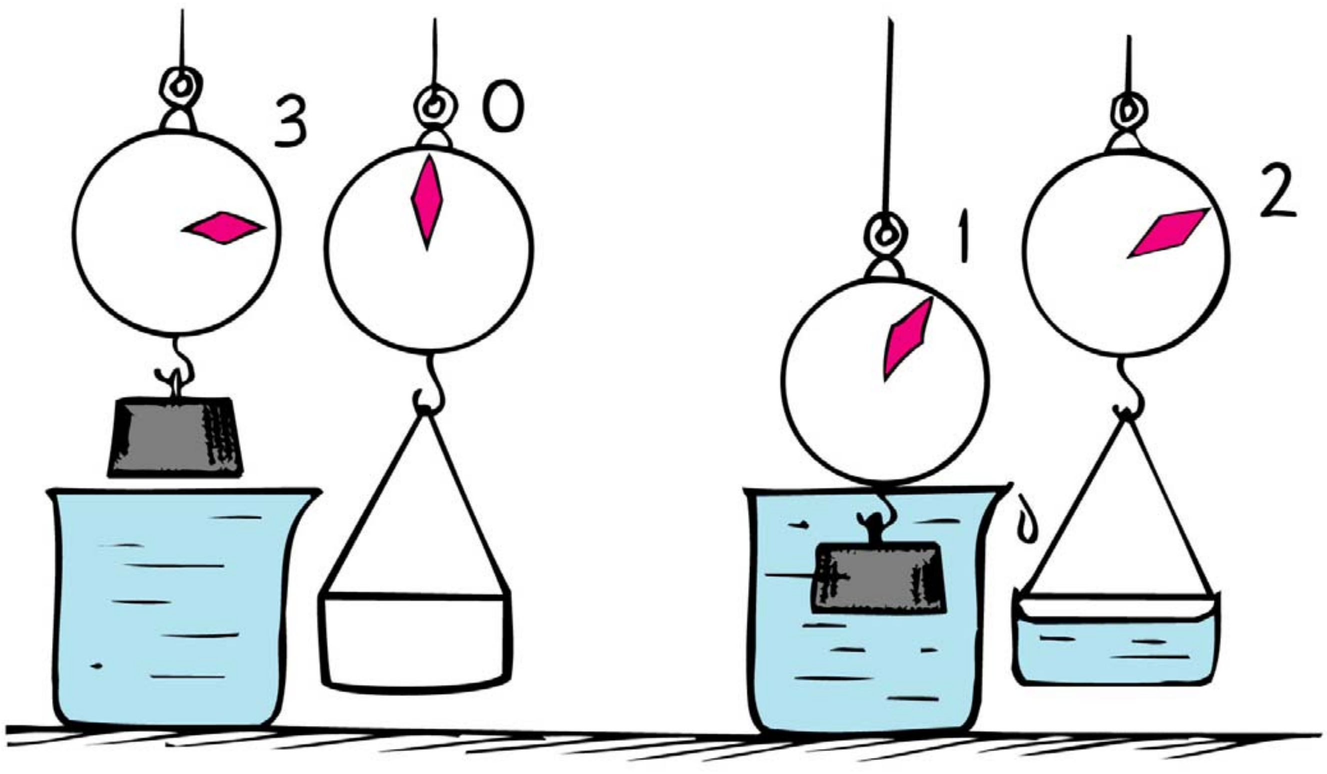
- *Difference* in pressure
- Any time in fluid, buoyant force upwards

- What determines force?
- F_B = weight of **fluid displaced**
- $F_B = \rho_{FLUID}\, g\, V_{FLUID\ DISPLACED}$



Archimedes' principle

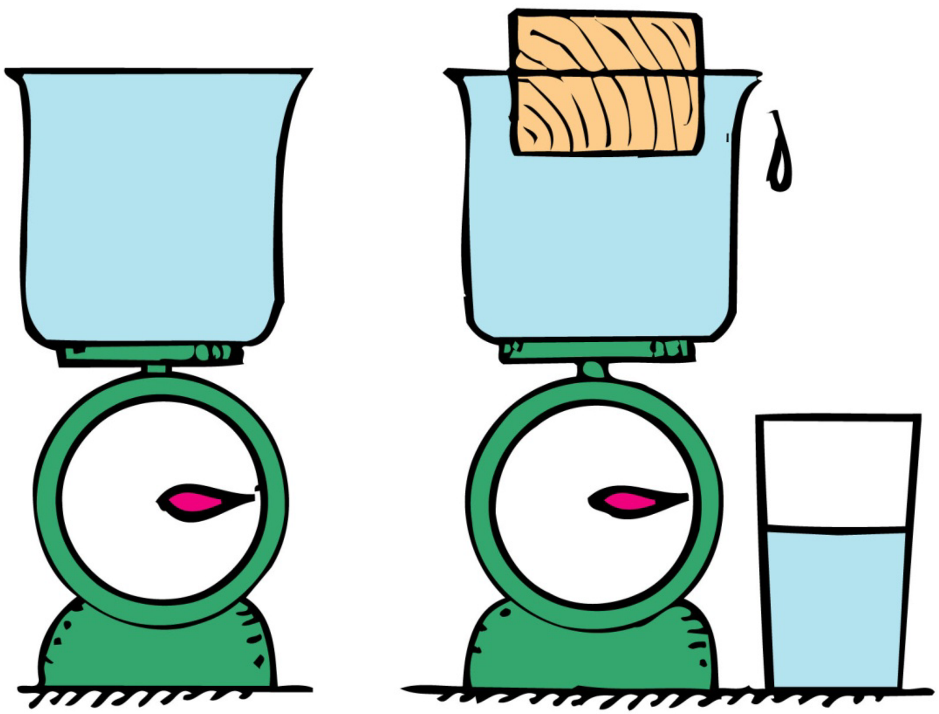
An immersed body is buoyed up by a force equal to the weight of the fluid it displaces



Flotation

If an object floats → buoyant force is equal to its weight

→ its density < that of fluid's



Floating versus Completely Submerged

- Floating:

  $F_B = W$ $\quad V_{DISPLACED} < V_{OBJECT}$ $\quad \rho_{OBJ} < \rho_{FLUID}$

- Completely Submerged (it sinks!) $\quad \boldsymbol{\rho_{OBJ} > \rho_{FLUID}}$

  $V_{DISPLACED} = V_{OBJECT}$

  $F_B = \rho\, g\, V_{OBJECT}$

Example: If ice has a density of 920 kg/m^3, what percentage of an iceberg sticks out above the waterline?

About 8% (92% under water)

Flotation – denser fluid

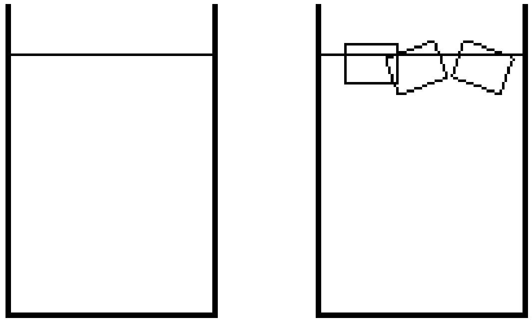
We will float "easier" in denser fluids → Dead Sea float!

Why? Salt water is more dense.

ρ_{water}=1000 kg/m^3

$\rho_{Dead\ Sea\ Water}$=1170 kg/m^3

Consider two identical glasses. One contains water. One contains a combination of ice and water. The water level is the same in both glasses. Which weighs more?



(1) The glass without ice cubes

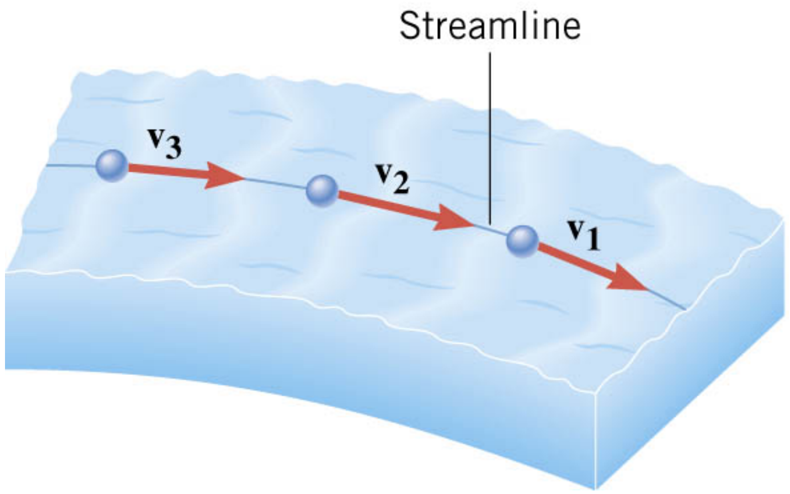
(2) The glass with ice cubes

(3) The two weigh the same

Ice less dense, but occupies more volume.
Each cube displaces the weight of the cube in water.
Think of the following: two beakers filled to the edge with water. Add an ice cube. The weight of the fluid lost over the edge equals the weight of the ice cube.

Fluids in Motion

- Ideal Fluid:
  - **incompressible: density constant**
  - **nonviscous: no friction between layers**



Flow:

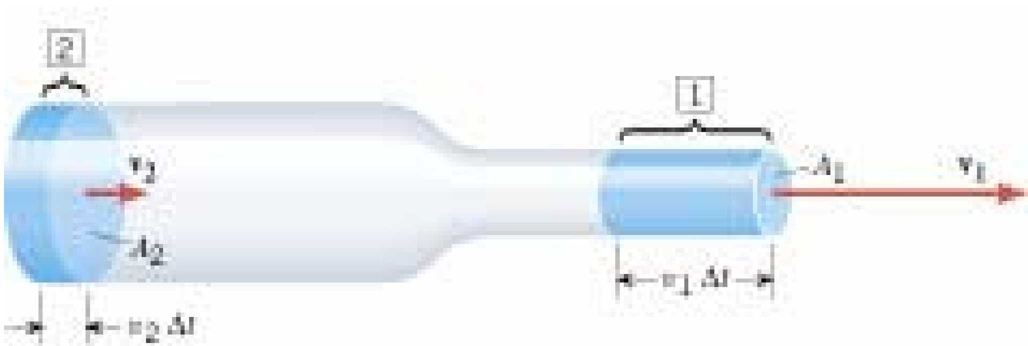
- Steady: v doesn't change at point
- Unsteady: v changes magnitude
- Turbulent: v erratic

Equation of Continuity

$$m = \rho \mathrm{Vol}$$

$$m = \rho\,(A\,v\Delta t)$$

$$m/\Delta t = \rho\,A\,v = \text{mass flow rate}$$



Equation of continuity:

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

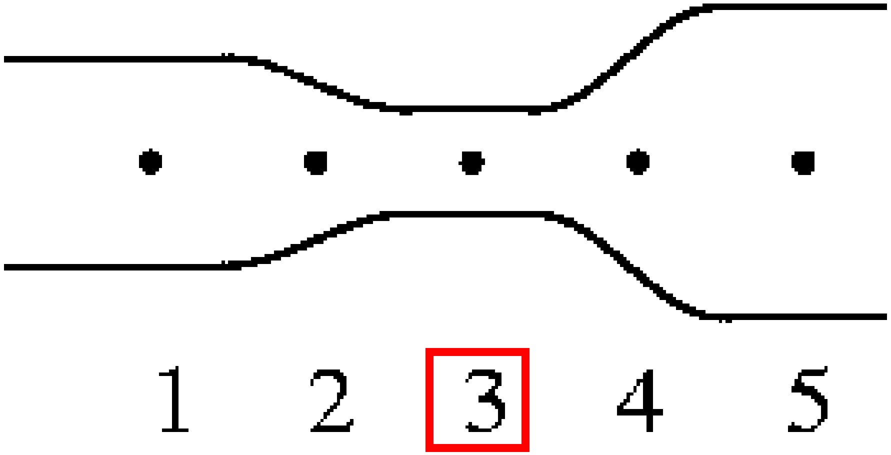
If *incompressible* fluid:

$$Q = A_1 v_1 = A_2 v_2$$

Q: Volume flow rate

Example:
Block off the end of a hose: Less A, higher v

An incompressible fluid is flowing through a pipe. At which point is the fluid traveling the fastest?

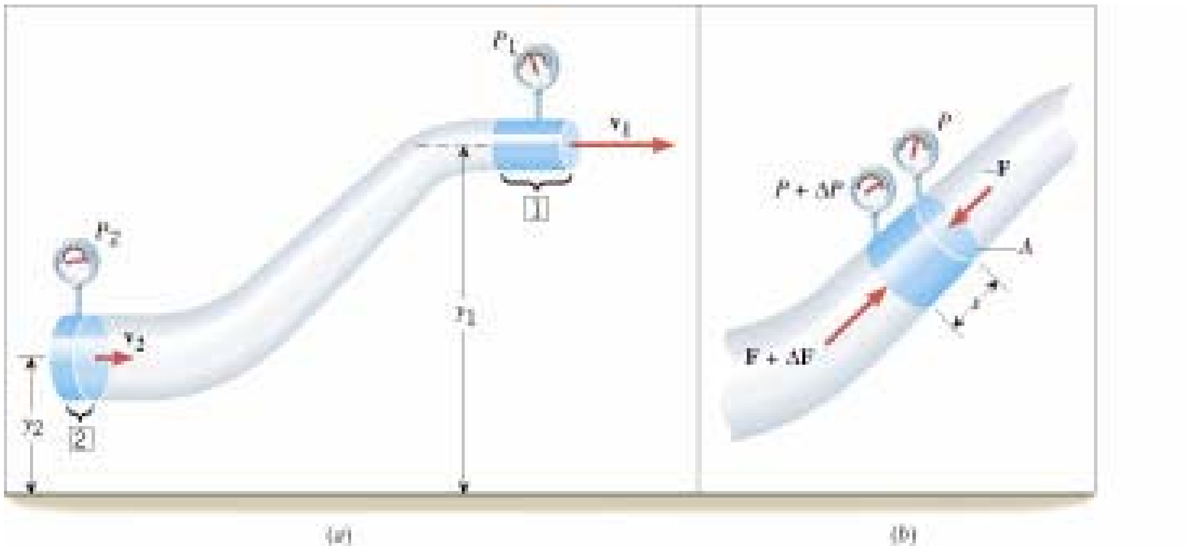


(6) All points have the same speed

Smallest cross-sectional area, highest speed

Bernoulli's Equation

What if the fluid is moving *and* changes height? Need to consider change in gravitational PE!



W_{NC} = ΔKE + ΔPE

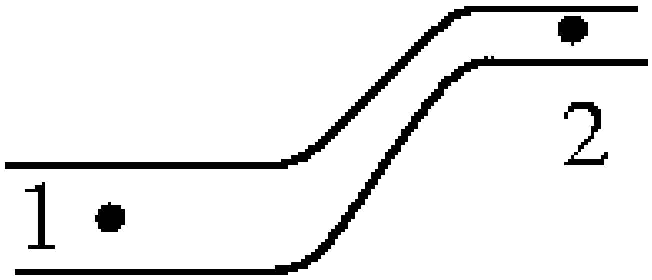
ΔPressure.A $(1/2)mv^2$ mgh

For two points in incompressible, nonviscous fluid with steady flow:

$$\boxed{P_1 + (1/2)\rho v_1^2 + \rho g y_1 = P_2 + (1/2)\rho v_2^2 + \rho g y_2}$$

Careful! In many cases *continuity* determines speed!

An incompressible fluid flows through a pipe. Compare the pressure at points 1 and 2.



$\boxed{\text{(1) Greater at 1}}$

(2) Greater at 2

(3) Both the same

(4) Not enough information

$P + (1/2)\,\rho v^2 + \rho g h = \text{constant}$

$(1/2)\,\rho v^2$ is larger (higher v due to smaller A)

$\rho g h$ is larger (higher)

Therefore

Consider a small, horizontal artery in which there is a constriction due to plaque. This constriction reduces the cross sectional area of the artery. The pressure in the constricted region is ______ the pressure in the unconstricted region.

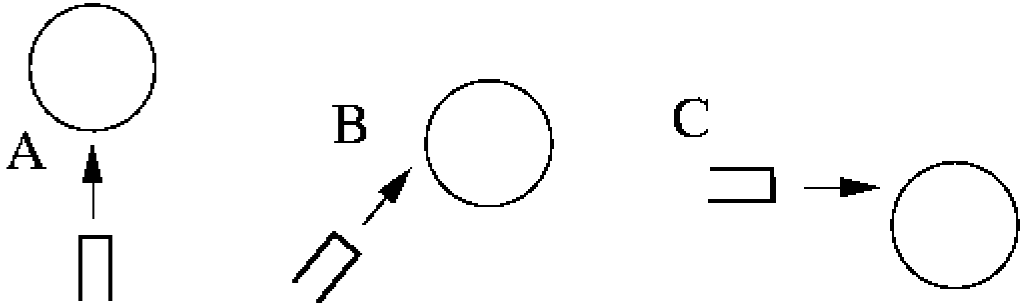
1. greater than
2. less than
3. the same as

Continuity: greater speed in constriction

Bernoulli: greater speed, lower pressure

Vascular flutter: If pressure too low, can close, then open, close, then open, ….

I will attempt to levitate a beach ball using an air blower. Under which scenarios will the beach ball levitate in a stable state (it may bounce around a little, but it won't fall).



(1) A (2) B (3) C (4) None (5) All

$\boxed{\text{(6) A and B}}$ (7) B and C (8) A and C

Gravity has to bring the ball back closer to the nozzle to keep the speed of the air high enough.

Example:

Calculate the lift force of an airplane wing with a surface area of $12.0m^2$. Assume the air above the wing is traveling at 70.0 m/s and the air below the wing is traveling at 60.0m/s. Assume the density of the air to be constant at 1.29 kg/m^3.

$F_{LIFT} = F_{UP} - F_{DOWN}$

$= P_{BELOW} A – P_{ABOVE} A$

$= (\Delta P) A$

From Bernoulli, find (ΔP) assuming Δy negligible.

$P_A + (1/2)\rho v_A^2 + \rho g y_A = P_B + (1/2) \rho v_B^2 + \rho g y_B$

$(\Delta P) = P_B – P_A = ((1/2)\rho v_A^2 – (1/2)\rho v_B^2) + (\rho g y_A – \rho g y_B)$

(assume ΔPE negligible – if y_A-y_B = 10cm, only 1.26 Pa)

$\Delta P = (1/2) (1.29)(70^2 – 60^2) = 838.5$ Pa

$F_{LIFT} = (838.5Pa)(12m^2) = 1.01 \times 10^4$ N

The Water Tank

Water is leaving a tank at a speed of 3.0 m/s. The tank is open to air on the top. What is the height of the water level above the spigot?

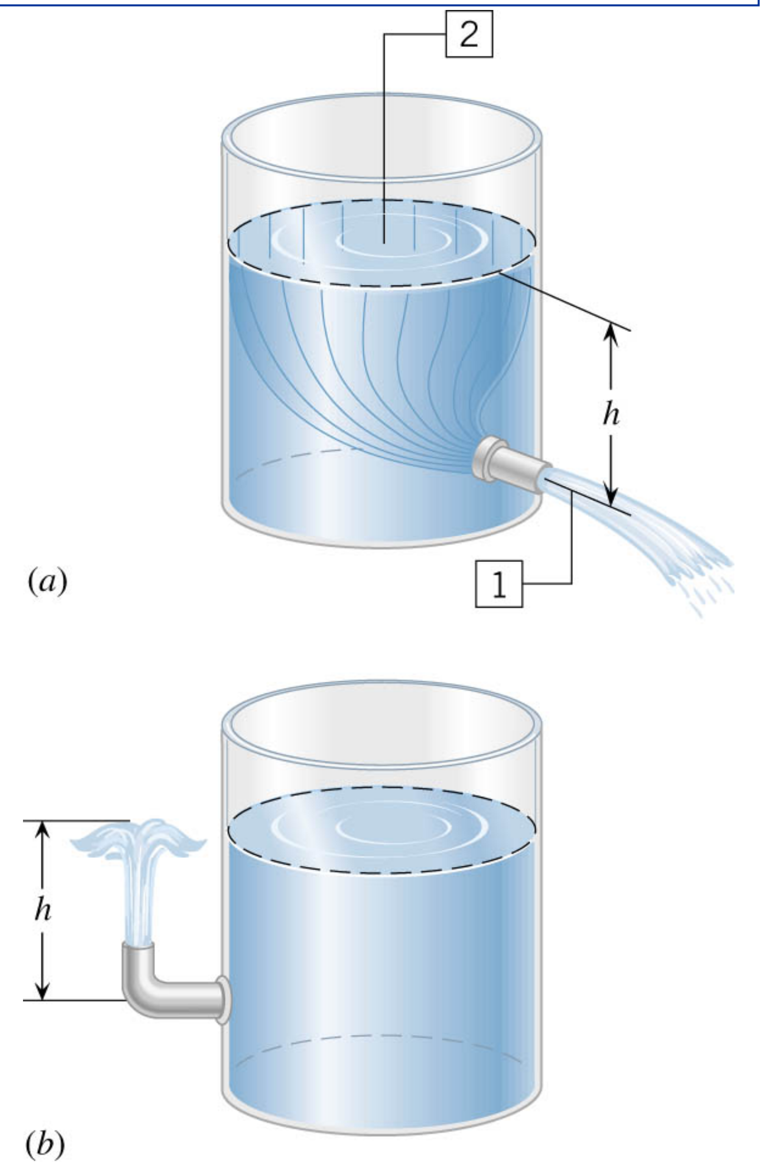
Assume the area of the tank is much larger than the area of the spigot.

$$P_2+\rho g h_2=P_1+\rho g h_1+(1/2)\,\rho(v_1)^2$$

Since $P_1=P_2$

$h_2-h_1=h = 0.459\text{m}$

What would happen if the tank were closed at the top and filled to the top?



Chapter 11

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

$m/\Delta t = \rho\ A\ v =$ mass flow rate

$$\rho_1\ A_1\ v_1 = \rho_2\ A_2\ v_2$$

$P = F/A$

$$Q = A_1\ v_1 = A_2\ v_2$$

F_B = weight of fluid displaced

$= \rho_{FLUID}\ g\ V_{FLUID\ DISPLACED}$

$$P_1 + (1/2)\rho v_1^2 + \rho g y_1 = P_2 + (1/2)\rho v_2^2 + \rho g y_2$$

$$Q = \frac{\pi R^4 (P_2 - P_1)}{8\eta L}$$

$P_{ATMOSPHERE} = 1.013\text{x}10^5$ Pa