Hello!

- I'm Chris Blake, your lecturer for the rest of semester
- We'll cover: fluid motion, thermal physics, electricity, revision
- MASH centre in AMDC 503 - 09.30-16.30 daily
- My consultation hours: Tues 10.30-12.30
- Wayne's consultation hours: Thurs 2.30-4.30
- cblake@swin.edu.au
- 03 9214 8624

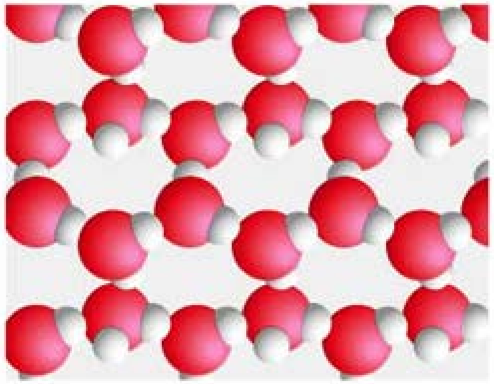
Fluid Motion

- Density and Pressure
- Hydrostatic Equilibrium and Pascal’s Law
- Archimedes' Principle and Buoyancy
- Fluid Dynamics
- Conservation of Mass: Continuity Equation
- Conservation of Energy: Bernoulli’s Equation
- Applications of Fluid Dynamics

A microscopic view

Solid

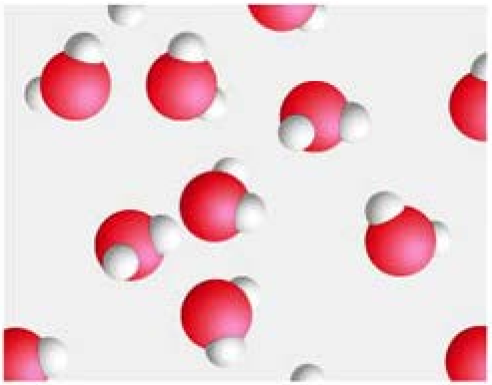
rigid body



Liquid

Fluid

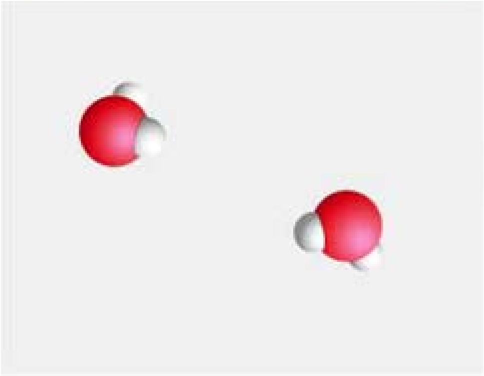
Incompressible



Gas

Fluid

compressible



What new physics is involved?

- Fluids can **flow** from place-to-place
- Their **density** can change if they are compressible (for example, gasses)
- Fluids are pushed around by **pressure** forces
- An object immersed in a fluid experiences **buoyancy**

Density

- The **density** of a fluid is the **concentration of mass**

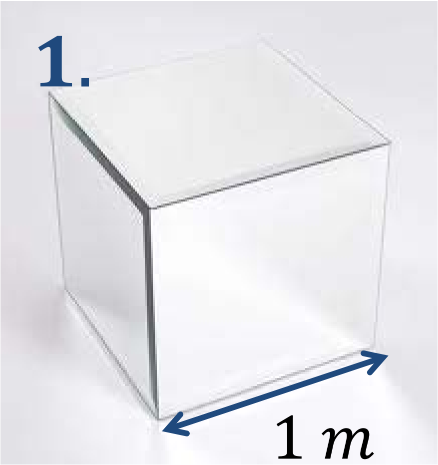
$$density = \frac{mass}{volume} \qquad \rho = \frac{m}{V} \qquad Units\ are\ \frac{kg}{m^3}$$

- Mass = 100 g = 0.1 kg
- Volume = 100 cm^3 = 10^{-4} m^3
- Density = 1 g/cm^3 = 1000 kg m^3

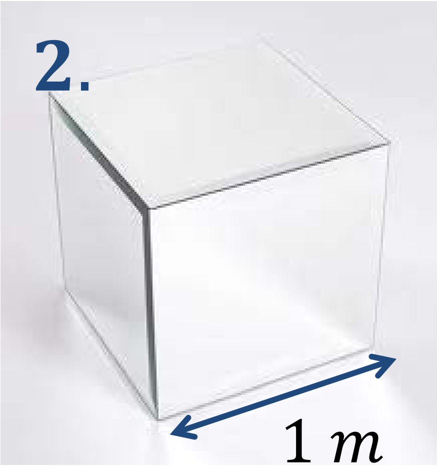
The shown cubic vessels contain the stated matter. Which **fluid** has the **highest** density ?

0%

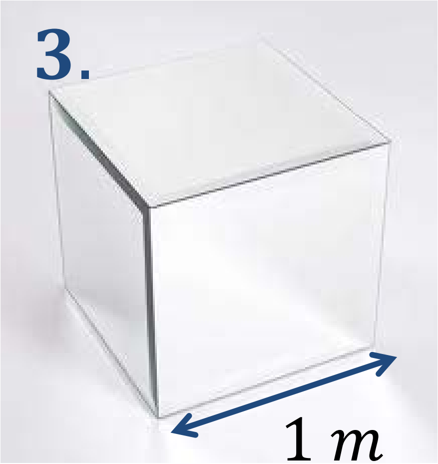
1 2 3 4 5



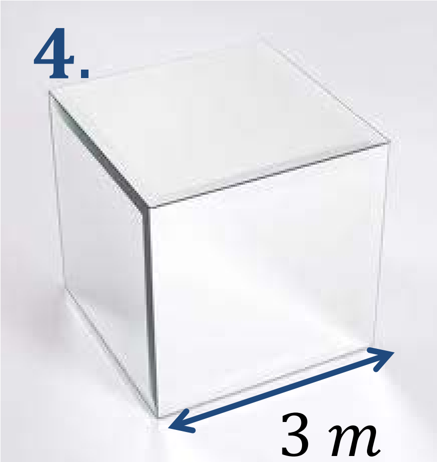
$1\ kg$ of water at $73°C$



$1\ kg$ of water at $273°C$



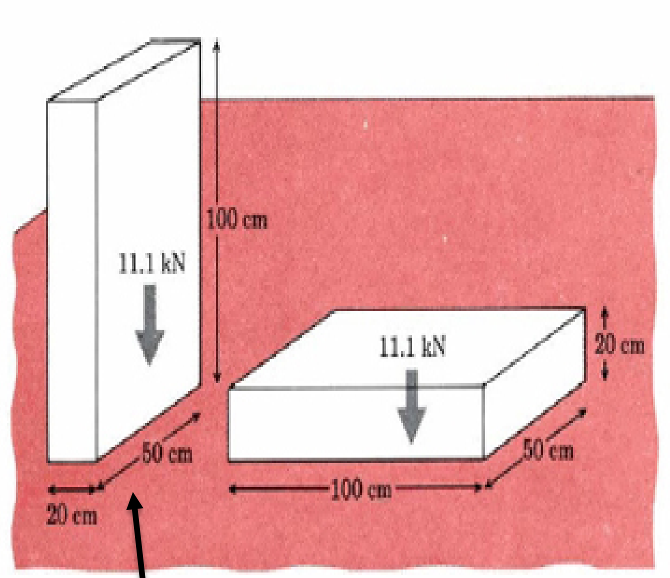
$1\ kg$ of water at $273°K$

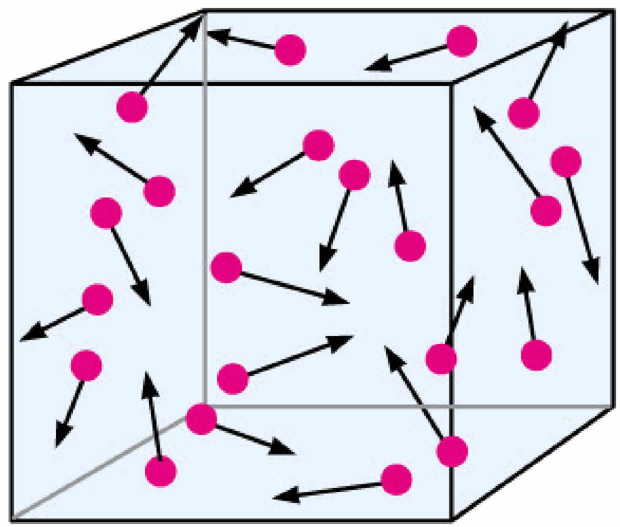


$1\ kg$ of water at $373°C$

Pressure

- **Pressure** is the concentration of a force – the **force exerted per unit area**

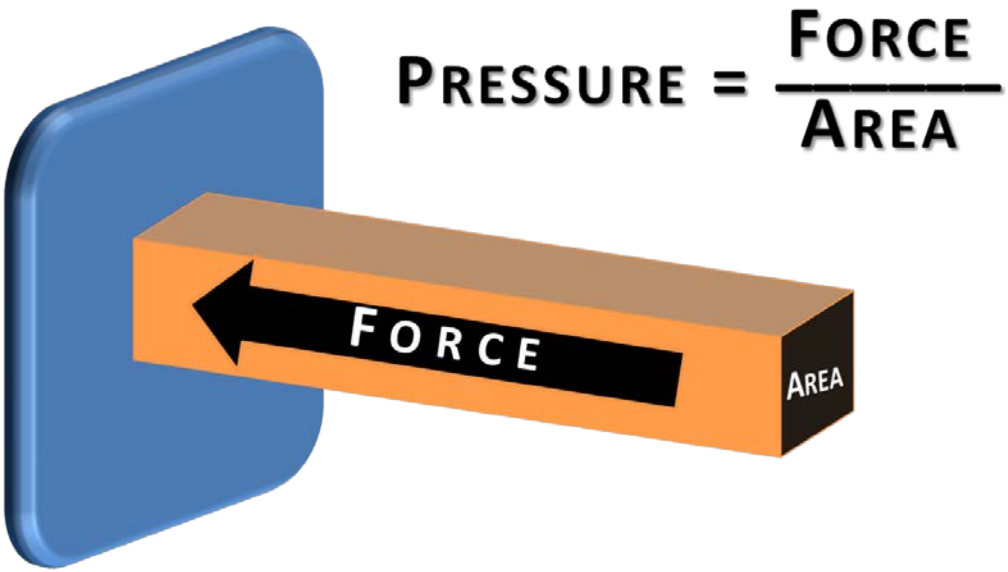




Greater pressure!
(same force, less area)

Exerts a pressure on the sides and through the fluid

Pressure

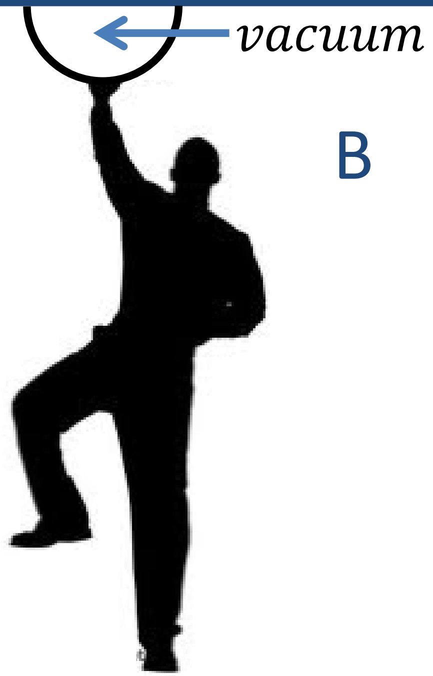


$$p = \frac{F}{A}$$

- **Units of pressure** are N/m^2 or Pascals (Pa) – 1 N/m^2 = 1 Pa
- **Atmospheric pressure** = 1 atm = 101.3 kPa = 1×10^5 N/m^2

A

What is responsible for the force which holds urban **climber B** in place when using suction cups.

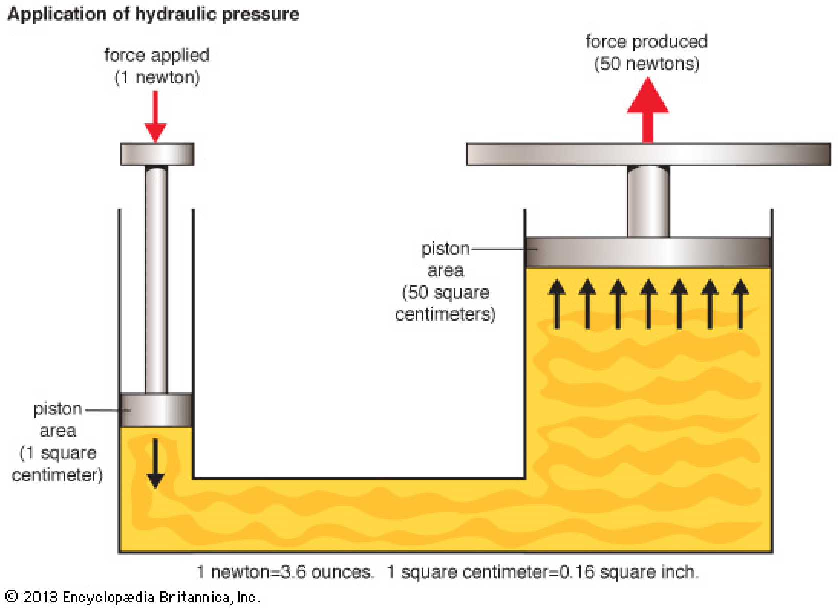


1. **The force of friction**
2. **Vacuum pressure exerts a pulling force**
3. **Atmospheric pressure exerts a pushing force**
4. **The normal force of the glass.**

0%

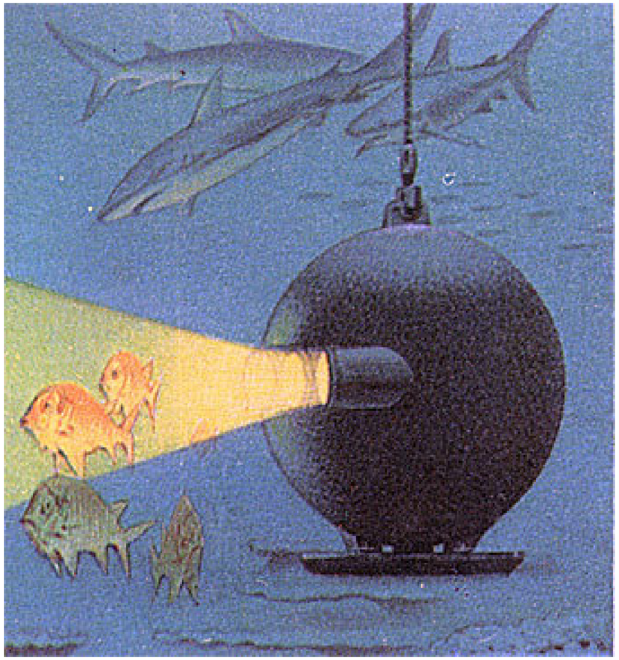
1. 2. 3. 4.

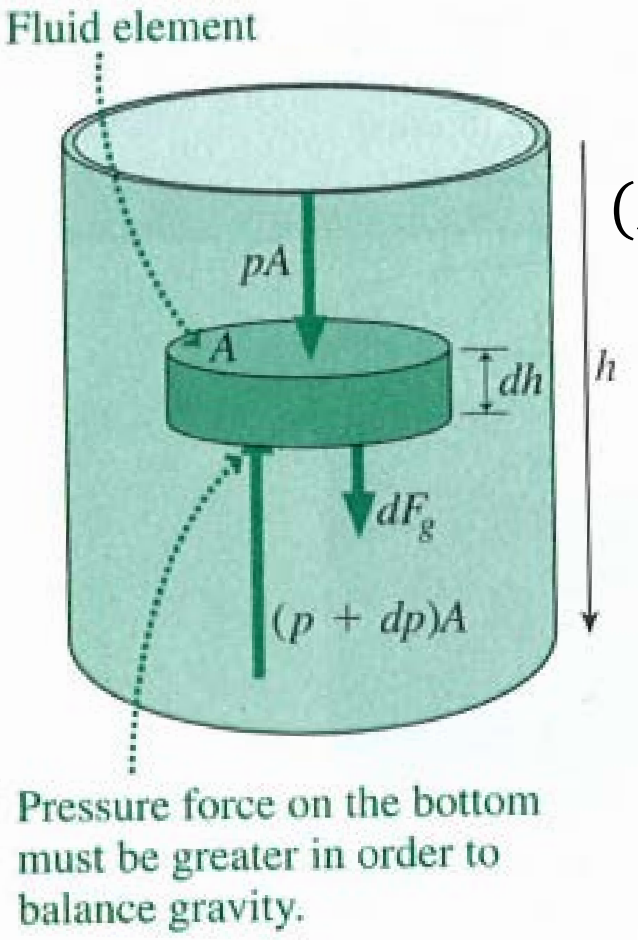
Hydrostatic Equilibrium



- **Pressure differences** drive fluid flow
- If a fluid is in **equilibrium**, pressure forces must balance
- **Pascal's law**: pressure change is transmitted through a fluid

Hydrostatic Equilibrium with Gravity





Derivation:

$$(P + dP)A - pA = mg$$

$$dP\,A = \rho\,A\,dh\,g$$

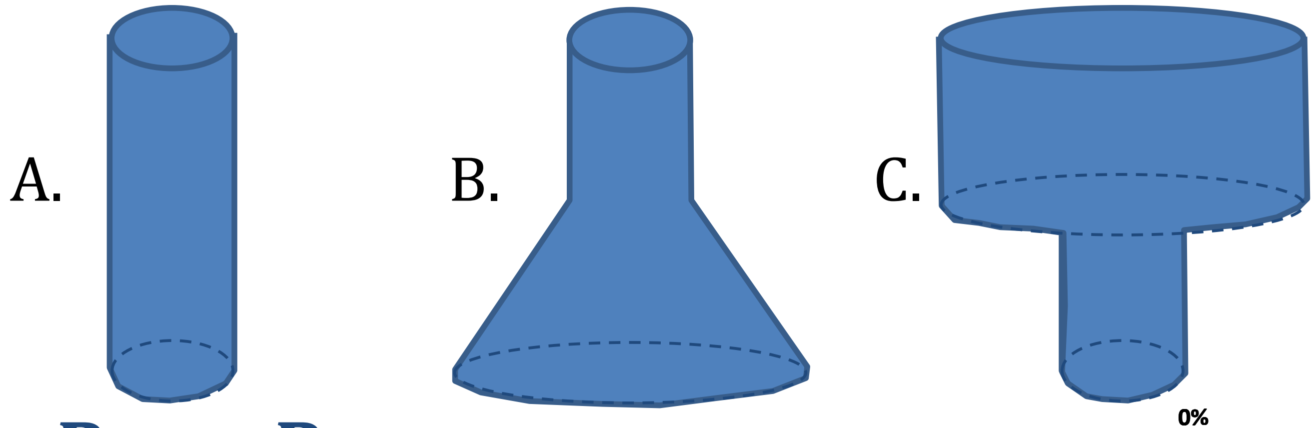
$$\frac{dP}{dh} = \rho g$$

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

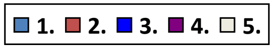
Pressure in a fluid is equal to the **weight of the fluid per unit area** above it:

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

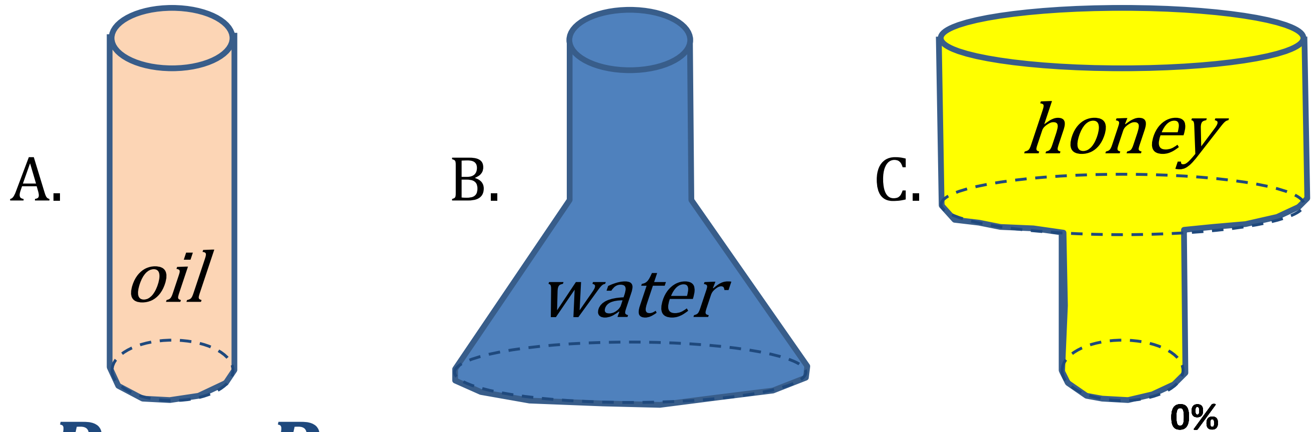
Consider the three open containers filled with water. How do the pressures at the bottoms compare ?



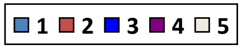
1. $P_A = P_B = P_C$
2. $P_A < P_B = P_C$
3. $P_A < P_B < P_C$
4. $P_B < P_A < P_C$
5. **Not enough information**



The three open containers are now filled with oil, water and honey respectively. How do the pressures at the bottoms compare ?

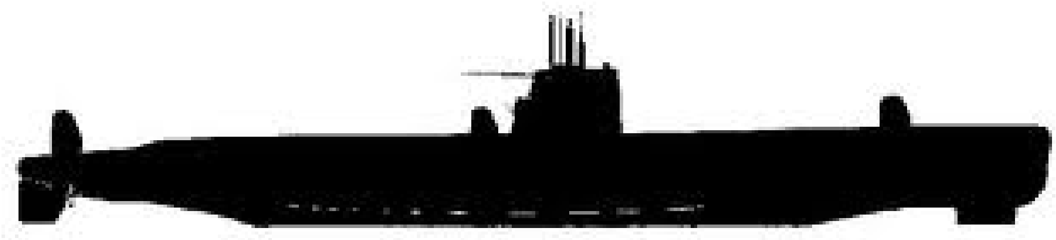


1. $P_A = P_B = P_C$
2. $P_A < P_B = P_C$
3. $P_A < P_B < P_C$
4. $P_B < P_A < P_C$
5. **Not enough information**



Calculating Crush Depth of a Submarine

Q. A nuclear submarine is rated to withstand a pressure difference of 70 atm before catastrophic failure. If the internal air pressure is maintained at 1 atm, what is the maximum permissible depth ?



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

$$P - P_0 = 70\ atm = 7.1\ \times 10^6\ Pa\ ;\ \ \rho = 1 \times 10^3\ kg/m^3$$

$$h = \frac{P - P_0}{\rho g} = \frac{7.1 \times 10^6}{1 \times 10^3 \times 9.8} = 720\ m$$

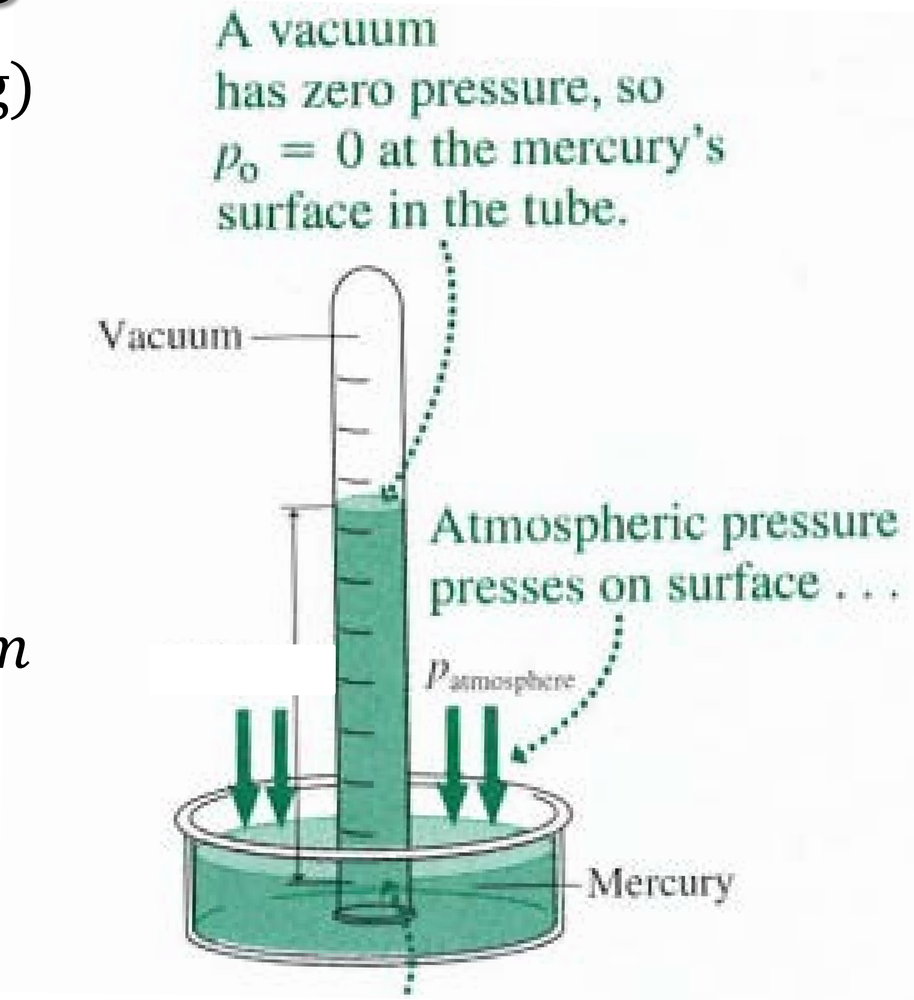
Measuring Pressure

Q. What is height of mercury (Hg) at 1 atm ?

$$\rho_{Hg} = 13.6\ g/cm^3$$

$$P = P_0 + \rho g h \rightarrow h = P/\rho g$$

$$h = \frac{1 \times 10^5}{1.36 \times 10^4 \times 9.8} = 0.75\ m$$



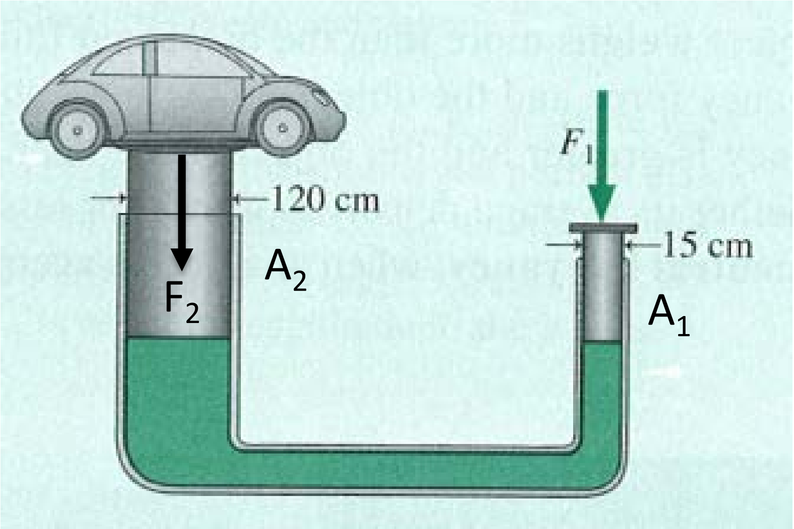
Atmospheric pressure can support a 10 meters high column of water. Moving to **higher density** fluids allows a table top **barometer** to be easily constructed.

$$p = p_0 + \rho g h$$

Pascal's Law

- Pressure force is transmitted through a fluid

Q. A large piston supports a car. The total mass of the piston and car is 3200 kg. What force must be applied to the smaller piston ?



Pressure at the same height is the same! (Pascal's Law)

$$\frac{F_1}{A_1} = \frac{F_2}{A_2} \qquad F_1 = \frac{A_1}{A_2}mg = \frac{\pi \times 0.15^2}{\pi \times 1.20^2} \times 3200 \times 9.8 = 490\ N$$

Gauge Pressure

Gauge Pressure is the pressure difference from atmosphere. (e.g. Tyres)

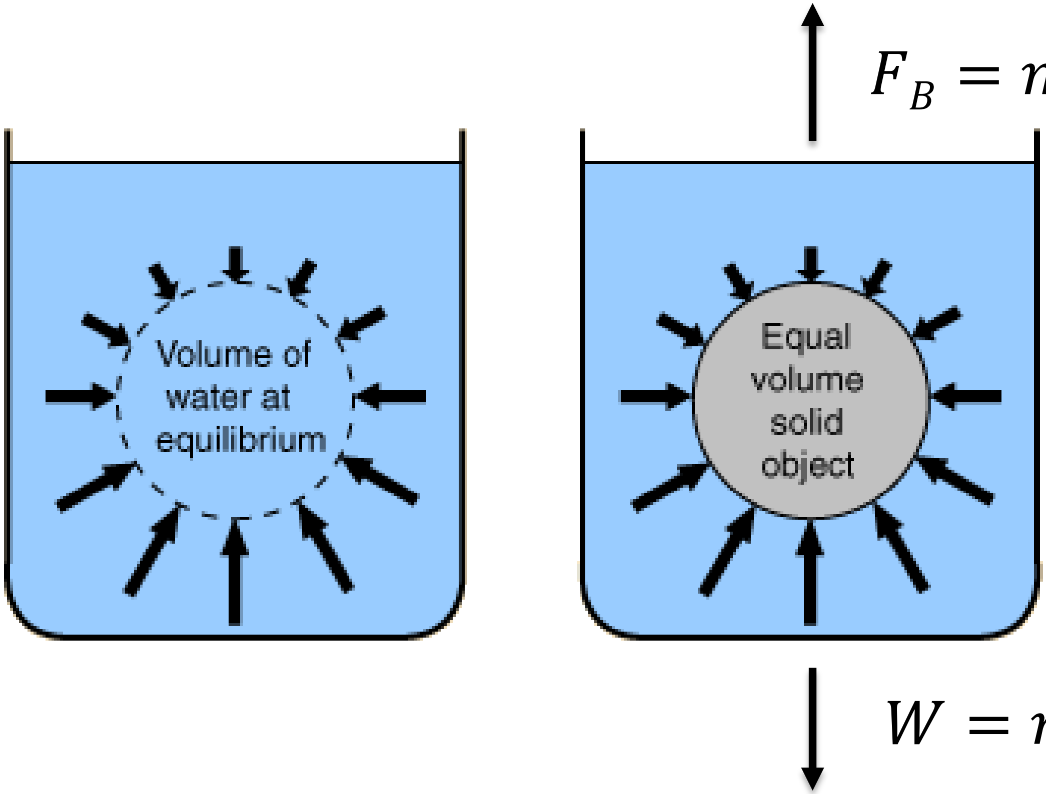
$$P_{absolute} = P_{atmosphere} + P_{gauge}$$

Archimedes' Principle and Buoyancy

Why do some things **float** and other things **sink** ?

Archimedes' Principle and Buoyancy

Objects immersed in a fluid experience a Buoyant Force!



$$F_B = m_{water}\, g = \rho_{water} V g$$

$$W = m_{solid}\, g = \rho_{solid} V g$$

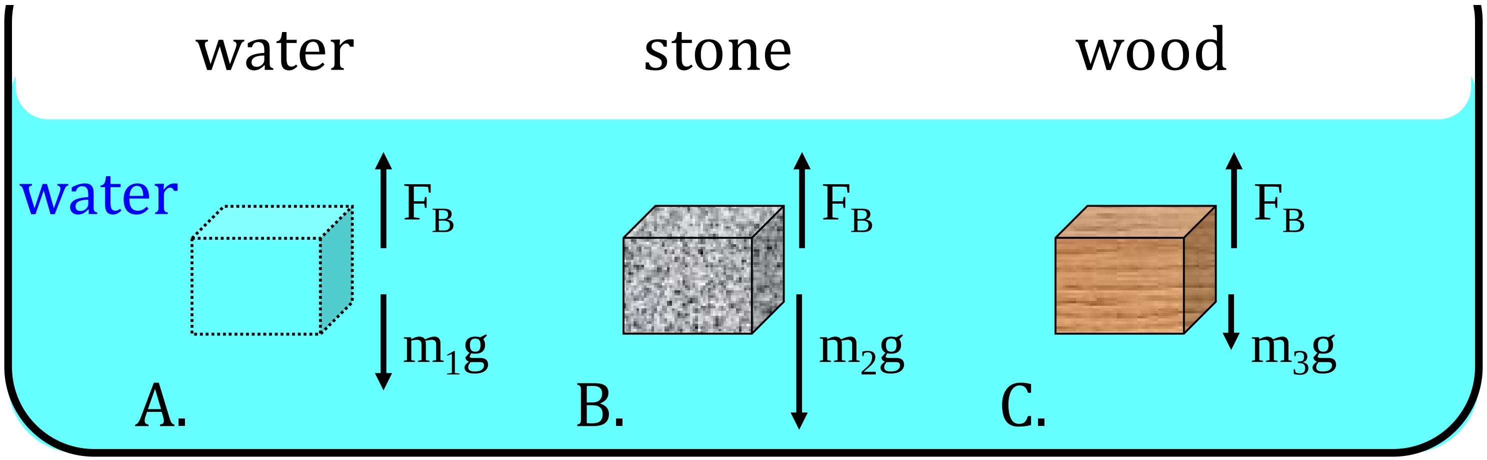
The **Buoyant Force** is equal to the weight of the **displaced** fluid !

Archimedes' Principle and Buoyancy

The hot-air balloon floats because the **weight of air displaced** (= the buoyancy force) is greater than the **weight of the balloon**

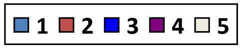
The **Buoyant Force** is equal to the weight of the **displaced** fluid !

Which of the three cubes of length l shown below has the largest buoyant force ?



0%

1. *water*
2. *stone*
3. *wood*
4. *the buoyant force is the same*
5. **Not enough information**



Example Archimedes' Principle and Buoyancy

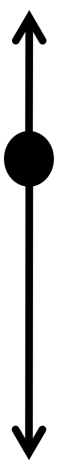
Q. Find the apparent weight of a 60 kg concrete block when you lift it under water, $\rho_{concrete} = 2200\ kg/m^3$

Interpret

Water provides a buoyancy force

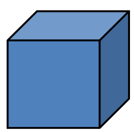
Apparent weight should be less

Develop



F_b

$w = mg$



$$\rho_{con} = \frac{m}{V}$$

$$V = \frac{m}{\rho_{con}}$$

Evaluate

$$F_{net} = mg - F_b = w_{apparent}$$

$$F_b = m_{disp\ water}\, g = \rho_{water} V g$$

$$w_{app} = mg - \frac{\rho_{water} mg}{\rho_{con}}$$

$$w_{app} = mg\left(1 - \frac{\rho_{water}}{\rho_{con}}\right)$$

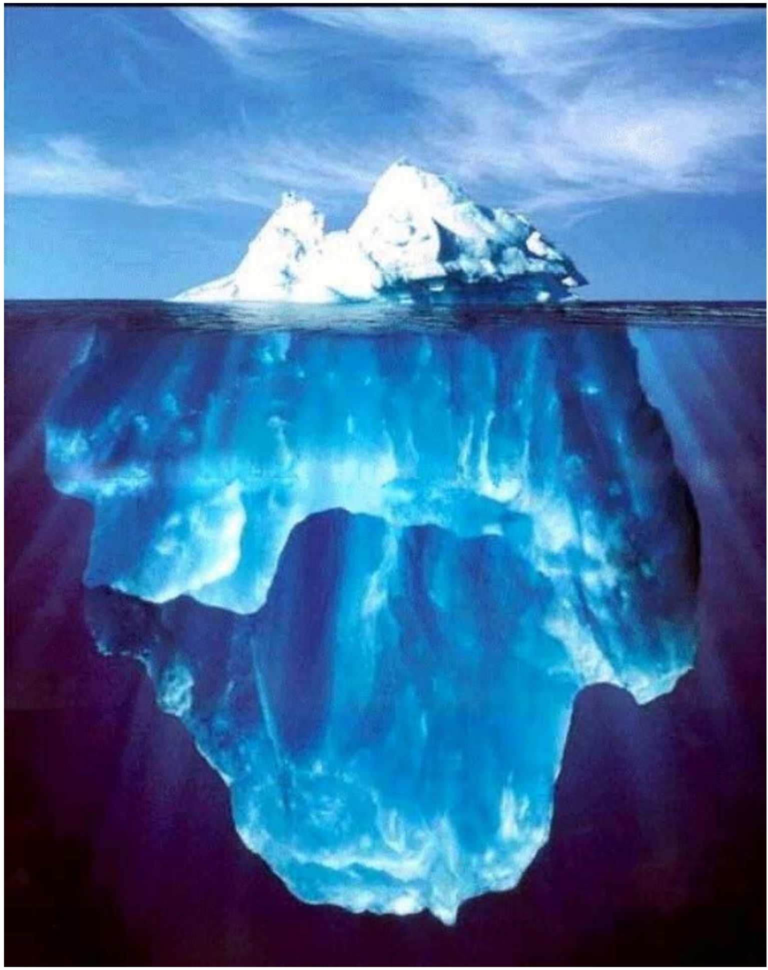
$$= 60 \times 9.8 \times \left(1 - \frac{1000}{2200}\right) = 321\ N$$

Assess

The **Buoyant Force** is equal to the weight of the **displaced** fluid.

Floating Objects

Q. If the density of an iceberg is 0.86 that of seawater, how much of an iceberg's volume is below the sea?



$$Buoyancy\ force\ F_B = weight\ of\ water\ displaced$$

$$V_{sub} = submerged\ volume$$

$$F_B = m_{water}\, g = \rho_{water} V_{sub}\, g$$

$$In\ equilibrium, F_B = weight\ of\ iceberg$$

$$F_B = m_{ice}\, g = \rho_{ice} V_{ice}\, g$$

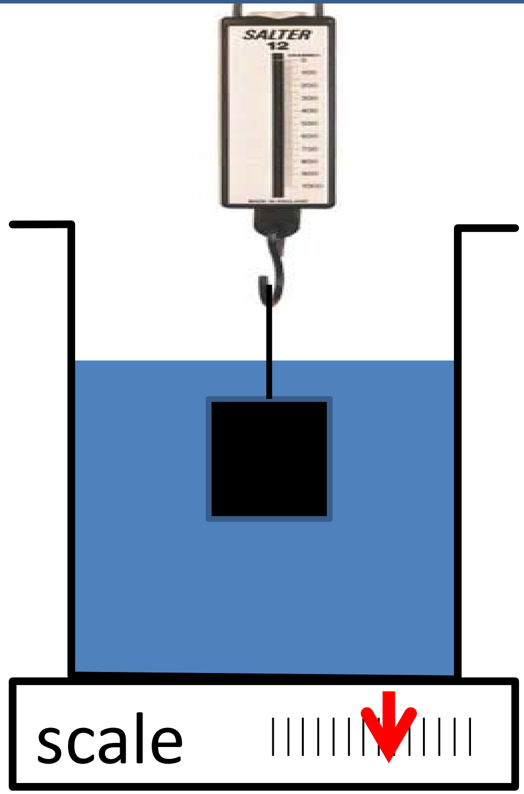
$$\rho_{water} V_{sub}\, g = \rho_{ice} V_{ice}\, g \rightarrow \frac{V_{sub}}{V_{ice}} = \frac{\rho_{water}}{\rho_{ice}} = 0.86$$

A beaker of water weighs w_1. A block weighting w_2 is suspended in the water by a spring balance reading w_3. Does the scale read

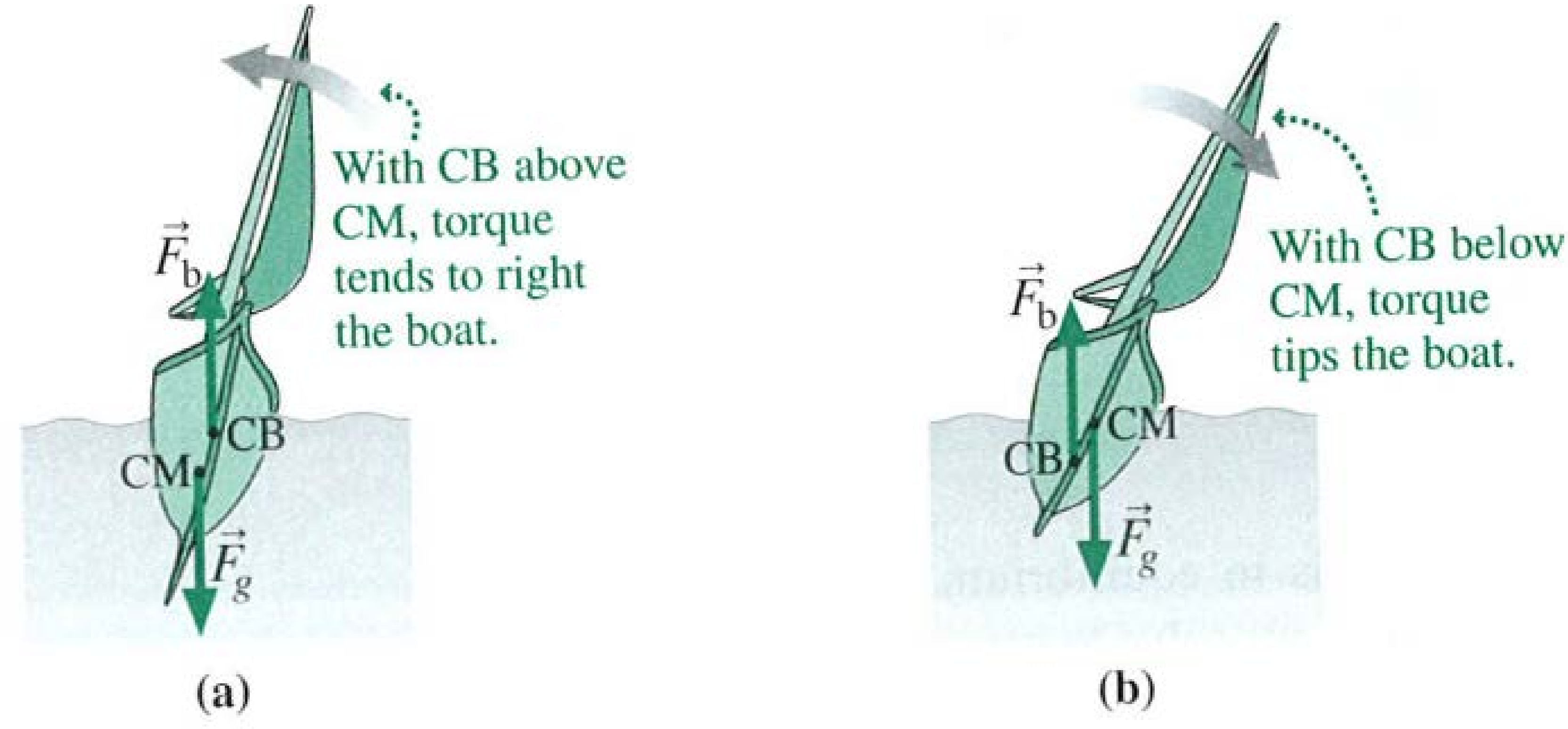
0%

1. w_1
2. $w_1 + w_2$
3. $w_1 + w_3$
4. $w_1 + w_2 - w_3$
5. $w_1 + w_3 - w_2$

1 2 3 4 5



Centre of Buoyancy



The **Centre of Buoyancy** is given by the Centre of Mass of the **displaced** fluid. For objects to float with stability the Centre of Buoyancy must be **above** the Centre of Mass of the object. Otherwise Torque yield Tip !

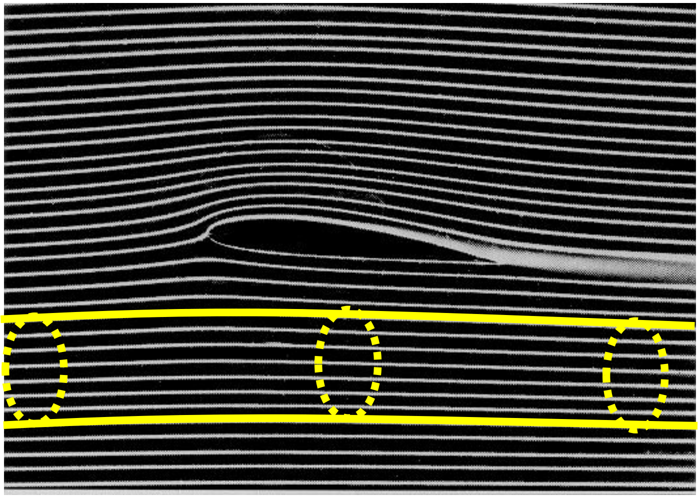
Fluid Dynamics

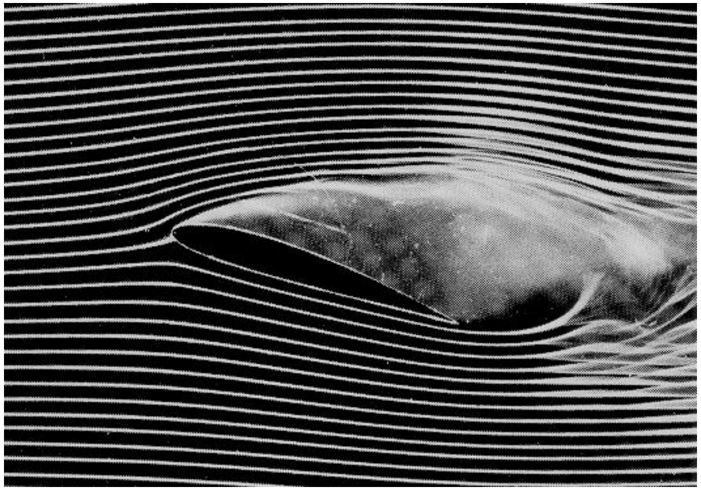
Laminar (steady) flow is where each particle in the fluid moves along a smooth path, and the paths do not cross.

Streamlines spacing measures velocity and the flow is always tangential, for steady flow don't cross. A set of streamlines act as a pipe for an **incompressible** fluid

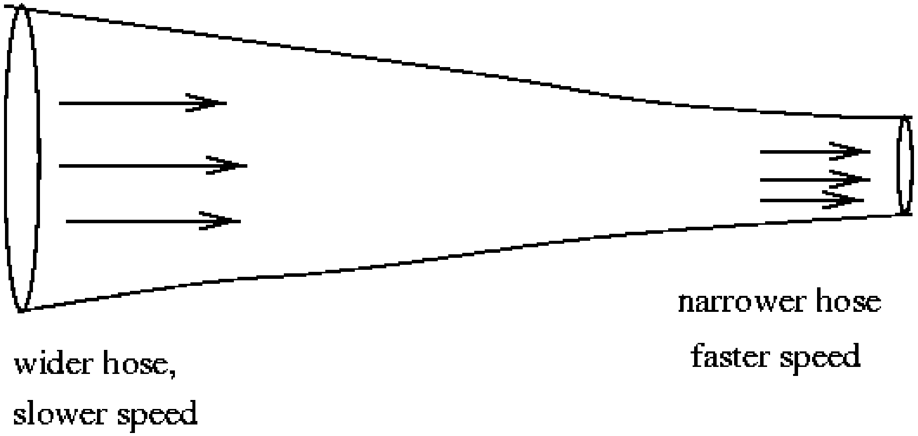
Non-viscous flow – no internal friction (water OK, honey not)

Turbulent flow above a critical speed, the paths become irregular, with whirlpools and paths crossing. Chaotic and **not considered here.**





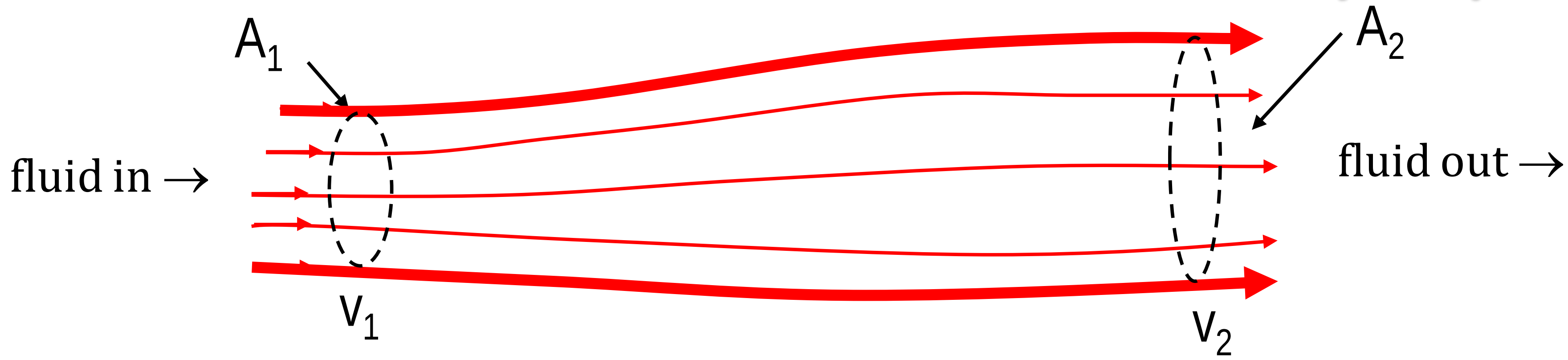
Conservation of Mass: The Continuity Eqn.



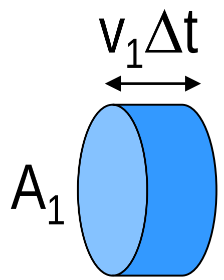
"The water all has to go somewhere"

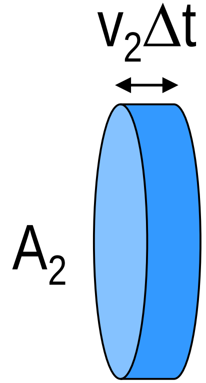
The rate a fluid enters a pipe must equal the rate the fluid leaves the pipe.
i.e. There can be **no sources or sinks** of fluid.

Conservation of Mass: The Continuity Eqn.



Q. How much fluid flows across each area in a time Δt:



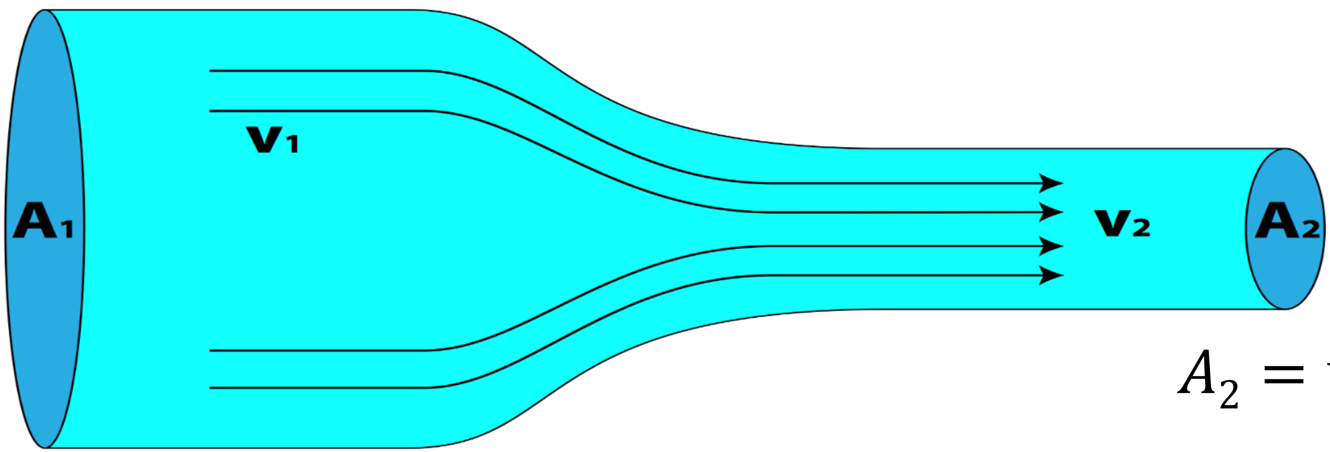


$$\Delta m = \rho V_1 = \rho A_1 v_1 \Delta t \qquad \Delta m = \rho V_2 = \rho A_2 v_2 \Delta t$$

$$flow\ rate: \frac{\Delta m}{\Delta t} = \rho A v \qquad continuity\ eqn: \quad A_1 v_1 = A_2 v_2$$

Conservation of Mass: The Continuity Eqn.

Q. A river is 40m wide, 2.2m deep and flows at 4.5 m/s. It passes through a 3.7-m wide gorge, where the flow rate increases to 6.0 m/s. How deep is the gorge?



$$A_2 = w_2 d_2$$

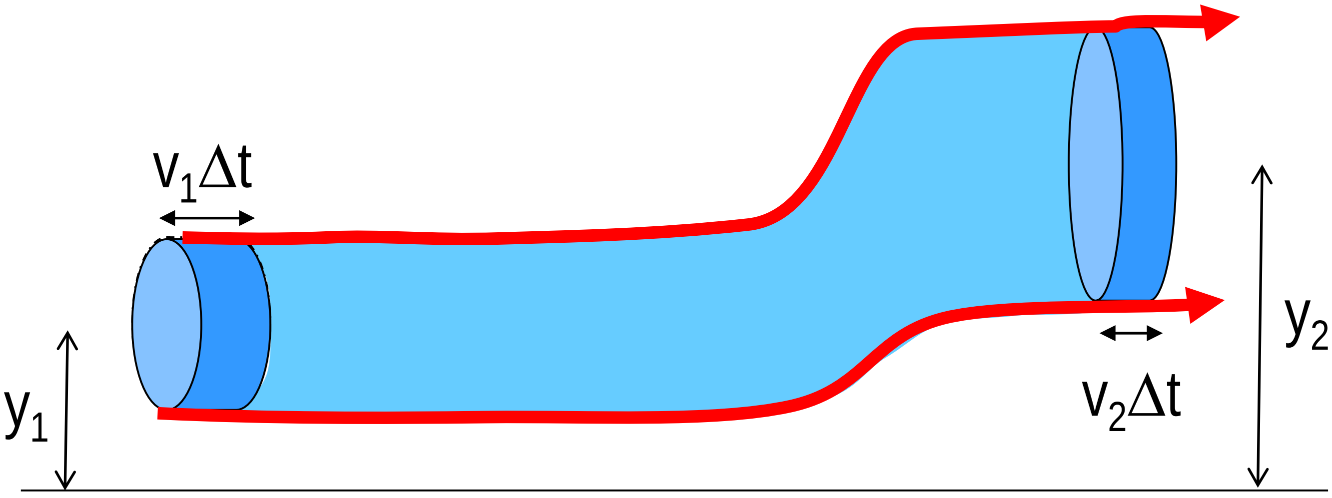
$$A_1 = w_1 d_1$$

$$Continuity\ equation : A_1 v_1 = A_2 v_2 \rightarrow w_1 d_1 v_1 = w_2 d_2 v_2$$

$$d_2 = \frac{w_1 d_1 v_1}{w_2 v_2} = \frac{40 \times 2.2 \times 4.5}{3.7 \times 6.0} = 18\ m$$

Conservation of Energy: Bernoulli's Eqn.

What happens to the energy density of the fluid if I raise the ends ?



Energy per unit volume

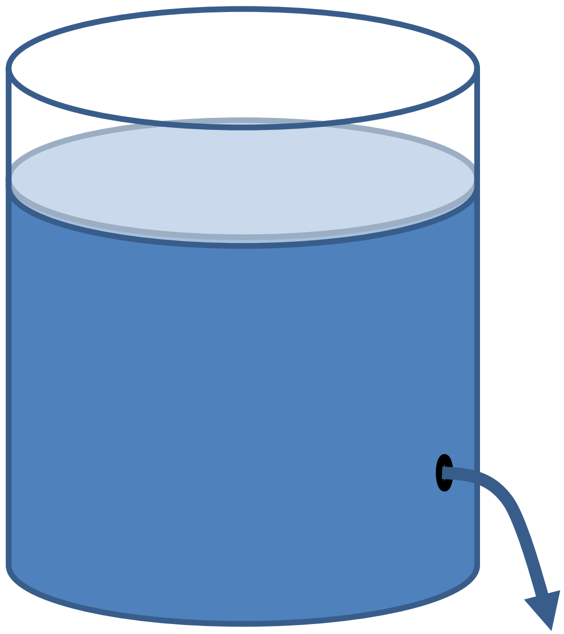
$$p_1 + \tfrac{1}{2}\rho v_1^2 + \rho g y_1 = p_2 + \tfrac{1}{2}\rho v_2^2 + \rho g y_2 = const$$

Total energy per unit volume is constant at **any** point in fluid.

$$p + \tfrac{1}{2}\rho v^2 + \rho g y = const$$

Conservation of Energy: Bernoulli's Eqn.

Q. Find the velocity of water leaving a tank through a hole in the side 1 metre below the water level.



$$P + \tfrac{1}{2}\rho v^2 + \rho g y = constant$$

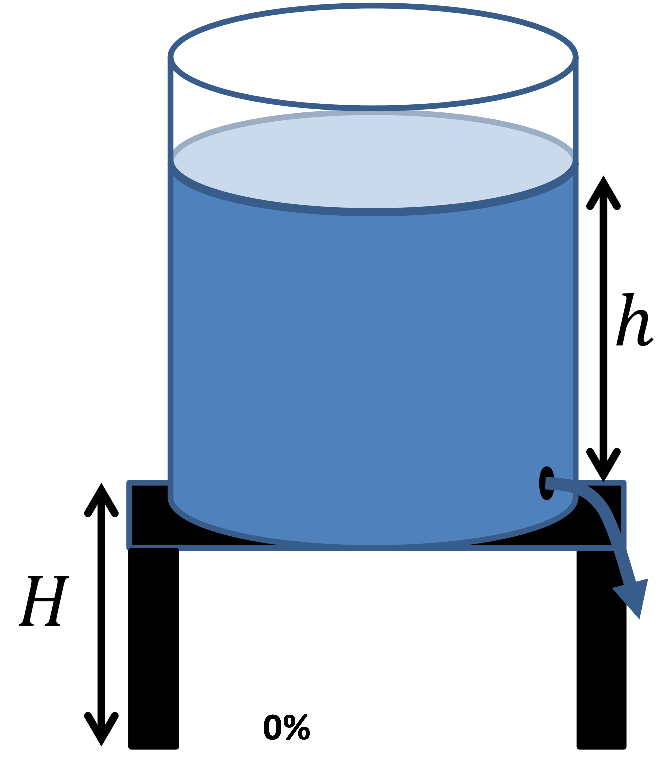
$$At\ the\ top:\ P = 1\ atm, v = 0, y = 1\ m$$

$$At\ the\ bottom:\ P = 1\ atm, v = ?, y = 0\ m$$

$$\cancel{P} + \rho g y = \cancel{P} + \tfrac{1}{2}\rho v^2$$

$$v = \sqrt{2gy} = \sqrt{2 \times 9.8 \times 1} = 4.4\ m/s$$

Which of the following can be done to increase the **flow rate** out of the water tank ?



1. Raise the tank ($\uparrow H$)
2. Reduce the hole size
3. Lower the water level ($\downarrow h$)
4. Raise the water level ($\uparrow h$)
5. None of the above

1 2 3 4 5

Summary: fluid dynamics

Continuity equation: mass is conserved!

$$\rho \times v \times A = constant$$

For liquids:

$$\rho = constant \rightarrow v \times A = constant$$

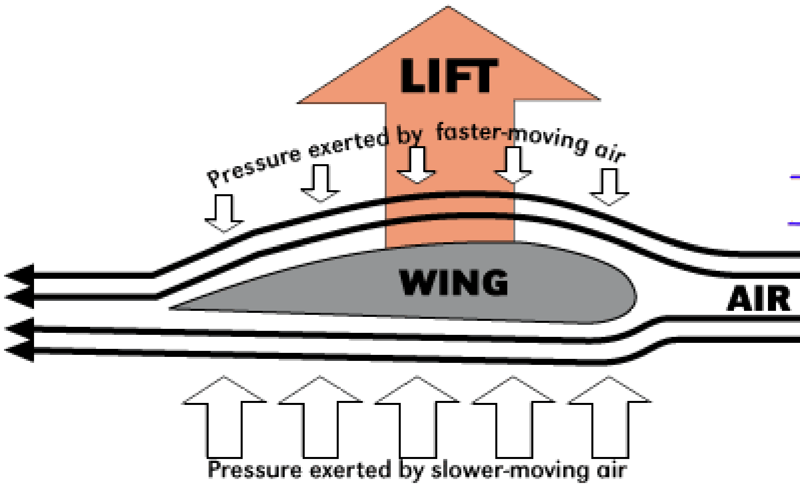
$(Density\ \rho, velocity\ v, pipe\ area\ A)$

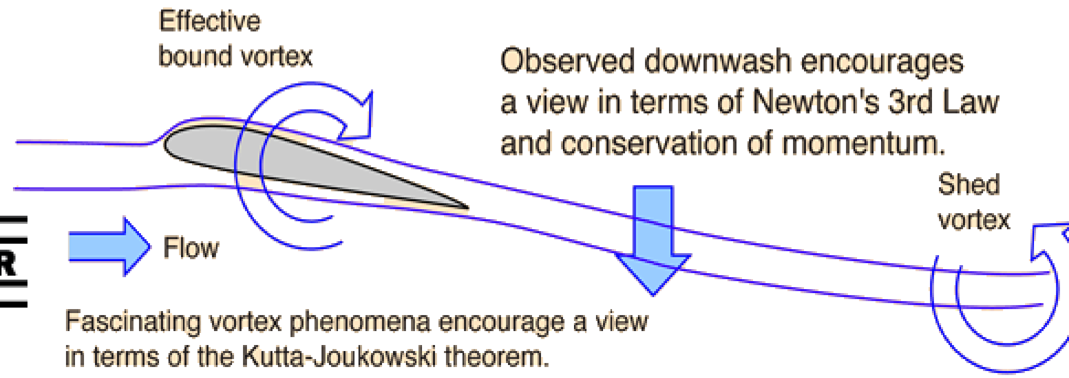
Bernoulli's equation: energy is conserved!

$$P + \tfrac{1}{2}\rho v^2 + \rho g y = constant$$

$(Pressure\ P, density\ \rho, velocity\ v, height\ y)$

Bernoulli's Effect and Lift





Newton's 3rd law
(air pushed downwards)

$$P + \frac{1}{2}\rho v^2 + \rho g y = constant$$

Lift on a wing is often explained in textbooks by Bernoulli's Principle: the air over the top of the wing moves faster than air over the bottom of the wing because it has further to move (?) so the pressure upwards on the bottom of the wing is smaller than the downwards pressure on the top of the wing.

Is that convincing? So why can a plane fly upside down?

Chapter 15 Fluid Motion Summary

- Density and Pressure describe bulk fluid behaviour
- Pressure in a fluid is the same for points at the same height
- In hydrostatic equilibrium, pressure increases with depth due to gravity
- The buoyant force is the weight of the displaced fluid
- Fluid flow conserves mass (continuity eq.) and energy (Bernoulli's equation)
- A constriction in flow is accompanied by a velocity and pressure change.
- Reread, Review and Reinforce concepts and techniques of Chapter 15

Examples 15.1 , 15.2 Calculating Pressure and Pascals Law
Examples 15.3 , 15.4 Buoyancy Forces: Working Underwater + Tip of Iceberg
Examples 15.5 Continuity Equation: Ausable Chasm
Examples 15.6, 15.7 Bernoulli's Equation – Draining a Tank and Venturi Flow