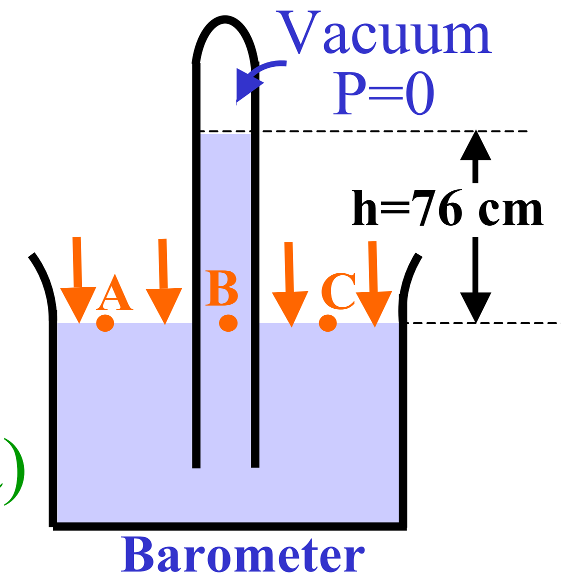
# Recap: Pressure

- Pressure = Force per unit area ($P = F/A$; units: Pascals)
- Density of object = mass / volume ($\rho = m/V$; units: $kg/m^3$)
- **Pascal's Law:** Pressure is transmitted equally in all directions throughout the fluid.
- In a fluid **gravity** is the cause of **hydrostatic pressure** resulting in an **increase in pressure** with depth.

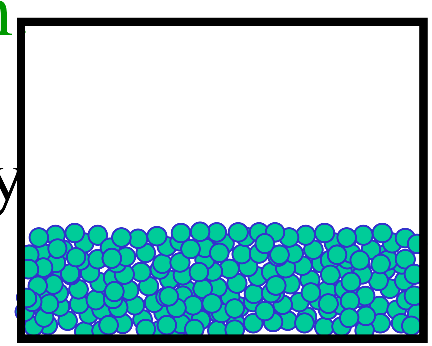
$$\text{Pressure} = F/A = \rho.g.h$$




- Pressure at A,B,C is same: at A, C (weight of atmosphere, at B (weight of mercury).
- Thus the height of mercury is a direct measure of atmospheric pressure.
- Force due to atmospheric pressure (~$10^5$ Pa) is very powerful.

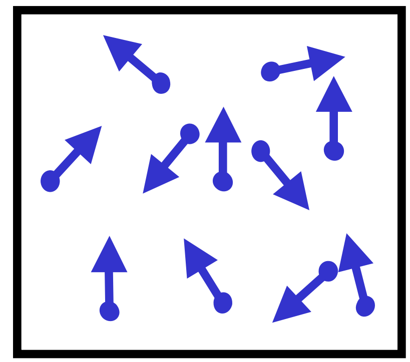
# Static Fluids (Chapter 9)

- Most **liquids** are **NOT readily compressible**, so increasing pressure does **NOT** change their **volume** much.
- This is because the **molecules** in a liquid are **closely packed together** (like in a solid) – they cannot easily be squeezed.



liquid

- **Density** of a **liquid** therefore stays the **same**.
- **Gases** (e.g. air) are much **easier to compress.** As the **pressure changes** the **volume changes**.
- Except at very high pressures the **atoms /molecules of a gas** are **separated by large distances** compared to size of atoms.



gas

- The **density** of a **gas** therefore **changes** with pressure.
- **Gases** can also **expand** if the **pressure** is **reduced**.
- Changes in **temperature** have much **bigger effect** on **gas** pressure /volume than on a **liquid.**

# Boyle's Law (Mariotte's Law) (17th century)

- How does the volume of a gas change with pressure at constant temperature?
- Experiments with "U" shaped tubes containing mercury liquid showed that the **volume** of trapped gas **decreases** as **pressure increases**.

$$P.V = \text{constant}$$

or $P_1.V_1 = P_2.V_2$

- So if **pressure increases** the **volume decreases** to keep their **product constant** (at fixed temperature).
- The density (ρ) also changes **inversely** with the volume change … (ρ = mass / volume).
- For example, if the volume decreases the density will increase and vice versa.

# Examples Using Boyle's Law

**Example 1:** Increase pressure on a volume of air of 0.5 $m^3$ from 1 x $10^5$ Pa (1 atmosphere) to 5 x atmospheric pressure (5 atmospheres) at constant temperature.

$$P_1.V_1 = P_2.V_2$$

$$V_2 = \frac{1 \times 0.5}{5} = 0.1 \text{ m}^3$$ i.e. Volume **reduces** 5 times

As density $\rho = \frac{m}{V}$ and density **increases** by 5 times.

**Example 2:** Same volume of air (0.5 $m^3$) at sea level is allowed to expand (at constant temperature) to height of 10 km where pressure = 26 x $10^3$ Pa.

$$P_1.V_1 = P_2.V_2$$

$$V_2 = \frac{0.5 \times (1 \times 10^5)}{26 \times 10^3} = 1.9 \text{ m}^3$$ (Volume **increased**)

(Density $\rho$ **decreases** by factor of ~ 4)

# Floatation

- **Why** do some objects **float** easily while others **sink**?
  - Does it depend on its weight?
  - What is the effect of objects shape?
- **Answer: Density is the key to floatation**!
- Objects whose **average density** is **greater** than the **fluid** they are immersed in will **sink**, but those **less dense** will **float**.
- **Example:** Wood is **less dense** ($\rho$ = mass / volume) than water and **floats**; steel is **more dense** and it **sinks**!

# Buoyancy Force

- If you **push down** on a block of **floating wood** you instantly feel a **force pushing back**.
- **Force is large** – very hard to submerge a low density object (e.g. life jacket).
- **The upward force is called Buoyancy Force.**
- The more you **push down** a partially submerged object (e.g. toy duck) the **larger the buoyancy** force response.

# Archimedes' Principle

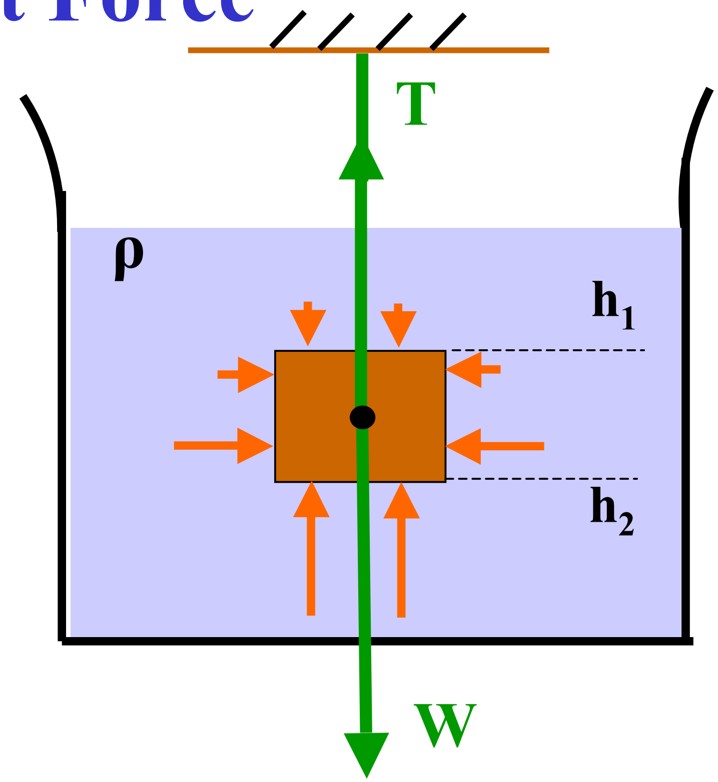
- Archimedes realized what determines the **strength** of the buoyancy force.
- When an object is **submerged** it **takes up space** previously occupied by the **liquid**, i.e. it **displaces** the fluid.
- The **more fluid displaced**, the **greater** the upward **buoyancy force**.
- Once an object is **completely submerged** it cannot **displace any more liquid** and the **buoyancy force** will remain **constant** (with depth change).

❖**The buoyant force acting on an object (partially or fully) submerged in a fluid is equal to the weight of fluid displaced.**

- An object will therefore **float** if it **displaces** a volume of fluid that is **heavier** than the object.
- i.e. The **buoyant force** is **greater** than **object's weight**…

# Origin of Buoyant Force

- The source of the buoyant force is the **change in pressure** with depth.
- **Pressure** acting on **bottom** of block is **larger** than **top** due to increase of pressure with depth
- Results in net **upward** force.




At a given depth: $P = \rho.g.h$

The pressure difference $= \rho.g.\Delta h$ (where $\Delta h = h_2 - h_1$)

Force due to pressure difference $= \rho.g.\ \underline{\Delta h.\ A}$ **(volume block)**

❖ **Buoyancy force = ρ.g.V = weight liquid displaced (m.g)**

- The **buoyant force** is therefore dependent on the **density** and **volume** (i.e. **weight**) of **liquid displaced**.

# State of Floatation (3 possibilities)

- The **weight of an object** and the resultant **buoyancy force** determine whether it will **float** or **sink**.

**1. Density of object greater than fluid density:**

- Weight of object is greater than weight of fluid displaced (as volume is same when fully submerged).
- **Net force** (weight – buoyancy) is **downward**; **it sinks**!
- Example: A submarine takes on sea water to replace air and increases its **average density** (i.e. weight) to submerge.

**2. Density of object less than fluid density:**

- Buoyant force is **larger** than object's **weight** when fully submerged.
- Net force is **upward**! Object will **float** at an **equilibrium level** where **buoyancy force = weight**.

**3. Density of object equals that of fluid:**

- The weight of object exactly equals the weight of fluid displaced when it is **fully submerged**.

## 3. Density of object equals that of fluid (cont):

- The object **floats** when **fully submerged**.
- Fish, and submarines exist in this state changing their **average density** slightly to **rise** or **fall** in depth.

## Effect of Shape on Floatation

- Metal is much more dense than water but can be made to float by creating a shape /volume whose **average density** is less than water.
- At **equilibrium** (floatation) the **buoyant force equals ships weight.**
- When it takes on **cargo**, the ship will **sink lower** in water (to new **equilibrium position**).
- In a storm if a ship takes on too much **water** its **average density** (and weight) will **increase** and it will **sink** if it exceeds water density.

# Floating in the Air

- **Buoyancy** force acts on objects **submerged** in a **gas** e.g. air.
- If a balloon is filled with a gas whose **density** is **less** than air, (and the **average density** of balloon and gas is **less** than air), then it will **rise**.
- **Helium gas** (He) is often used (hydrogen too dangerous). Old Zeppelin balloons used **hydrogen** with disastrous consequences.
- Balloons are made of very **light materials** e.g. mylar (often coated with aluminum).
- They are **thin**, **light**, **strong** and **impermeable** to the gas contained.

Note: Helium easily escapes through normal elastic balloon – why they only stay up at children's parties for a day or so…

- **Hot air balloons**: as air expands when heated, it becomes **less dense** and balloon **rises**.
- A balloon will **rise** until its **average density** equals that of the **surrounding air** (just like a submarine floating in water).

# Summary

- **Archimedes' principal** states that the **buoyant force** acting on an object is **equal** to the **weight** of fluid displaced.
- If the **average density** of object is **greater** than density of fluid displaced, the **weight** of object will **exceed buoyant force** and it will **sink** (and vice versa).
- **Buoyancy force** is due to **pressure difference** between **top** and **bottom** of submerged object (as pressure increases with depth).
- **Buoyancy is a very useful force**:
  - Ship floatation; cargo transport.
  - Balloon flights
  - Density determination (irregular shaped objects – Archimedes' original goal).