TOPIC 2— MECHANICS FOUNDATIONS:

- **Displacement**— A measured distance in a given direction— tells us not only the distance of an object from a particular reference point, but also the direction from the reference point— is a *vector.*
- **Velocity**— Is speed in a given direction, and is also a *vector*.
- **Acceleration**— is the rate of change of velocity in a given direction (velocity/time). The unit in SI is metres per second per second, or ms^{-2}. Is also a *vector*.

- Motion can be 'relative', ie. taken from a different reference point. The determination of speed, and also velocity and acceleration depends on what it is measured to.

- Speed and velocity can be both 'instantaneous' and 'average' Average is the speed taken over a certain time period, but Instantaneous is the speed taken at a certain point:

  $$v_{\text{av}} = \frac{\Delta s}{\Delta t}$$

  The instantaneous speed is given as the limit of this, or the derivative.

- Both displacement-time and velocity-time can be graphed— the area under a velocity-time graph is the displacement (when both positive and negative areas are graphed).

- Linear Motion with Constant Acceleration:
  There are 4 equations for this type of momentum:

  - $\boxed{\boldsymbol{v} = \boldsymbol{u} + \boldsymbol{a}t}$ — The definitions of accleration. If a body starts from rest then its speed after time t will be given by $v = at$. If its initial speed is u then this equation applies.

  - $\boxed{\boldsymbol{s} = \boldsymbol{u}t + \frac{1}{2}\boldsymbol{a}t^2}$ — The distance travelled is the area under the speed-time graph and the body starts from rest, then $s = \frac{1}{2}\ vt^2$. But if the body starts from speed u then we must add the area ut.

  - $\boxed{\boldsymbol{v}^2 = \boldsymbol{u}^2 + 2\boldsymbol{as}}$ — We can eliminate the time from the last equation by substituting in $t = \frac{v - u}{a}$. We eventually end up with this equation.

  - $\boxed{\boldsymbol{s} = \frac{(\boldsymbol{u} + \boldsymbol{v})}{2}t}$

- Acceleration due to free fall is called the *acceleration due to gravity.* It is denoted g in SI, and is usually given the value 9.8 ms^{-2}.

- Force and Mass:

- A **force** in physics is recognised by the effect or effect that it produces. It is some that can caused and object to:
    - deform, ie. change its shape.
    - speed up
    - slow down
    - change direction.

  Force is a vector. A force produces an acceleration.

- Mass and Weight— weight is the gravitational force , and depends on the acceleration due to gravity.

- Newton's First Law of Motion:

  'every object continues on a state of rest or uniform motion in a straight line unless acted upon by an external net force.'

  Equilibrium follows from Newton's First Law— that the sum of the forces is zero, which is expressed as $\sum F = 0$.

  Static Equilibrium is like a book resting on a table, the weight of the book (due to gravity) W, is equal to the normal force the table exerts on the book, N.

  Dynamic Equilibrium is like a book being pulled along a table with constant velocity, gravity and the normal reaction still act, but there is now also a frictional force F_{fr} acting which is equal in magnitude but opposite in direction to an applied force F_{A}.

- Newton's Second Law of Motion:

  'The acceleration of an object is directly proportional to the net force acting on it and is inversely proportional to its mass. The direction of the acceleration is in the directio of the net force acting on the object.'

  This can be summarised by the equation $\boldsymbol{F} = m\boldsymbol{a}$.

  The SI unit of force is the Newton, which is the force which produces an acceleration of 1 ms^{-2} for a mass of 1 kg.

- Newton's Third Law of Motion:

  'When a force acts on a particle an equal and opposite force acts on another particle somewhere in the universe.'

  eg. a book on a table— table force equal to book force.

Types of Forces:

- **Gravitational Force**— the force that gives rise to the weight of an object. Also this force acts between all particles in the Universe. Is the weakest of the four.
- **Weak-Interaction Force**— is 10^{26} times stronger than gravity. The interaction which is responsible for certain aspects of the radioactive decay of nuclei.
- **Electromagnetic Interaction Force**— 10^{37} times stronger than gravity. The force that exists between particles as a consequence of the electrical charge that they carry.
- **Strong Nuclear Interaction Force**— strongest of all four forces, is 10^{39} times stronger than gravity, and it is the force that holds protons and neutrons together in the nucleus.

Work, Energy & Power:

- $\boxed{W = Fd}$ — work related to the force and the distance moved.
- $\boxed{W = mgh}$ — work to move a mass a certain height, or up a slope.

- Potential Energy— the energy 'stored' in an object.

- If a force F (eg. on a spring) produces an extension x (beyond its natural length) then, $\boxed{F = kx}$, where k is the spring constant.

  The resulting elastic energy is given by $\boxed{E_{\text{elas}} = \frac{1}{2}ke^2}$

- Kinetic Energy:

- Kinetic Energy is given by $\boxed{E_{\text{k}} = \frac{1}{2}mv^2}$

- Forms & Transformations of Energy:

  - **Chemical Energy**— this is energy that is associated with the electronic structure of atoms, and is therefore associated with electromagnetic force. Examples include combustion, in which carbon combines with oxygen to produce *thermal energy, light energy* and *sound energy.*
  - **Nuclear Energy**— The energy associated with the nuclear structure of atoms and is therefore associated with the strong nuclear force. Examples include the splitting of nuclei of uranium, by neutrons thermal energy.
  - **Electrical energy**— energy associated with an electric current; eg. *thermal energy* and *chemical energy* can be used to boil water and produce steam; the *kinetic energy* and *thermal energy* are used to rotate magnets, where it produces electric current, then transformed into *thermal* and *light energy*, and *kinetic energy*.

Kinetic Energy Example:

'An object of mass 4.0 kg slides without friction down an inclined plane. If the plane makes an angle of 30º with the horizontal calculate the increase in speed of the object after it has travelled a distance if 2.0 m'.

The force down the plane is the component of the weight down the plane
= $mg\sin 30^\circ = 20$ N

The work done, W, is equal to $Fd = 20 \text{ x } 2.0 = 40$

This corresponds to the kinetic energy that the object has gained in travelling these two metres. Therefore:

$$E_k = \frac{1}{2} mv^2$$
$$= 40$$

Therefore,

$$v^2 = \frac{2 \text{ x } 40}{4}$$
$$= \sqrt{20}$$
$$\approx 4.5 \text{ ms}^{-1}.$$

Energy Conservation:

- In many examples, $E_K + E_P$ = constant, and energy is conserved.

- For example:
'An object of mass 4.0 kg, slides from rest without friction down an inclined plane. The plane makes an angle of 30º with horizontal and the object starts from a vertical height of 0.5 m. Find the speed of the object when it reaches the bottom of the plane.'

With Energy Principles:

The potential energy at the top is transformed into the kinetic energy at the bottom.

Therefore,

$$\Delta PE = \Delta KE$$
$$mgh = \frac{1}{2} mv^2$$
$$v^2 = 2\,gh$$

$v \quad = \sqrt{2\,g\,h}$
$\quad = 3.2 \text{ ms}^{-1}$.

With Kinematics:

The force down the plane is given by $mg \sin \theta = 20$ N

Using Newton's 2nd Law (F = ma), the acceleration is given as $a = \dfrac{20}{4.0} = 5 \text{ ms}^{-2}$.

Therefore:

$v^2 = u^2 + 2as$

$u = 0$

$s = \dfrac{0.5}{\sin\theta} = \dfrac{0.5}{\sin 30^{\circ}} = 1.0$

$v^2 = 0^2 + 2 \times 5 \times 1$

$v = \sqrt{10}$

$\approx 3.2 \text{ ms}^{-1}$.

- Power:
- We define power as the **rate of working**.
- $\boxed{\text{Power} = \dfrac{\text{Work}}{\text{Time}}}$
- The unit of power is called the **joule per second**, or the **watt** (W).
- $\boxed{\Delta W = F \, \Delta s}$
- $\boxed{P = F\,v}$

Projectile Motion:

- In projectile motion, the vertical and horizontal components of motion are taken independently. All projectile motion follows a parabolic path.

Example:

A particle is fired horizontally with a speed of 25 ms^{-1} from the top of a vertical cliff of height 80m. Find:

(a) The time of flight.
(b) The distance from the base of the cliff to where it strikes the ground;
(c) The velocity with which it strikes the ground.

(a) The vertical velocity with which it strikes the ground is found using:

$v^2 = u^2 + 2as$
$u = 0$
$a = g$
$s = 80\ (=h)$

$$v_y = \sqrt{2gh} = \overline{2 \text{ x } 10 \text{ x } 80}$$
$$= 40$$

The vertical velocity with which it strikes the ground is 40 ms^{-1}.
The time is therefore found using $v_y = u_y + gt$.

$$t = \frac{v_y}{g} = \frac{40}{10} = 4$$
$$= 4 \text{ seconds.}$$

(b) The distance travelled from the base of the cliff can be found using $s_x = u_x + a_x\, t$.

$s = ut$
$= 25 \text{ x } 4$
$= 100$ m.

The range is 100 m.

(c) This is found using the resultant of the vertical and horizontal components of the final velocity.

$$v = \sqrt{40^2 + 25^2} = 47 \text{ ms}^{-1}.$$

The angle to the horizontal is given by

$$\theta = \text{arc tan}\left(\frac{40}{25}\right)$$
$$= 68^{o} \text{ to the horizontal.}$$

Linear Momentum:

- Momentum— $\boxed{p = mv}$

- $$F_{net} = \frac{\Delta p}{\Delta t} = \frac{p_f - p_i}{\Delta t} = \frac{mv - mu}{\Delta t} = \frac{m(v-u)}{\Delta t} = \frac{m\Delta v}{\Delta t} = ma$$
- The change in momentum is called **impulse** and is given by $F\Delta t$.

- Momentum in collisions is always conserved:

$$m_1v_1 + m_2v_2 = m_1v_3 + m_2v_4$$

- In elastic collisions, kinetic energy is also conserved:

$$\frac{1}{2}m\,v_1^2 + \frac{1}{2}m\,u_2^2 = \frac{1}{2}m\,v_3^2 + \frac{1}{2}m\,v_4^2$$

Simple Harmonic Motion:

- There are many systems that use simple harmonic motion— eg. a simple pendulum, a cork pushed below the surface of water, then released, and the vibrations on a tuning fork.
- Simple Harmonic motion follows the cosine curve roughly. When the displacement of the motion is at the extremes, the force is at a maximum, as is the acceleration, but the velocity is zero. At the equilibrium position, the acceleration is zero as the force is zero, but the velocity is at its maximum.

Circular Motion:

- In circular motion, for example, a car going round a bend, the centripetal acceleration is directed towards the circle. The force is also directed towards this direction. The velocity is directed as a tangent to the movement of the object which is flying around.

TOPIC 3 — THERMAL PHYSICS

Thermal Energy/Moving Particle Theory/States of Matter:

- **Thermal energy** is the energy of particles which make up matter. It is also loosely called **heat**.
- An understanding of this is based on the **moving particle theory** or **kinetic theory** that uses models to explain the structure and nature of matter. The assumptions of this theory are:
  - All matter is composed of extremely small particles.
  - All particles are in constant motion.
  - If particles collide with neighbouring particles, they conserve kinetic energy.
  - A mutual attractive force exists between particles.
- The *atom* is the smallest neutral particles that represents an element. They contain protons, neutrons, and electrons, and other sub-atomic particles. All these are referred to as *particles* in physics.
- Brownian motion is evidence for the constant motion of particles, eg. pollen grains in water under a microscope (random zig-zag motion), or smoke cells in air. Motion becomes more vigorous as thermal energy increases with heating. Number of particles moving in all directions with a certain velocity is constant over time.

- Four states of matter— solid, liquid, gas, and plasma.
- **Plasma** is made by heating gas atoms and molecules to a sufficient temperature to cause them to ionise. The resulting plasma consists of some neutral particles but mostly positive ions and electrons, or other negative ions. The Sun, stars, and indeed most of our universe are composed of plasma.

Macroscopic Properties:

Characteristic	Solid	Liquid	Gas
Shape	Definite	Variable	Variable
Volume	Definite	Definite	Variable
Compressibility	Almost incompressible	Very slightly compressible	Highly compressible
Diffusion	Small	Slow	Fast
Comparative Density	High	High	Low

Macroscopic properties are observable behaviours of a material, such as those mentioned above. These can provide evidence for the nature and structure of a substance.

Microscopic Characteristics:

Characteristic	Solid	Liquid	Gas
Kinetic Energy	Vibrational	Vibrational Rotational Some translational	Mostly translational Higher rotational Higher vibrational
Potential Energy	High	Higher	Highest
Mean molecular Separation	r_0	R_0	$10r_0$
Thermal Energy of Particles	$< \frac{\varepsilon}{10}$	$< \varepsilon, > \frac{\varepsilon}{10}$	$> \varepsilon$
Molecules per m^3:	10^{28}	10^{28}	10^{25}

Microscopic characteristics explain what is happening at the atomic level.

Change of State:

A substance can undergo a change of state or a phase change, at different temperatures. Each substance has its own characteristic boiling and melting point, eg. Oxygen has a melting point of –218.8ºC and a boiling point of –183ºC at standard pressure. Benzene also has its own melting point (5.5ºC) and boiling point (80ºC):

> When solid benzene is heated the temperature begins to rise. When the temperature reaches 5.5ºC the benzene begins to melt. Although the heating continues the temperature of the solid–liquid benzene mixture remains constant until all the benzene has melted. Once all the benzene has melted the temperature starts to rise until the liquid begins to boil at a temperature of 80ºC. With continued heating the temperature remains constant until all the liquid benzene has been converted to a gaseous state. The temperature then continues to rise, as the gas is in a closed container.

- We can also explain the microscopic behaviour of phase changes using the moving particle theory.

Thermal Concepts: Thermal Energy and Heat:

Thermal energy is concerned with the total potential and kinetic energy associated with a group or system of particles.

Heat is the transfer of energy from a region of high temperature to a region of low temperature, and heating is the energy transfer process.
Temperature is at the microscopic level, the degree of hotness or coldness of a body as measured by a thermometer. It is measured in Degrees Kelvin. (K = ºC + 273)

Temperature is at the microscopic level, the measure of the **average kinetic energy per molecule** associated with its movements. For gases, it can be shown that

$$v^2 \propto T$$

Internal Energy:

Thermal energy of a system is referred to as **thermal energy**. It is the sum total of potential energy and kinetic energy of the particles making up the system.

The potential energy is due to:
- The energy stored in bonds called bond energy— a form of **chemical** potential energy.
- Intermolecular forces of attraction between particles.

The kinetic energy is due to, mainly, the translational, rotational, and vibrational motion of the particles.

Specific Heat Capacity, Specific Latent Heat and Heat Transmission:

Heat Capacity:

- When different substances undergo the same temperature change they can store or release different amounts of thermal energy. They have different heat capacities:
  - A substance with a *high* heat capacity will take in thermal energy at a slower rate than a substance with a *low* heat capacity, as it needs more time to absorb a greater quantity of thermal energy. It will also cool more slower.

- $$\textbf{Heat Capacity} = \frac{\Delta Q}{\Delta T} \text{ JK}^{-1}$$

ΔQ is the change in thermal energy in joules.
ΔT is the change in temperature in degrees Kelvin.

Specific Heat Capacity:

Heat capacity does not take into account the fact that different masses of the same substance can absorb or release different amounts of thermal energy.

Specific heat capacity is the heat capacity per unit mass. It is defined as the quantity of thermal energy required to raise the temperature of one kilogram of a substance by one degree Kelvin.

$\Delta Q = m\, c\, \Delta T$

DQ is the change in thermal energy required to produce a temperature change (J).
m is the mass of the material (kg)
D*T* is the temperature change (K)

Common specific heat capacities for substances at room temperature (except ice):

Substance	**Specific Heat ($J.kg^{-1}.K^{-1}$)**	**Substance**	**Specific Heat ($J.kg^{-1}.K^{-1}$)**
Lead	1.3×10^2	Iron	4.7×10^2
Mercury	1.4×10^2	Aluminium	9.1×10^2
Zinc	3.8×10^2	Sodium	1.23×10^3
Brass	3.8×10^2	Ice	2.1×10^3
Copper	3.85×10^2	Water	4.18×10^3

- Common methods to determine this: Calorimeter Method, Immersion Heater in Metal Block (Direct Methods), Method of Mixtures (Indirect Method).

- *Example: A block of mass 3.0 kg at a temperature of 90.0ºC is transferred to a calorimeter containing 2.00 kg of water at 20.0ºC. The mass of the calorimeter cup is 0.210 kg. What will be the final temperature of the water?*

  The thermal energy gained by the water and the calorimeter cup will be equal to the thermal energy lost by the copper.

  $[m\, c\, \Delta T]_{copper} = [m\, c\, \Delta T]_{calorimeter\ cup} + [m\, c\, \Delta T]_{cup}$

  Thermal energy lost by the copper = $(3.0\ kg)(3.85 \times 10^2\ Jkg^{-1}K^{-1})\ (90.0 - T_f)K$
  Thermal energy gained by the water = $(2.0\ kg)(4.18 \times 10^3\ Jkg^{-1}K^{-1})\ (20.0 - T_f)K$
  Thermal energy gained by the cup = $(0.21\ kg)(9.1 \times 10^2\ Jkg^{-1}K^{-1})\ (T_f - 20.0)K$

  Therefore,

  $1.04 \times 10^5 - 1.115 \times 10^3 T_f = (8.36 \times 10^3 T_f - 1.67 \times 10^5) + (1.91 \times 10^2 T_f - 3.82 \times 10^3)$

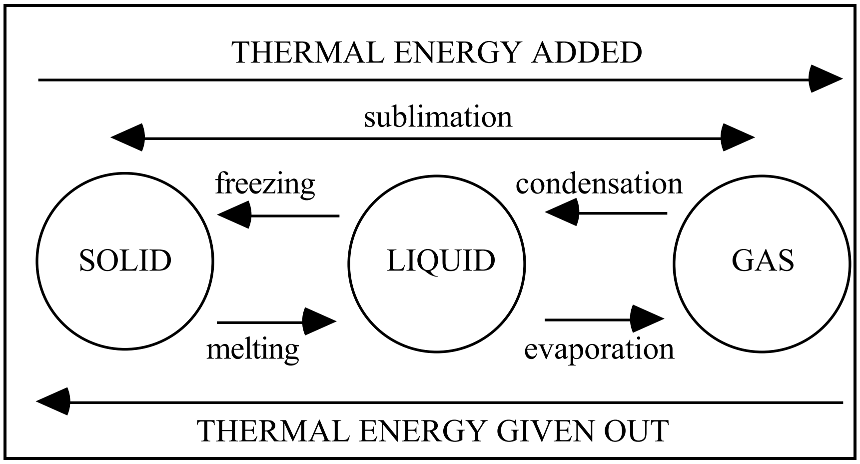
  $-9.67 \times 10^3 T_f = -2.75 \times 10^5$

$T_f = 28.4^{o}$ C.

Therefore the final temperature of the water is 28ºC.

Latent Heat:

Thermal energy which a particle absorbs in melting, evaporating or sublimating or given out in freezing, condensing or sublimating is called *latent heat* because it does not produce a change in temperature:



When thermal energy is absorbed/released by a body, the temperature may rise/fall, or it can remain constant. If the temperature remains constant then a phase change will occur as the thermal energy must either increase the potential energy of the particles as they move further apart or decrease the potential energy of the particles as the move closer together. If the temperature changes then the energy must increase the kinetic energy of the particles.

- The quantity of heat required to change one kilogram of a substance is called the *latent heat of transformation*.

$$\Delta Q = mL$$

<u>Common Latent Heats</u>:

Substance	Melting Point (K)	Latent Heat of Fusion ($\times 10^5$ Jkg^{-1})	Boiling Point (K)	Latent Heat of Vaporisation ($\times 10^5$ Jkg^{-1})
Oxygen	55	0.14	90	2.1
Ethanol	159	1.05	351	8.7
Lead	600	0.25	1893	7.3
Copper	1356	1.8	2573	73
Water	273	3.34	373	22.5

Methods of Heat Transfer:

- **Thermal Conduction**— the process in which a temperature difference causes the transfer of thermal energy from the hotter region of the body to the colder region by particle collision without there being any net movement of the substance itself.

- **Thermal Convection**— the process in which a temperature difference causes the mass movement of fluid particles from areas of high thermal energy to areas of low thermal energy (the colder region).

- **Thermal Radiation**— energy produced by a source because of its temperature that travels as electromagnetic waves. It does not need the presence of matter for its transfer.

Thermal Conductivity

- Thermal conductivity is a measure of how well a material will conduct heat. It provides a way of comparing the rates of flow of heat in different materials.

Thermal Conductivity of Conductors and Insulators:

Substance	**Thermal Conductivity $W.m^{-1}.K^{-1}$**	**Substance**	**Thermal Conductivity $W.m^{-1}.K^{-1}$**
Silver	418	Window Glass	1.1
Copper	385	Brick	0.84
Aluminium	238	Water	0.56
Steel	40	Rubber	0.2
Iron	80	Asbestos	0.16
Lead	38	Wood	0.18–0.16
Mercury	8	Air	0.023

- We define Thermal Conductivity as the following:

$$\frac{\Delta Q}{\Delta t} = -k.\ A.\ \frac{\Delta T}{\Delta x}$$

ΔQ is the rate of flow of thermal energy from the hotter to the colder face (W)
k is the constant of proportionality called the thermal conductivity of the material.
$\frac{\Delta T}{\Delta x}$ is the temperature gradient across the object (Km^{-1})
A is the cross-sectional area of the object (m^2)

Therefore $\frac{\Delta Q}{\Delta t}$ is proportional to $\frac{\Delta T}{\Delta x}$ the temperature gradient.

Thermal Properties of Gases:

- Pressure measured in atmospheres, Pascals, millimetres of Mercury, etc.
  1 atm = 1.01 x 10^5 Nm^{-2} = 101.3 kPa = 760 mmHg.

- Avogadro's Law— equal volumes of gases at the same temperature and pressure contained the same number of particles. One mole of any gas contains the Avogadro number of particles N_A. One mole of a gas occupies 22.4 dm^3 at 0ºC and 101.3 kPa pressure (STP) and contains 6.02 x 10^{23} particles.

- Boyle's Law: the pressure of a gas at constant temperature is proportional to its volume.
  $$P_1V_1 = P_2V_2$$

- Charles' or Gay-Lussac's Law— the volume of a fixed mass of gas at constant pressure is directly proportioanl to its absolute (Kelvin) temperature. The volume of a fixed mass of gas increases by $\frac{1}{273}$ of its volume at 0ºC for every degree rise in temperature provided the pressure is constant.
  $$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

- The Pressure (Admonton) Law— the pressure of a fixed mass of gas at constant pressure is directly proportioanl to its absolute (Kelvin) temperature. The volume of a fixed mass of gas increases by $\frac{1}{273}$ of its pressure at 0ºC for every degree rise in temperature provided the volume is constant.
  $$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

- The Combined Gas Law— this is a combination of the above 3 laws:
  $$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

- The Ideal Gas Equation— this combines the above equations, and Avogadro's Law:
  $$PV = nRT$$
  R is the universal gas constant = 8.31 J. mol^{-1}. K^{-1}.

Real and Ideal Gases:

- An *ideal* gas is one that obeys the gas laws and fits the ideal gas equation exactly.

- A *real* gas conforms to the laws under certain limited conditions but can condense to liquids, then solidify if the temperature is lowered.
- *Real* gases have relatively small forces of attraction between particles.
- This is not allowable for an *ideal* gas.

The Kinetic Theory of Gases:

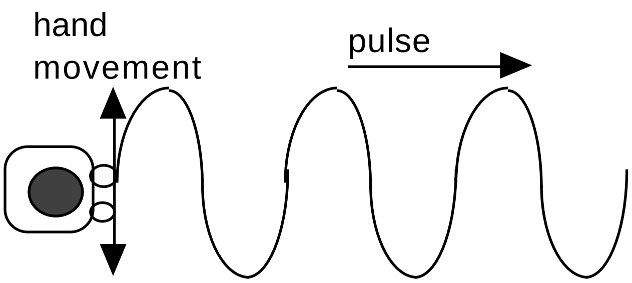
- This is the moving particle theory applied to gases. Relates the macroscopic behaviour of an ideal gas to the microscopic behaviour of its molecule.
- Assumptions/Postulates are:
    - Gases consist of identical tiny particles called atoms (for monatomic gases such as neon or argon) or molecules.
    - The total number of molecules in any sample of gas is extremely large.
    - The molecules are in constant random motion.
    - The range of the intermolecular forces is small compared to the average separation of the molecules.
    - The size of the particles is relatively small compared with the distance between them.
    - Collisions of a short duration occur between molecules and the walls of the container and the collisions are perfectly elastic.
    - No forces act between particles except when they collide, and hence particles move in straight lines.
    - Between collisions the molecules move with constant velocity, and obey Newton's Laws of Motion.

- Based on these postulates is the view of an ideal gas with molecules moving with random straight line paths at constant speeds until they collide with the sides of the container or with one another. Their paths over time are therefore zigzags. Because the gas molecules can move freely and are relatively far apart, they occupy the total volume of the container.
- Pressure molecules exert is due to collisions with sides of container.
- Temperature is a measure of the average kinetic energy per molecule. With a temperature increase, the collisions increase, and therefore the pressure.
- When volume is decreased, molecules take up a smaller volume, and hence are more frequent, thus leading to an increase in pressure.

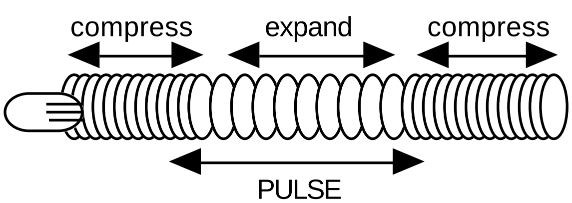
TOPIC 4 — Waves:

Types of Waves:

1 Transverse:
The source that produces the waves vibrates at right angles to the direction of travel of the wave. Particles of the medium through which the wave travels also vibrate at right angles to the direction of travel of the wave.



2 Longitudinal:
The source that produces the waves vibrates in the same direction as the direction of travel of the wave, as do the particles of the medium through which the wave travels.



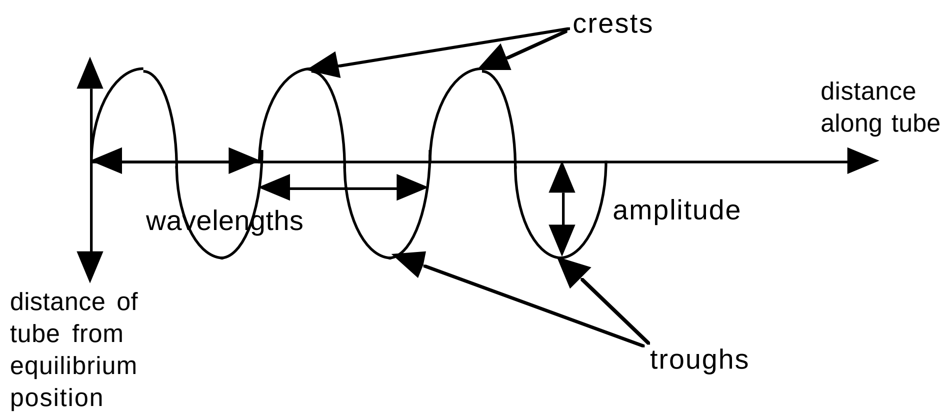
Transformation of Energy:

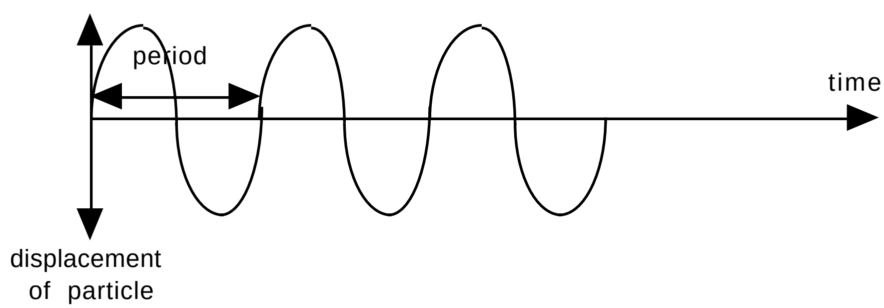
- A wave is a means by which energy is transferred between two points in a medium without net transfer of the medium itself.
- Energy is carried, not the medium, eg. a wave on a lake does not transport water, even though the water can be carried by the wind.

Terminology:

- Amplitude (*A*,*a*)— the maximum displacement of a particle from its equilibrium position. Also equal to the maximum displacement of the source.
- Period (*T*)— The time it takes for a particle to complete one complete oscillation (this also applies for the source).
- Frequency (*f*)— Number of oscillations per second by the particle (also the source). The frequency is the inverse of the period, ie. $f = \frac{1}{T}$.

- Wavelength (λ)— distance along the medium between two successive particles with the same displacement. Is equal to the distance between successive troughs and crests.
- Wave Speed (v,c)— The speed with which energy is carried in the medium by the wave— it depends on only the nature and properties of the medium.
- Crest— the maximum height of a wave.
- Trough— the minimum height of a wave.
- Compression— in longitudinal waves, refers to a region where particles are 'bunched up'.
- Rarefaction— in longitudinal waves, refers to region where particles are 'stretched out'.





- The relationship between wavelength, frequency and wave speed is found the following way:

$$\text{Speed } v = \frac{\text{distance}}{\text{time}} = \frac{\frac{\lambda}{2}}{\frac{T}{2}} = \frac{\lambda}{T} \times \frac{2}{2} = \frac{\lambda}{T}, \text{ but as } f = \frac{1}{T} \text{ then } \boxed{v = f\lambda}.$$

The frequency of a wave is determined by its source. Wave speed is determined by the properties of the medium in which the wave travels.

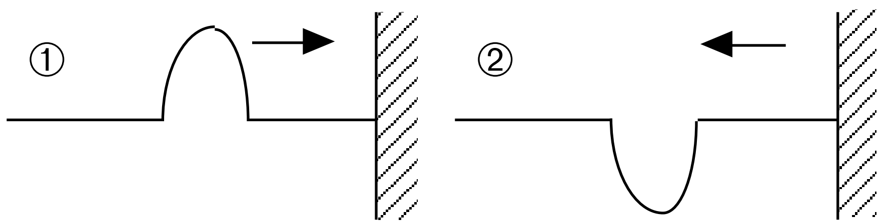
Electromagnetic Waves:

- Are transverse waves.
- Can all travel in a vacuum.
- Travel at the same speed in a vacuum, ie. $c = 3.0 \times 10^8$ ms^{-1}.

Order of frequency of waves (from lowest to highest): Radio Waves, Microwaves, Infra-red, Visible Light (including white light), Ultra-Violet, X-Rays, γ-Rays.

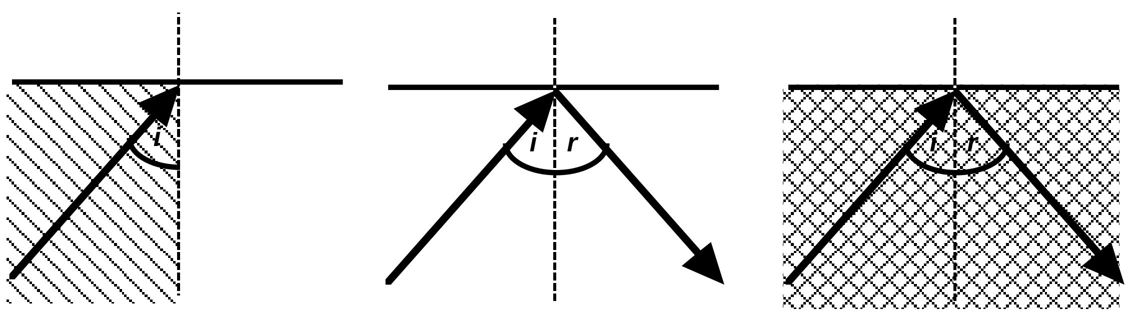
Reflections:

One Dimension:



- The pulse keeps its shape, but is inverted, like a positive & negative sine curve. The curves undergo a 180º change in phase (or a π change in phase).

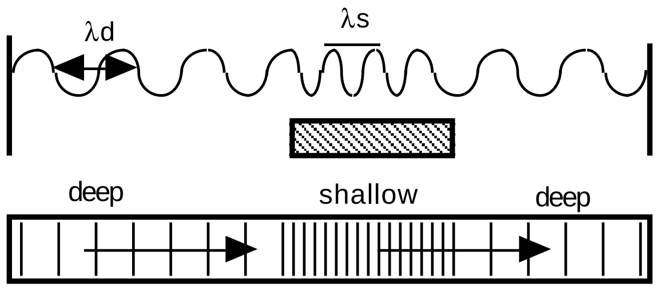
Two Dimensions:



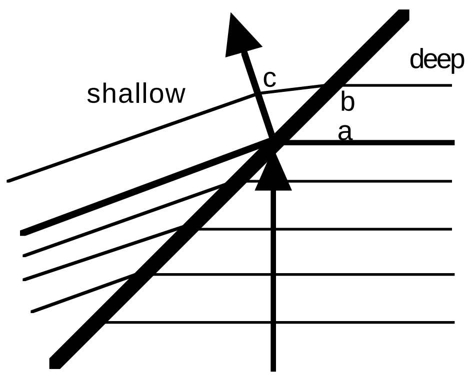
- Angle of Incidence = Angle of Reflection

Refraction of Waves:

Perspex Sheet in Ripple Tank Experiment:



- $\dfrac{v_d}{v_s} = \dfrac{\lambda_d}{\lambda_s}$



— 2 Dimensions

The wavelength is smaller in the shallow water, and the direction of travel of wavefronts also alters. For example, by the time part *a* of the wavefront reaches part *b*, the refracted wave will have reached part *c*, since it is travelling more slowly.

This is also seen in light rays. They travel more slowly in water/glass than in air. For example a coin on the floor of a pool will appear to be further out in the pool and further up than it actually is.

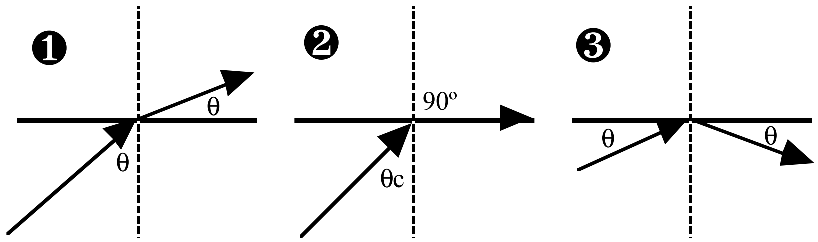
Snell's Law:

- $n_1 \sin \theta_1 = n_2 \sin \theta_2$

We also have that $\dfrac{\sin \theta_1}{\sin \theta_2} = \dfrac{c_1}{c_2}$ and $n = \dfrac{c}{v}$

$c = 3.0 \times 10^8$ ms^{-1}.

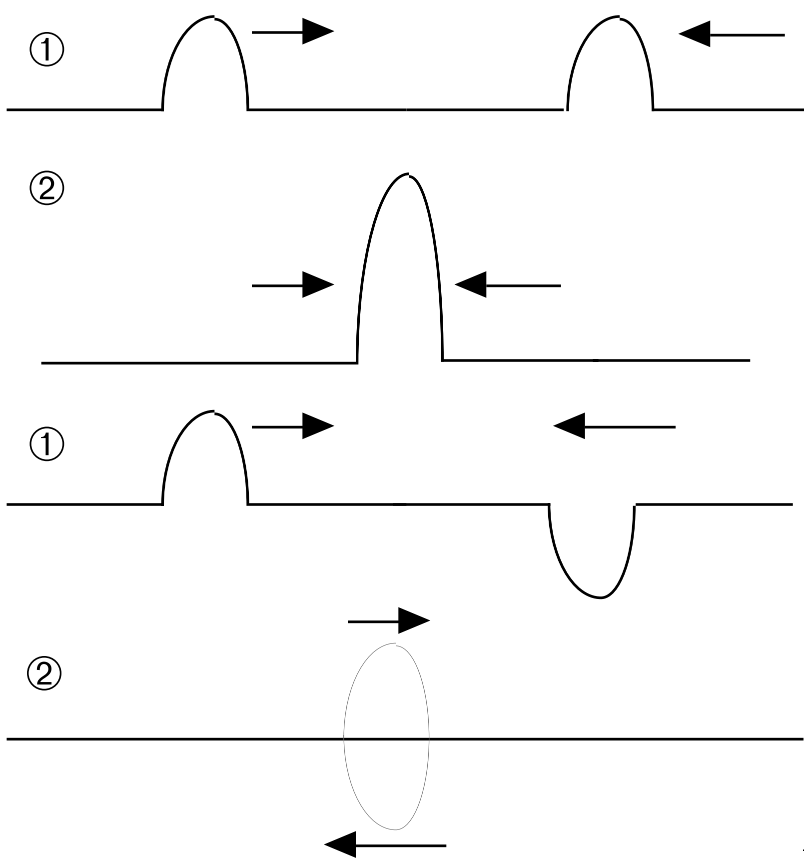
Critical Angle:



- $\sin \theta_c = \frac{n_2}{n_1} \sin 90^{\circ} = \frac{n_2}{n_1}$

Linear Superposition— Constructive & Destructive Interference:

- Linear superposition can be seen where two waves overlap. To find the effect of 2 causes together, one needs to examine the effect of each cause.



— Constructive

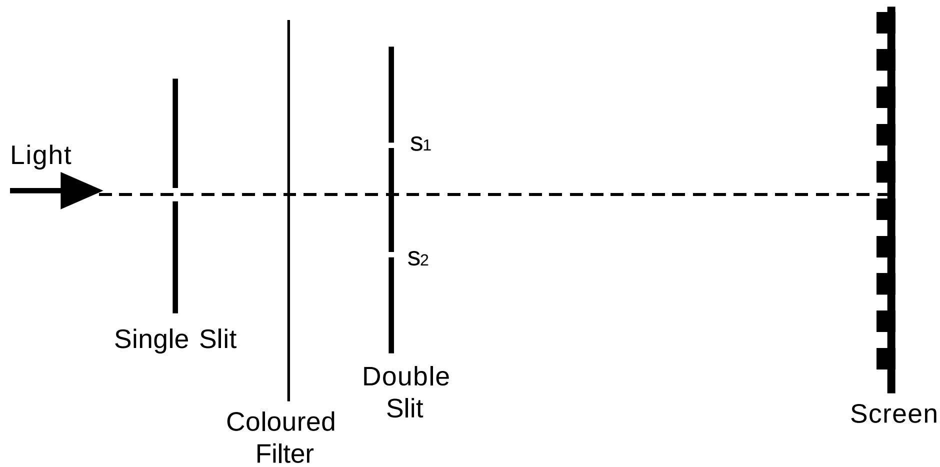
— Destructive

- If waves are in phase (eg. $y = \sin q$ & $y = \sin (q + \pi)$), they give complete constructive interference.

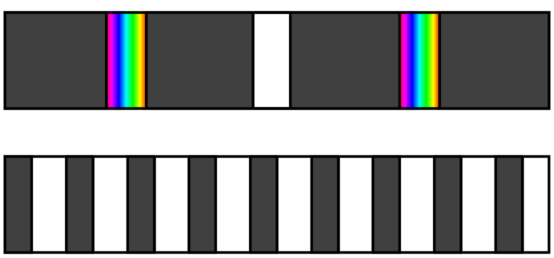
- If waves are out of phase (ie. by π), they give complete destructive interference.

Young's Double Slit Experiment:

- Young's Experiment is one of the greatest experiments in physics and did much to reinforce the wave theory of light. It was set up as below.



Sunlight was allowed to fall on a narrow single slit. A few centimetres away he placed a double slit. The screen was placed a metre from the slits. Young then observed a pattern of multicoloured 'fringes' on the screen. When a multicoloured filter was placed between the single and double slits a pattern consisting of bright coloured fringes separated by darkness was observed:


Patterns for White and Monochromatic Light

The single slit ensures that the light falling on the double slit is coherent. The light waves from each slit then interfere and produce the interference pattern on the screen. Without the filter a pattern is formed for every wavelength present in the sunlight. Hence the multi-coloured fringe pattern. The brightest constructive interference is found in the middle of the screen.

The Formation of Beats:

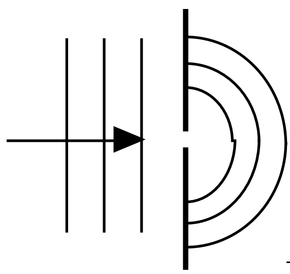
- This is another example of the interference of waves. It is done by adding together two waves of nearly the same frequency (see diagram, p. 299, IB Text). The resulting wave has regularly spaced minima. These minima are known as 'beats'. The 'beat frequency' is equal to the difference of the two separate sources f_1 and f_2:

- $f_{beat} = |f_1 - f_2|$

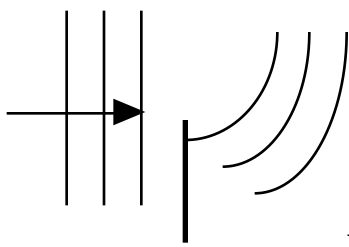
- This can be found in several ways, eg. when tuning a piano. The note is in tune when there are no beats between the tuning fork sound and the piano note.

Diffraction:

- When waves pass through a slit or any aperture and pass the edge of a barrier they always spread out to some extent into the region not directly in the path of the waves. This is called *diffraction.* It is shown clearly in a ripple tank:



— Diffraction through an Aperture.



— Diffraction on the edge of a barrier.

There are many other examples, for example sound waves being picked up behind a barrier, or looking at a tungsten filament lamp or laser through a narrow slit.

- The larger the aperture, the less effect there is on the diffraction of the waves. This is why Young's experiment used very narrow slits, because only at very small apertures can the effect be seen.

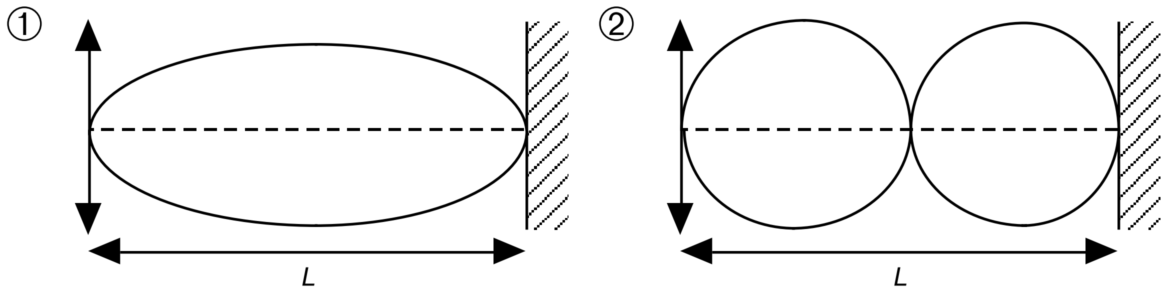
Polarisation:

- A wave travelling along a string is said to be polarised, as its vibrations only occur in one dimension. Three-dimensional waves vibrate in an infinite number of planes and are said to be unpolarised. But this can be resolved, and we can say that polarisation only occurs with transverse wave motion.
- Certain materials can block transmission of certain planes of vibration— these are called *polarises.* Two polarises can be used (vertical and horizontal) to completely block off light.

- Reflection of light is usually partial polarisation— eg. polaroid sunglasses.

Standing Waves:

- If we vibrate waves (eg. rubber tube or slinky spring) at a certain frequency, the wave takes a shape that does not seem to move. These are called *standing waves*:



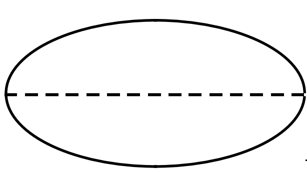
- In the case for diagram 1, $f = \frac{v}{2L}$ where L is the length of the tube. For diagram 2, the frequency is $f = \frac{v}{L}$.
- There are always nodal points on standing waves. This is where there is no movement at all in the string. Antinodes (points of maximum displacement) will oscillate back and forth

Resonance:

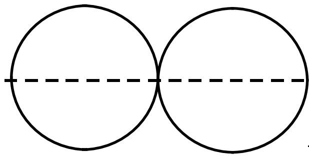
- When we push a swing and leave it to its own devices to keep swinging, it is swinging at its *natural frequency*. Our pushing maintains oscillation and reinforces the amplitude of oscillation. It is an example of resonance. When an oscillatory system is driven by a driving force that has a frequency equal to the natural frequency of oscillation of the system, the system will *resonate.*
- We find this in many different situations, eg. radio and television, driving a car on a bumpy road.

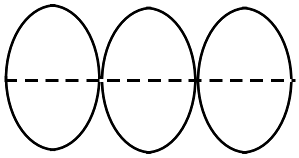
Resonance and Standing Waves:

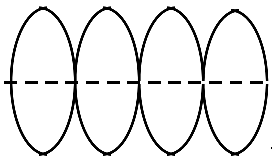
- If a wire is plucked in the middle, then we actually set up a standing wave. The travelling waves are reflected back and forth from the end of the wire, and interfere to cause standing waves. The first four harmonics, or modes of vibration, are shown:



— 1st Harmonic (Fundamental)


— 2nd harmonic


— 3rd Harmonic

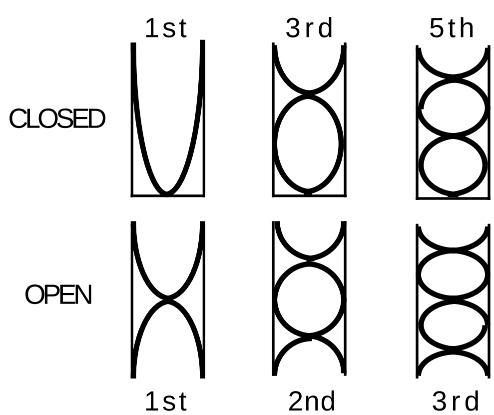

— 4th Harmonic

- The first harmonic is called the *fundamental*, is the dominant vibration and will in fact be the one the ear will hear above all the others. The diagrams show part of what is called a *harmonic series.* Different fundamentals can be obtained by pinching the string along its length and then by plucking it or altering its tensions. Also, on a violim, different notes are found by holding the string down at different places and then bowing it.

- If a strecthed string is vibrated to a frequency equal to the fundamental frequency or one of the harmonics then we set up the standing wave, using the phenomenon of frequency. There are an infinite number of natural frequencies of oscillations, each corresponding to a standing wave.

- Resonance is seen in sound pipes. The air molecules are set vibrating, the sound wave travels to the bottom of the pipe, and is reflected back and then again reflected when it reaches the open end. The waves interfere to produce a standing wave. However they do not undergo a phase change, so there is always an antinode at the open end of the pipe.

- Harmonics for Open and Closed Pipes are shown below:



- Pipes with open and closed ends produce different harmonics even though they are the same dimensions. They have a different harmonic series. A pipe open at one end can only produce odd harmonics.
- This is essentially the way in which organs, brass instruments, and woodwind instruments produce musical sounds.