Physics (9702) - AS Level

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1. Physical Quantities and Units

1.1. Physical Quantities

- All physical quantities consist of a numerical magnitude and a unit:

Estimating Physical Quantities

Quantity	Estimate
Height of an Adult Human	$2\,m$
The mass of an adult human	$70\,kg$
Mass of a car	$1000\ kg$
Power of a lightbulb	$60\ W$
Speed of sound in air	$330 ms^{-1}$
Speed of a car on the motorway	$30 ms^{-1}$
Weight of an apple	$1\,N$
Density of water	$1000 kgm^{-3}$
Time taken for a sprinter to run 100m	$10 s$
Current in a domestic appliance	$13 A$
E.M.F of a car battery	$12 V$
Atmospheric pressure	$1.0 \times 10^5 Pa$
Young's modulus of a given material	Something $\times 10^{11}$

1.2. SI Units

Quantity	Base Unit
Mass (m)	Kilogram (kg)
Length (l)	Meter (m)
Time (t)	Second (s)
Temperature (T)	Kelvin (K)
Electric Current (I)	Ampere (A)

- All units (excluding those above) can be broken down into the base units
- Homogeneity can be used to prove equations.
- An equation is homogenous if base units on the left side are the same as those on the right side.

Multiples

Multiple	Prefix	Symbol
10^{12}	Tera	(T)
10^{9}	Giga	(G)
10^{6}	Mega	(M)
10^{3}	Kilo	(k)

Sub-Multiples

Sub-multiple	Prefix	Symbol
10^{-3}	Milli	(m)
10^{-6}	Micro	(μ)
10^{-9}	Nano	(n)
10^{-12}	Pico	(p)

1.3. Errors and Uncertainties

- Systematic Errors:
  - Constant error in one direction: too big or too small
  - Errors made by instruments used and wrong techniques
  - It cannot be eliminated by repeating or averaging
  - If systematic error is small, measurement is accurate
  - Accuracy: the degree of agreement between the result of a measurement and the true value of quantity.
- Random Errors:
  - Random fluctuations or scatter about a true value
  - Caused by the observers and environmental techniques
  - This can be reduced by repeating and averaging
  - When random error is small, measurement is precise
  - Precision: the degree of agreement of repeated measurements of the same quantity (regardless of whether it is close to the true value or not)

Calculations Involving Errors

For a quantity $x = (5.0 \pm 0.2) mm$

- Absolute Uncertainty $\Delta x = \pm 0.2 mm$
- Fractional Uncertainty $\frac{\Delta x}{x} = 0.04$
- Percentage Uncertainty $= \frac{\Delta x}{x} \times 100\% = 4\%$
- Combining errors:
  - When values are added or subtracted, add absolute error

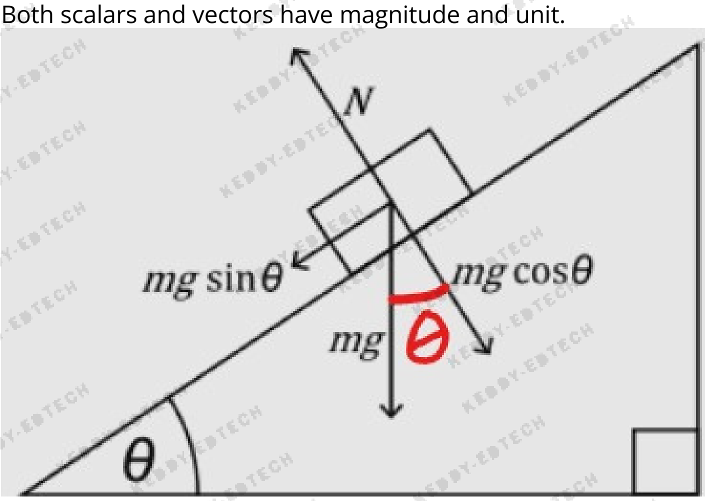
    If $p = 2x + y$ or $p = \frac{2x - y}{3}$, then $\Delta p = 2\Delta x + \Delta y$ or $\Delta p = \frac{2\Delta x + \Delta y}{3}$
  - When values are multiplied or divided, add % errors
  - When values are raised to a certain power (e.g., squared), multiply the percentage error by the power

    If $r = 2xy^3$, then $\frac{\Delta r}{r} = \frac{\Delta x}{x} + 3\frac{\Delta y}{y}$

1.4. Scalars and Vectors

- Scalar: has magnitude only, cannot have direction
  e.g., speed, energy, power, work, mass, distance
- Vector: has magnitude and direction
  e.g., displacement, acceleration, force, velocity, momentum, weight, electric field strength

Both scalars and vectors have magnitude and unit.



- A force vector can be split into its vertical and horizontal components, which are independent.
- Pythagoras theorem ($a^2+b^2=c^2$) and vector parallelograms can add coplanar vectors.

2. Kinematics

2.1. Kinematics Concepts

- Distance: total length moved irrespective of direction
- Displacement: shortest distance in a certain direction
- Speed: distance traveled per unit of time, no direction
- Velocity: the rate of change of displacement
- Acceleration: the rate of change of velocity

2.2. Equations of Motions

$s = ut + \frac{1}{2}at^2$

$v = u + at$

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

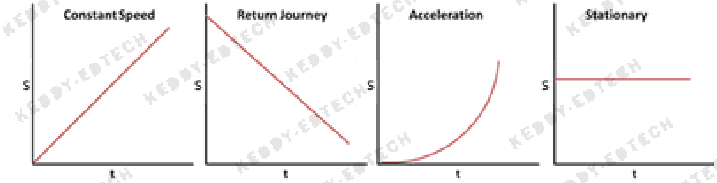
$s = \frac{(v_1 + v_2)}{2} \times t$

$s = vt - \frac{1}{2}at^2$

2.3. Linear Motion

- Distance: total length moved irrespective of direction
- Displacement: distance in a certain direction
- Speed: distance traveled per unit of time, no direction
- Velocity: the rate of change of displacement
- Acceleration: the rate of change of velocity

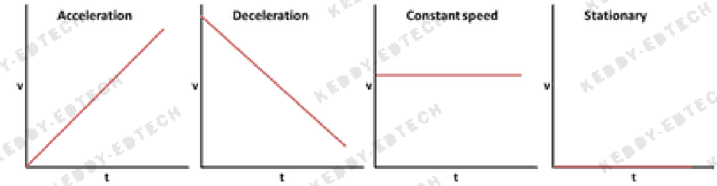
- Displacement-time graph:
  - Gradient = velocity



2.4. Non-Linear Motion

Velocity-time graph:

- Gradient = acceleration
- The area under graph = change in displacement



Uniform acceleration and straight-line motion equations:

$v = u + at$

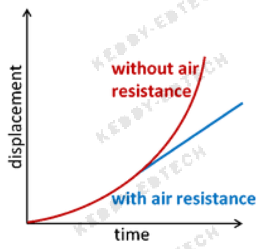
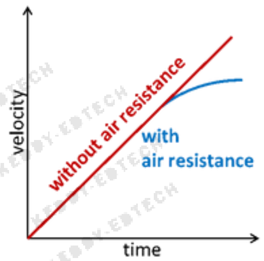
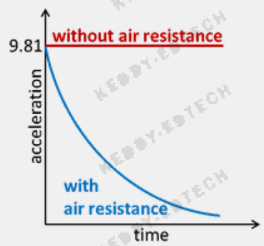
$s = ut + \frac{1}{2}at^2 = vt - \frac{1}{2}at^2$

$s = \frac{1}{2}(u + v)t$

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

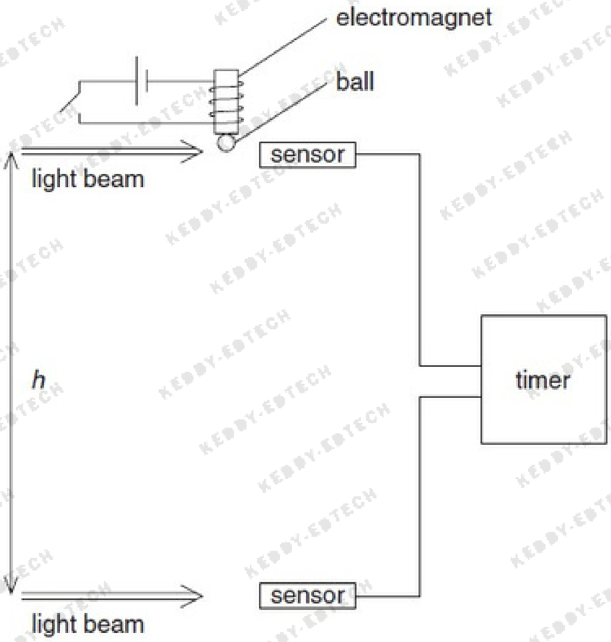
- Acceleration of free fall = $9.81 ms^{-2}$

2.5. Motion of Freefalling Bodies

Displacement	Continues to curve as it accelerates	
	Graph levels off as it reaches terminal velocity	
Velocity	Continues to accelerate constantly	
	Graph curves as it decelerates and levels off to terminal velocity	
Acceleration	Straight line	
	Graph curves down to zero because the resultant force equals zero	

2.6. Determining Acceleration of Free Fall

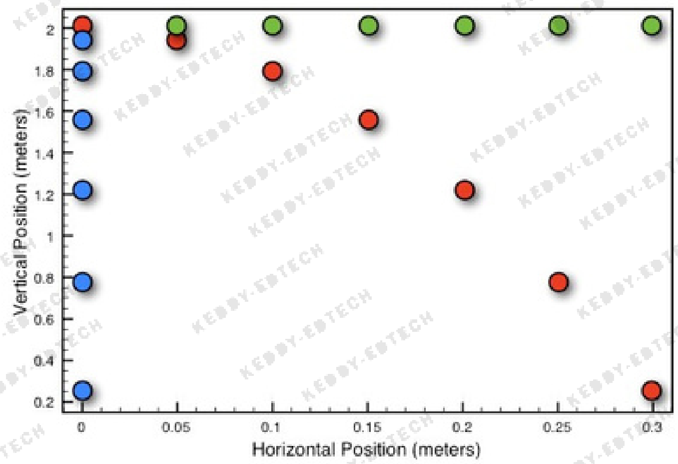
- A steel ball is held on an electromagnet.
- When the electromagnet is switched off, the ball interrupts a light beam, and a timer starts.
- As the ball falls, it interrupts a second beam of light & timer stopped
- Vertical distance h is plotted against $t2$



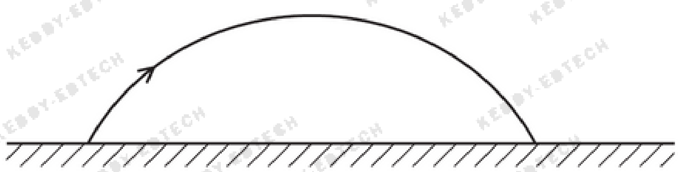
$s = ut + \frac{1}{2}at^2$ and $u = 0$; $s = \frac{1}{2}at^2$ i.e $h = \frac{1}{2}gt^2$

2.7. Projectile motion

Projectile motion: uniform velocity in one direction and constant acceleration in perpendicular direction

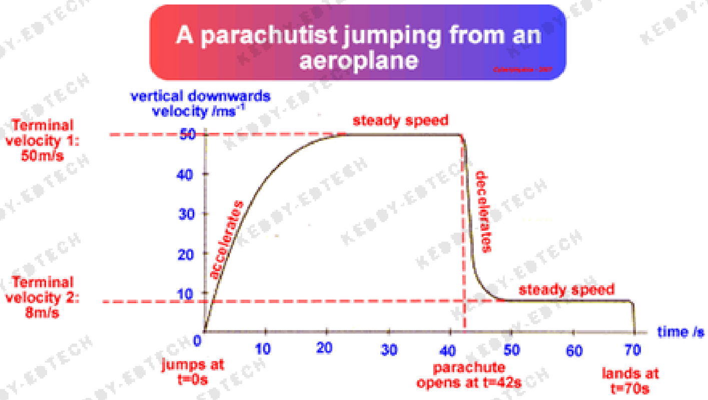


- Horizontal motion = constant velocity (speed at which projectile is thrown)
- Vertical motion = constant acceleration (caused by the weight of the object, constant free fall acceleration)
- Curved path – parabolic ($y \propto x2$)



		Component of Velocity
	Horizontal	Vertical
Without air Resistance	Constant	Increases at a constant rate
With Air resistance	Decreases to zero	Increases to a constant value

2.8. Motion of a Skydiver



3. Dynamics

3.1. Newton's Laws of Motion

- First Law: if a body is at rest, it remains at rest, or if it is in motion, it moves with a uniform velocity until it is acted on by resultant force or torque
- Second Law: the rate of change of momentum of a body is proportional to the resultant force and occurs in the direction of force; $F=ma$
- Third Law: if a body *A* exerts a force on a body *B*, then body *B* exerts an equal but opposite force on body *A*, forming an action-reaction pair

3.2. Momentum

- Linear Momentum: product of mass and velocity

$p = mv$

- Force: rateof change of momentum

$F = \frac{mv - mu}{t}$

- PrincipleofConservation of Linear Momentum: when bodies inasystem interact, total momentum remains constant,provided no external force acts on the system.

$m_A u_A + m_B u_B = m_A v_A + m_B v_B$

3.3. Mass and Weight

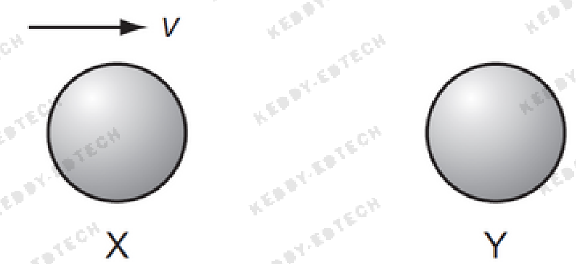
Mass	Weight
Measured in kilograms	Measured in Newtons
Scalar quantity	Vector quantity
Constant throughout the universe	Not constant
	$W = mg$

- Mass: is a measure of the amount of matter in a body, & is the property of a body that resists change in motion.
- Weight: is the force of gravitational attraction (exerted by the Earth) on a body.

3.4. Elastic Collisions

- Total momentum conserved
- Total kinetic energy is conserved

Example: Two identical spheres collide elastically. Initially, X is moving with speed *v* and Y is stationary. What happens after the collision?



X stops and Y moves with speed v:

(relative velocity before collision) = (relative velocity after collisions)

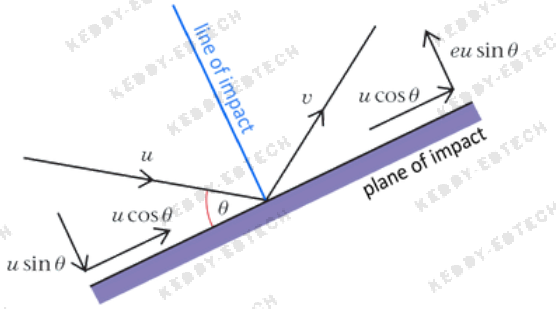
$u_A - u_B = v_B - v_A$

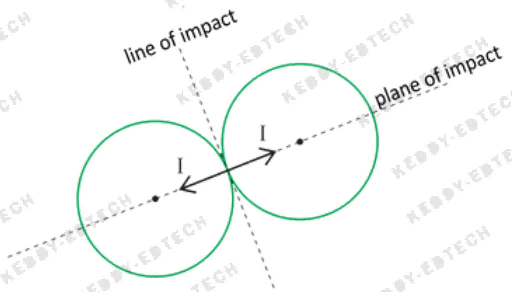
3.5. Inelastic Collisions

relative speed of approach > relative speed of separation

- Total momentum is conserved
- Total kinetic energy is not conserved
- Perfectly inelastic collision: only momentum is conserved, and the particles stick together after collision (i.e. move with the same velocity)
- In inelastic collisions, total energy is conserved but *Ek* may be converted into other forms of energy e.g. heat

3.6. Collisions in Two Dimensions



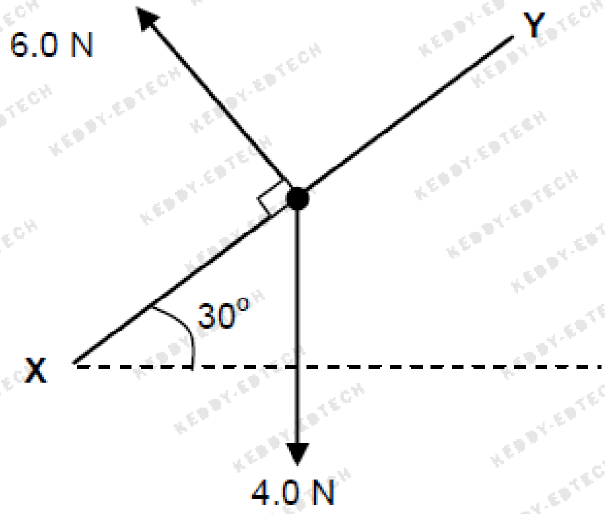


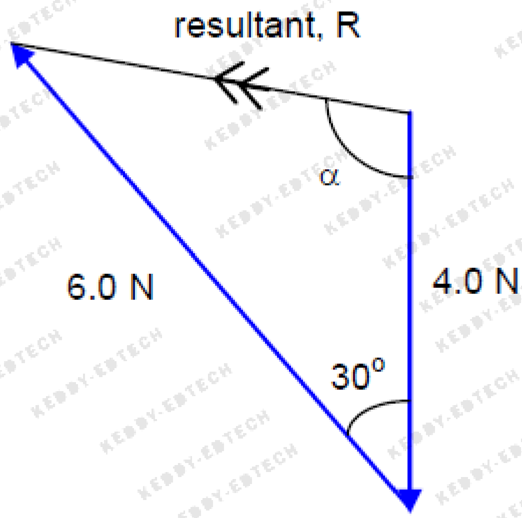
- Change in momentum (impulse) affecting each sphere acts along line of impact
- Law of conservation of momentum applies along line of impact
- Components of velocities of spheres along plane of impact unchanged
- Note the direction of the velocities when calculating

4. Forces, Density, and Pressure

4.1. Introduction

- Force: rate of change of momentum
- Density: mass per unit of volume of a substance
- Pressure: force per unit area
- Finding resultant (nose to tail):
  - By accurate scale drawing
  - Using trigonometry





- Forces on masses in gravitational fields: a region of space in which a mass experiences an (attractive) force due to the presence of another mass.
- Forces on charge in electric fields: a region of space where a charge experiences an (attractive or repulsive) force due to the presence of another charge.
- Upthrust: an upward force exerted by a fluid on a submerged or floating object
- Origin of Upthrust:

  Pressure on Bottom Surface > Pressure on Top Surface

  ∴ Force on Bottom Surface > Force on Top Surface

  ⇒ Resultant force upwards
- Frictional force: force that arises when two surfaces rub
  - Always opposes relative or attempted motion
  - Always acts along a surface
  - Value varies up to a maximum value

- Viscous forces:
  - A force that opposes the motion of an object in a fluid;
  - Only exists when there is motion.
  - Its magnitude increases with the speed of the object
- Centre of gravity: point through which the entire weight of the object may be considered to act
- Couple: a pair of forces which produce rotation only
- To form a couple:
  - Equal in magnitude
  - Parallel but in opposite directions
  - Separated by a distance *d*
- Moment of a Force: product of the force and the perpendicular distance of its line of action to the pivot

$Moment = Force \times \perp Distance\ from\ Pivot$

- Torque of a Couple: the product of one of the forces of the couple and the perpendicular distance between the lines of action of the forces.

$Torque = Force \times \perp Distance\ between\ Forces$

- Conditions for Equilibrium:
  - The resultant force acting on it in any direction equals zero.
  - The resultant torque about any point is zero.
- Principle of Moments: for a body to be in equilibrium, the sum of all the anticlockwise moments about any point must be equal to the sum of all the clockwise moments about that same point.

4.2. Pressure in Fluids

- Fluids refer to both liquids and gases
- Particles are free to move and have EK ∴ they collide with each other and the container. This exerts a small force over a small area causing pressure to form.

Derivation of Pressure in Fluids

Volume of water = $A \times h$

Mass of Water = $density \times volume = \rho \times A \times h$

Weight of Water = $mass \times g = \rho \times A \times h \times g$

Pressure = $\frac{Force}{Area} = \frac{\rho \times A \times h \times g}{A} = \rho gh$

5. Work, Energy, Power

5.1. Energy Conservation

- Law of Conservation of Energy: the total energy of an isolated system cannot change—it is conserved over time. Energy can be neither created nor destroyed but can change form, e.g. from g.p.e to k.e

5.2. Work Done

- Work done by a force: the product of the force and displacement in the direction of the force

  W= Fs

5.3. Gravitational, Elastic and Electric Potential Energy

- Gravitational Potential Energy:
  - Energy possessed by a mass due to its position in the gravitational field
  - Arises in a system of masses where there are attractive gravitational forces between them.
- Elastic potential energy:
  - Energy stored in a body due to a change in its shape
  - Arises in a system of atoms where there are attractive / repulsive short-range inter-atomic forces between them
- Electric potential energy:
  - Arises in a system of charges where there are attractive / repulsive electric forces between them

5.4. Deriving Gravitational Potential Energy

$W = Fs$ & $w = mg = F$

$\therefore W = mg.s$

s in direction of force = h above ground

$\therefore W = mgh$

5.5. Deriving Kinetic Energy

$W = Fs$ & $F = ma$

$\therefore W = mas$

$v^2 = u^2 + 2as \Rightarrow as = \frac{1}{2}(v^2 - u^2)$

$\therefore W = m\frac{1}{2}(v^2 - u^2)$

$\therefore W = \frac{1}{2}mv^2$

5.6. Internal Energy

- Internal energy: sum of the K.E. of molecules due to its random motion & the P.E. of the molecules due to the intermolecular forces.

- Gases: $k.e. > p.e.$
  - Molecules far apart and in continuous motion = $k.e$
  - Weak intermolecular forces so very little p.e.
- Liquids: $k.e. \approx p.e.$
  - Molecules able to slide to past each other ke
  - Intermolecular force present and keep shape = $p.e.$
- Solids: $k.e. < p.e.$
  - Molecules can only vibrate ∴ $k.e.$ very little
  - Strong intermolecular forces $p.e.$ high

5.7. Power and Efficiency

- Power: workdone per unit of time

$$Power = \frac{\text{Work Done}}{\text{Time Taken}}$$

- Deriving it to form $P = Fv$

$$P = \frac{Wd}{T} \quad \& \quad W.d = Fs$$

$$\therefore P = \frac{Fs}{T} = F\left(\frac{s}{t}\right)$$

$$\therefore P = Fv$$

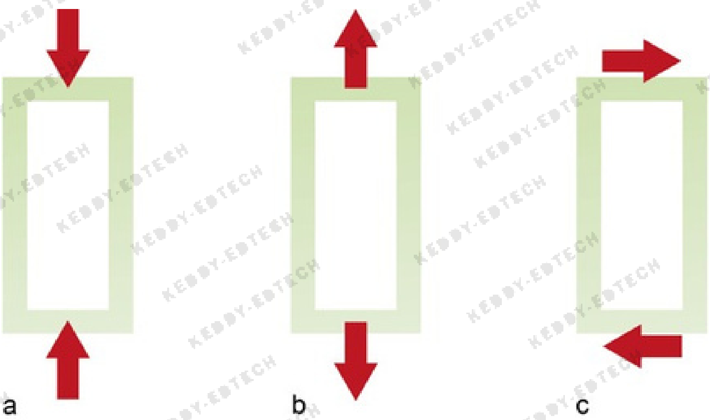
- Efficiency: ratio of (useful) output energy of a machine to the input energy

$$Efficiency = \frac{\text{Useful Energy Ouput}}{\text{Total Energy Input}} \times 100$$

6. Deformation of Solids

6.1. Stress and Strain

- Deformation is caused by a force
- Tensile force
  - Act away from each other, object stretched out and increased in length (extension)
- Compressive force
  - Act towards each other, object squashed and decreased in length (compression)



a Compressive | b Tensile | c Shear

6.2. Elastic and Plastic Behaviour

- A spring produces an extension when a load is attached
- Hooke's law: the extension produced is proportional to the applied force (due to the load) as long as the limit of proportionality hasn't been reached.

$$F = ke$$

Where k is the spring constant (unit: force per unit extension); e is the extension.

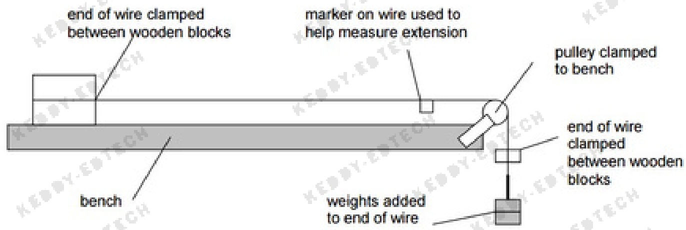
- Limit of proportionality: the point beyond which the extension is no longer proportional to the force
- Calculating effective spring constants:

Series	Parallel
$\frac{1}{k_E} = \frac{1}{k_1} + \frac{1}{k_2}$	$k_E = k_1 + k_2$

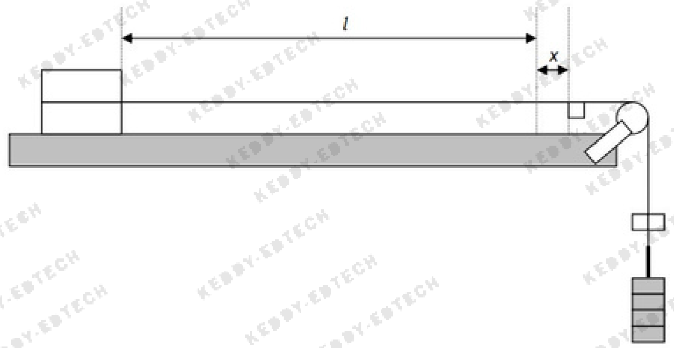
6.3. Determining Young's Modulus

Measure diameter of wire using micrometer screw gauge

Set up arrangement as diagram:



Attach weights to end of wire and measure extension



Calculate Young's Modulus using formula

6.4. Stress, Strain and Young's Modulus

- Stress: the force applied per unit cross-sectional area

$\sigma = \frac{F}{A}$ (N m^{-2} or Pascals)

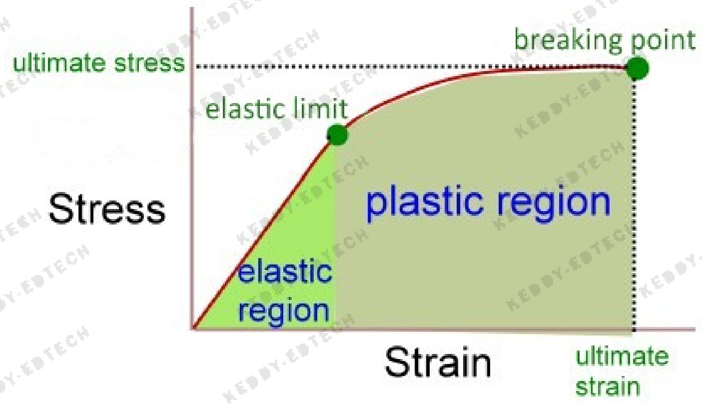
- Strain: fractional increase in original length of wire

$\varepsilon = \frac{e}{l}$ (no units)

- Young's Modulus: ratio of stress to strain

$E = \frac{\sigma}{\varepsilon}$ in N m^{-2} or Pascals

- Stress-Strain Graph:

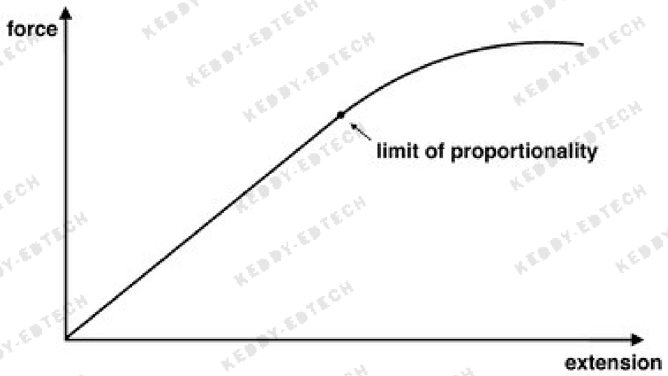


Gradient = Young's modulus

Area under the curve = work done per unit volume = energy stored per unit volume

- Elastic deformation: when deforming forces are removed, the spring returns back to its original length
- Plastic deformation: when deforming forces are removed, the spring does not return to its original length
- Elastic limit: maximum stress that can be applied before causing plastic deformation

Force-Extension Graph:



Gradient = Spring constant

The area under the curve = work done = strain energy stored

- Strain energy: the potential energy stored in or work done by an object when it is deformed elastically
- Strain energy = area under force-extension graph

$W = \frac{1}{2}Fx = \frac{1}{2}kx^2$

7. Waves

7.1. Progressive Waves

- Wave motion: a propagation of disturbance that travels from one location to another.
- Displacement: distance of a point from its undisturbed (equilibrium) position
- Amplitude: maximum displacement of a particle from an undisturbed position
- Period: time taken for one complete oscillation
- Frequency: number of oscillations per unit time

$f = \frac{1}{T}$

- Wavelength: distance from any point on the wave to the next precisely similar point (e.g. crest to crest)
- Wave speed: speed at which the waveform travels in the direction of the propagation of the wave
- Progressive waves transfer energy from one position to another.

7.2. Deducing Wave Equation

Speed $= \frac{\text{Distance}}{\text{Time}}$

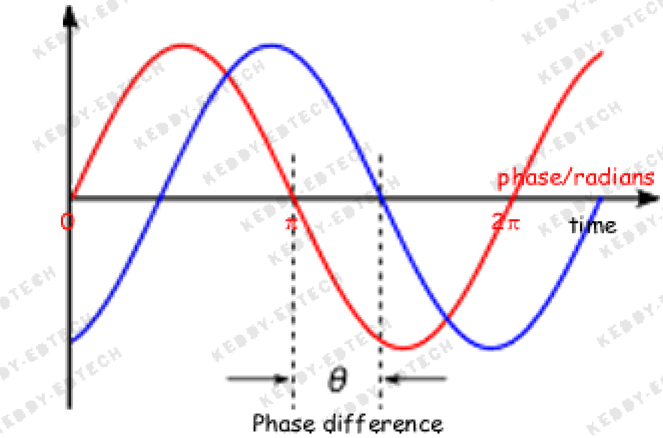
- Distanceof1 wavelength is λ and time taken for this is T

$\therefore v = \frac{\lambda}{T}$

$f = \frac{1}{T}$ so $v = f\lambda$

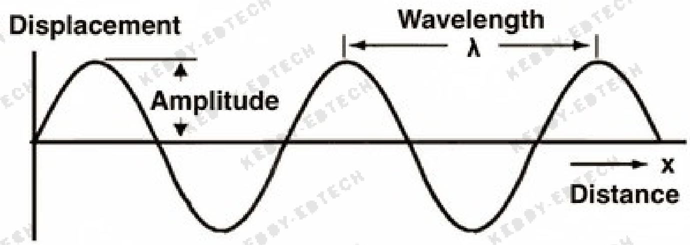
7.3. Phase Difference

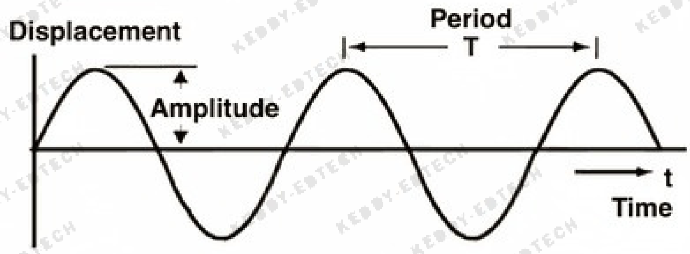
- Phase difference between two waves is the difference in terms of fraction of a cycle or in terms of angles (A B)
- Wave A(red) leads wave B(blue) by θ or Wave B lags wave A by θ
- Phase difference = $\frac{x}{\lambda} \times 2\pi$ (unit: radians or degrees)



- In phase (in step): phase difference = 0, 2π, …, $2n\pi$
- Antiphase: phase difference = π, 3π, …, $(2n+1)\pi$

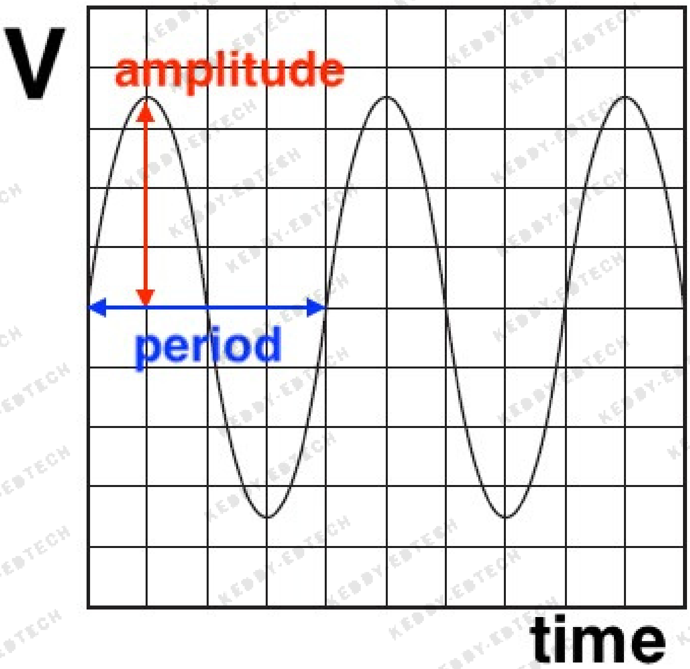
7.4. Wave Graphs





- Displacement-distance graph: for a fixed time
- Displacement-time graph: for a fixed position

7.5. Cathode-Ray Oscilloscope



- Used to determine frequency and amplitude
- Y-gain: increase in voltage per unit (determine amplitude)
- Time-base: increase in time per unit (determine period and frequency)

7.6. Intensity

- Rate of energy transmitted per unit area perpendicular to direction of wave propagation (unit: W m−2)

Intensity = $\frac{\text{Power}}{\text{Cross Sectional Area}}$

Intensity ∝ Amplitude^2

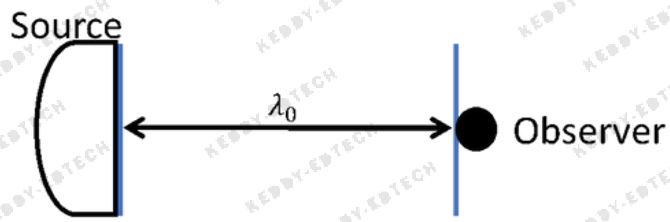
For a point source: Intensity = $\frac{\text{Power}}{\text{Cross Sectional Area}} = \frac{\text{Power}}{4\pi r^2}$

$\therefore$ Intensity $\propto \frac{1}{r^2}$

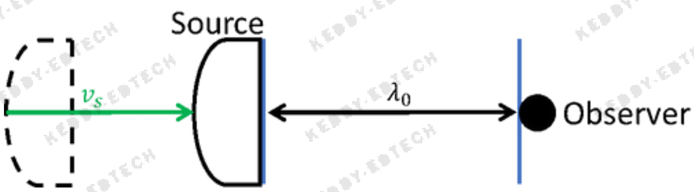
$\therefore$ Amplitude $\propto \frac{1}{r}$

7.7. The Doppler Effect

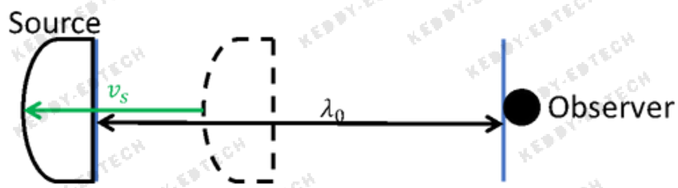
- Arises when source of waves moves relative to observer
- Can occur in all types of waves, including sound & light
- Source stationary relative to Observer:



- Source moving towards Observer:



- Source moving away from Observer:



- Change in wavelength leads to change in frequency
- Observed frequency (*f*0) is different from actual frequency (*fs*);related by equation:

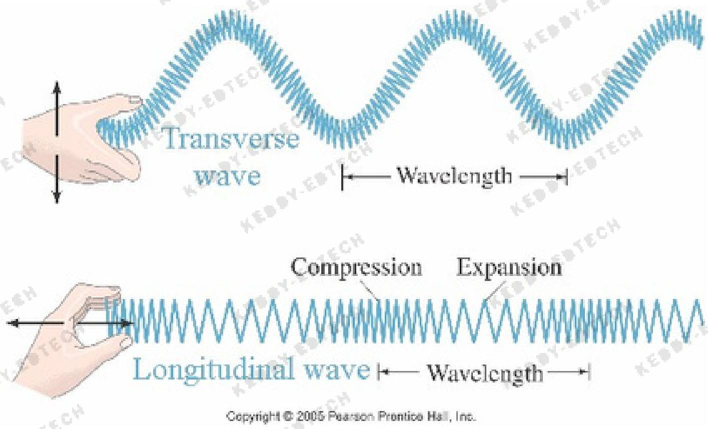
$f_0 = \frac{f_s v}{v \pm v_s}$

- source moves towards observer: $v - v_s$, *f*0 increases; blue shift
- source moves away observer: $v + v_s$, *f*0 decreases; red shift

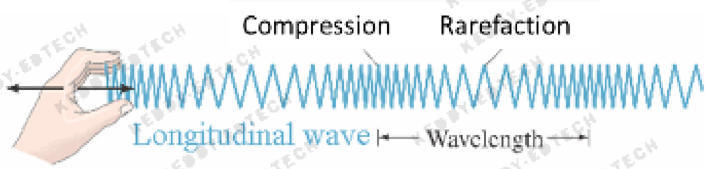
where *v* is speed of wave and *vs* is speed of source relative to observer

7.8. Transverse and Longitudinal waves

- Transverse Waves
- Oscillation of wave particles perpendicular to direction of propagation
- Polarization can occur
- E.g. light waves



- Longitudinal Waves
  - Oscillations of wave particle parallel to direction of propagation
  - Polarization cannot occur
  - E.g. sound waves



7.9. Polarization

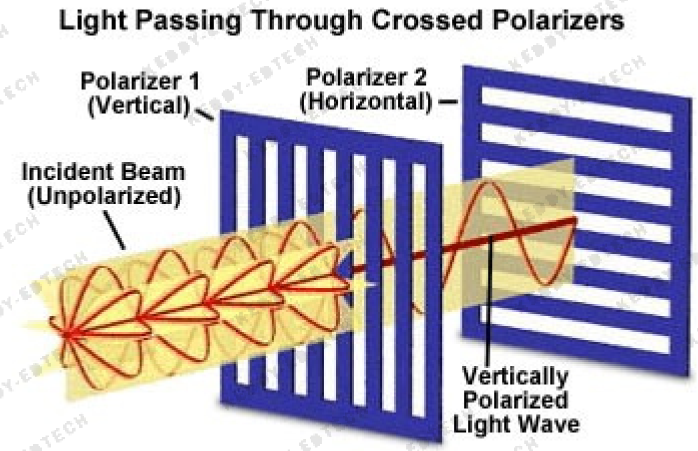


Figure 1

- Polarization: the action of restricting the vibration of a transverse wave wholly or partially to one direction.
- ONLY transverse waves can be polarized.
- Malus' Law: $I=I_0\cos^2\theta$

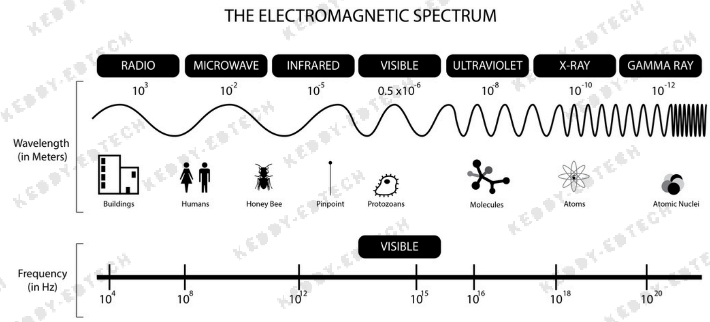
$A=A_0\cos\theta$, $I\propto A^2$

where I is the intensity, A is the amplitude, θ is the angle between the

transmission axis of the polaroid and the plane of the incident polarized wave.

7.10. Electromagnetic Waves

- As electromagnetic wave progresses, wavelength decreases and frequency increases



- Visible light: 400 nm - 700 nm

All electromagnetic waves:

- All travel at the speed of light: $3*10^8 ms^{-1}$
- Travel in free space (don't need medium)
- Can transfer energy
- Are transverse waves

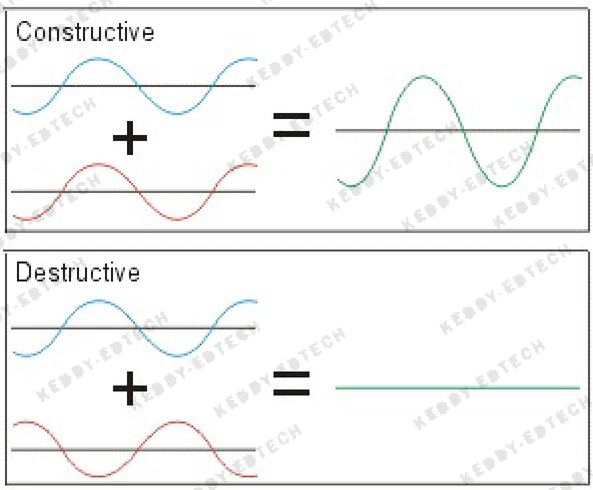
8. Superposition

8.1. Principle of Superposition

- When two or more waves of the same type meet at a point, the resultant displacement is the algebraic sum of the individual displacements

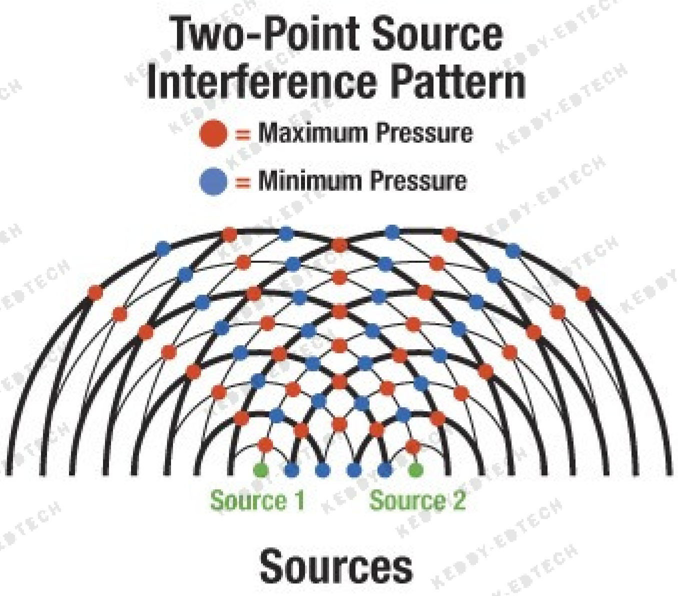
8.2. Interference and Coherence

- Interference: the superposition of two or more waves in similar or same direction to give a resultant wave whose amplitude is given by the principle of superposition.
- Coherence: same type of waves having same frequency/wavelength and a constant phase difference.
- Constructive
  - Two sources in-phase: path difference = $n\lambda$
  - Two sources anti-phase: path difference = $n\lambda2$
- Destructive
  - Two sources in-phase: path difference = $n\lambda2$
  - Two sources anti-phase: path difference = $n\lambda$



n = 1, 2, 3, ...

8.3. Two-Source Interference

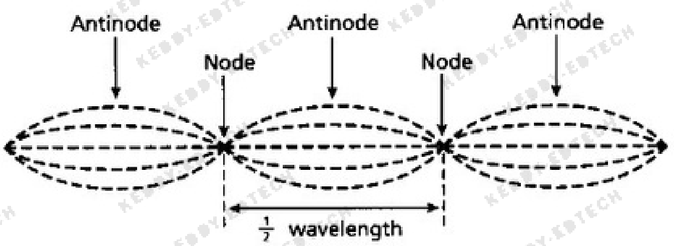


- Conditions for Observable Two-Source Interference:
  - Meet at a point
  - Must be of the same type
  - Must be coherent
  - Must be unpolarized or have the same plane of polarization
  - Must have approximately the same amplitude
- Demonstrating Two-Source Interference:

Water	Ripple generators in a tank
Light	Double slit interference
Microwaves	Two microwave emitters

8.4. Formation of Stationary waves

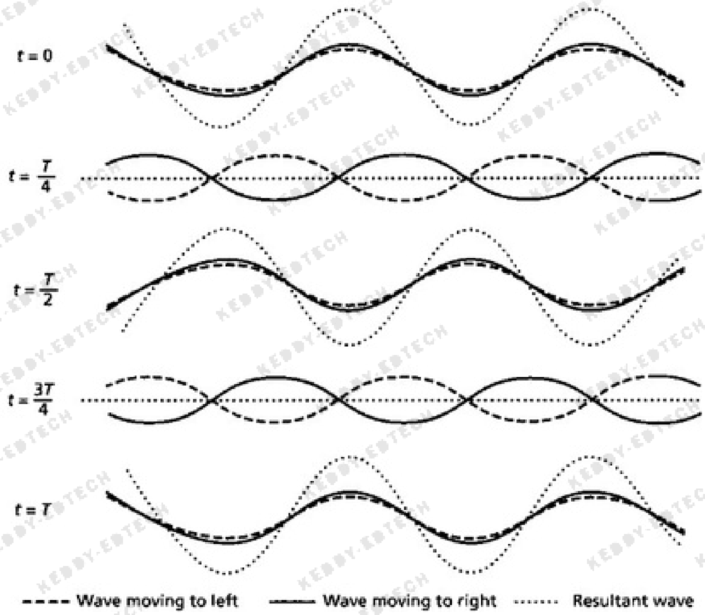
- A stationary wave is formed when two progressive waves of the same frequency, amplitude and speed, travelling in opposite directions are superposed.
- Node: region of destructive superposition where waves always meet out of phase by π, ∴ displacement = zero (closed end)
- Antinode: region of constructive superposition where waves meet in phase ∴ particle vibrate with max amplitude (open end)



- Neighboring nodes & antinodes separated by 12 λ
- Between 2 adjacent nodes, particles move in phase; they are out of phase with the particles between the next two nodes by π

- Stationary waves cannot transfer energy.

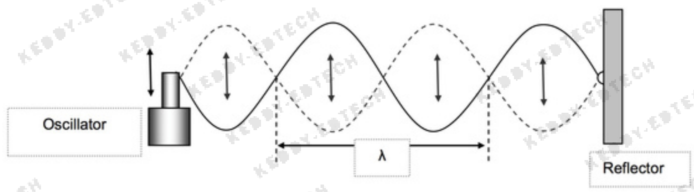
Stationary wave at different times:



8.5. Stationary Wave Experiments

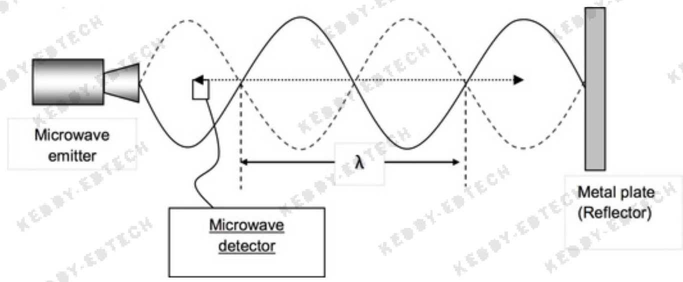
Stretched String:

- String either attached to wall or attached to weight
- Stationary waves will be produced by the direct and reflected waves in the string.



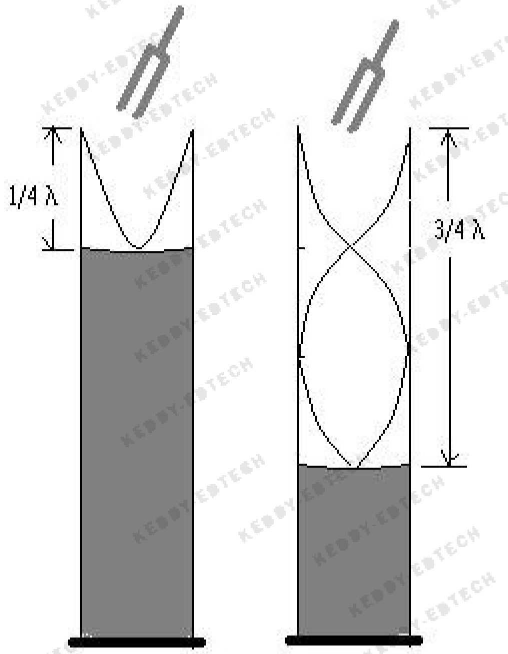
Microwaves:

- A microwave emitter placed a distance away from a metal plate that reflects the emitted wave.
- By moving a detector along the path of the wave, the nodes and antinodes could be detected.



Air Columns:

- A tuning fork held at the mouth of an open tube projects a sound wave into the column of air in the tube.
- The length can be changed by varying the water level.
- At certain lengths tube, the air column resonates
- This is due to the formation of stationary waves by the incident and reflected sound waves at the water surface.
- Node always formed at surface of water

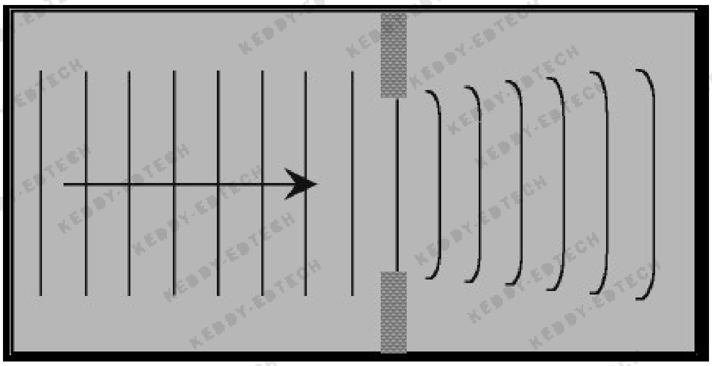


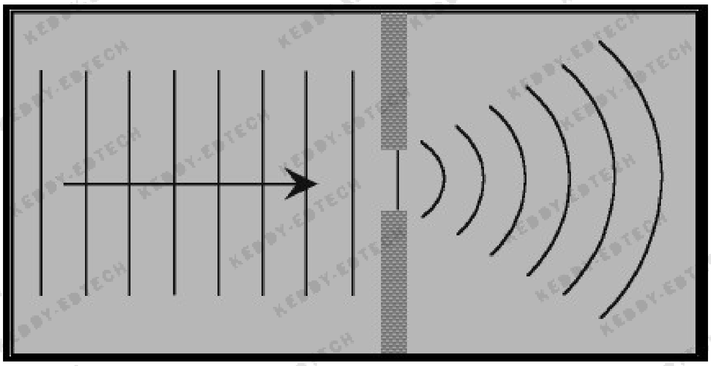
8.6. Stationary and Progressive Waves

Stationary Waves	Progressive Waves
Stores energy (cannot transfer energy)	Transmits energy
Have nodes & antinodes	No nodes & antinodes
Amplitude increases from node to antinode	Amplitude constant along length of the wave
Phase change of π at node	No phase change

8.7. Diffraction

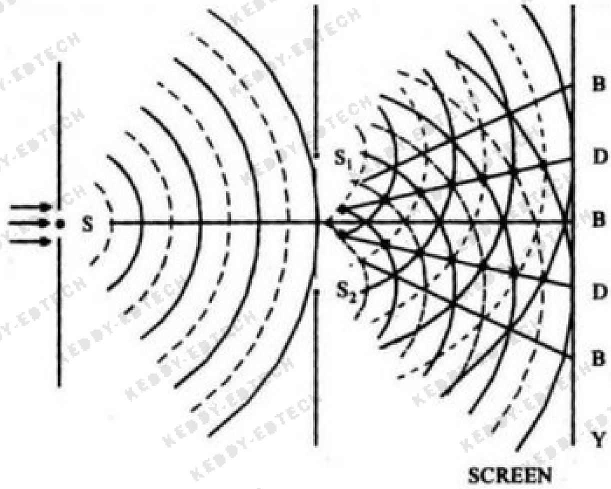
- Diffraction: the spreading of waves as they pass through a narrow slit or near an obstacle
- For diffraction to occur, the size of the gap should be equal to the wavelength of the wave.





Gap Width	Amount of diffraction
$>>\lambda$	smallest
λ<Gap<2λ	limited
$\leq \lambda$	greatest

8.8. Double-Slit Interference



$\lambda = \frac{ax}{D}$

Where*a*= slit separation

D= distance from slit to screen

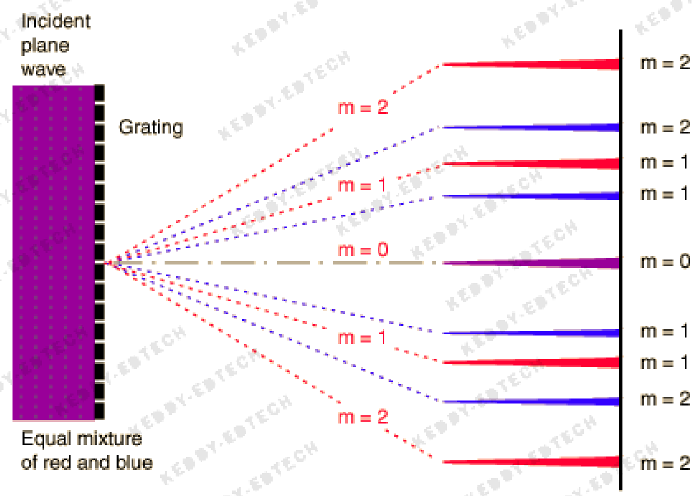
x= fringe width

- If white light is used:
  - Central fringe is white: all wavelengths are in step
  - Other fringes show colored effects: different wavelength (red light will be further than violet light because $\lambda red > \lambda violet$

Increase amplitude of one source	Decrease amplitude of one source
fringe spacing does not change	fringe spacing does not change
bright fringes are brighter	bright fringes are darker dark
dark fringes are darker	fringes are brighter

- Experimental Arrangement
  - Add a single slit before the double slit: ensure that the two waves are coherent (needed when using light bulbs).
  - Use lasers: light is more concentrated; light is monochromatic (makes fringes clearer); no single slit needed.

8.9. Diffraction Grating



$d\sin\theta = n\lambda$

Where d = distance between successive slits = $\frac{1}{N}$

N= number of slits per meter

θ= angle from horizontal equilibrium

n= order number

λ= wavelength

	double-slit	diffraction grating
pattern	closely spaced bright fringes on a dark background	widely spaced bright fringes on a dark background
features	less bright and sharp	brighter and sharper (more slits: more light pass through; narrower slits: more diffracted)

9. Electricity

9.1. Introduction

- Electric Current: the flow of charged particles
- Charge at a point. Product of the current at that point and the time for which the current flows,

$Q = It$

- Q = Charge, I = Current, t = time taken to flow through point
- Coulomb: charge flowing per second passes a point at which the current is one ampere
- Charge is Quantised: charge values are not continuous; they are discrete.
- All charges are multiples of charge of 1e: 1.6×10^{-19}C

- Potential Difference: two points have a potential difference of 1V if the work required to move 1C of charge between them is 1 joule
- Volt: joule per coulomb

$W = VQ$

W = Work Done V = Voltage Q = Charge

$P=VI$; $P=I^2R$; $P = \frac{V^2}{R}$

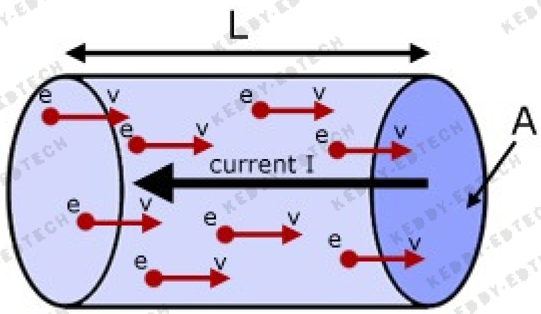
P = Power

V = Voltage

I = Current

R = Resistance

9.2. Current-Carrying Conductors



- Electrons move in a certain direction when p.d. is applied across a conductor causing current
- Deriving a formula for current:

$I = \frac{Q}{t}$

Q	t
vol. of container = LA	time needed = $t = \frac{L}{v}$
No. of free electrons = nLA	
Total charge = $Q = nLAq$	

$\therefore I = \frac{nLAq}{L/v}$

$I = Anvq$

Where L = length of conductor

A = cross-sectional area of conductor

n = no. free electrons per unit volume

q = charge on 1 electron

v = average electron drift velocity

9.3. Resistance and Resistivity

- Resistance: defined as the ratio of the potential difference to the current (unit: Ω)

$R = \frac{V}{I}$

- Ohm is defined as volt per ampere (Ω=VA^{-1})

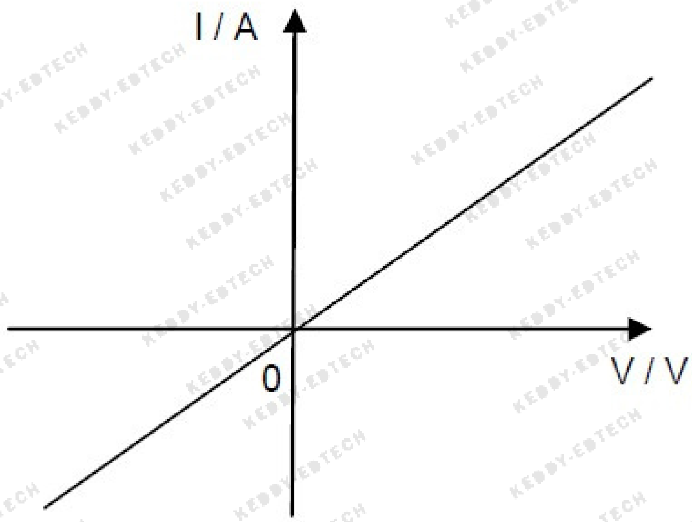
- Ohm's Law: the current in a component is proportional to the potential difference across it provided physical conditions (e.g. temp) stay constant
- Ohmic Component: obeys Ohm's law

$R = \frac{\rho L}{A}$

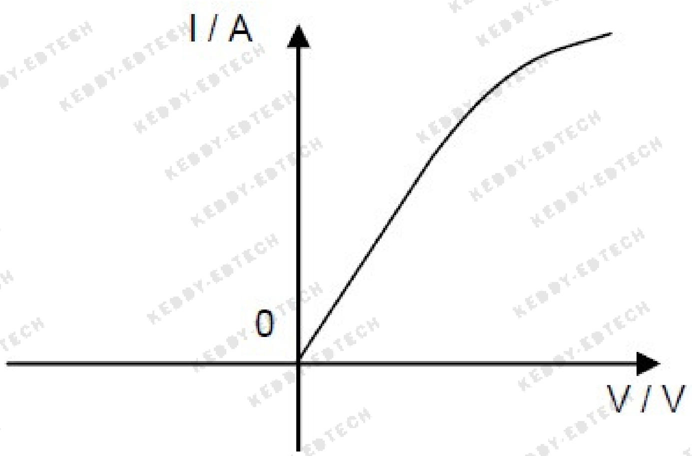
- ρ = resistivity (constant for the same material at constant temperature; unit: Ωm)
- L = length
- A = cross-sectional area

9.4. I-V Characteristics

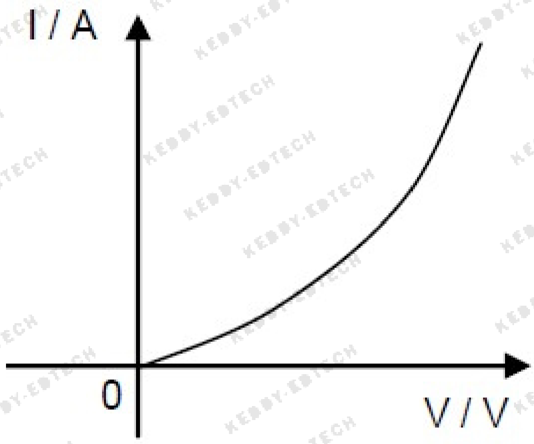
- Metallic Conductor
  - Ohmic conductor
  - V/I constant
  - Temperature constant



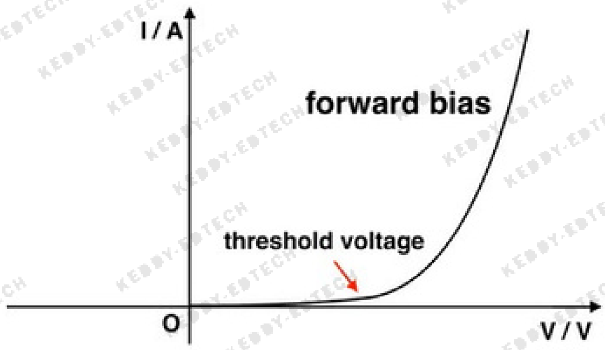
- Filament Lamp
  - Non-ohmic conductor
  - Volt ↑
  - Temp. ↑
  - Vibration of ions ↑
  - Collision of ions with e- ↑
  - Resistance ↑



- Thermistor (Negative Temperature Coefficient)
  - Non-ohmic conductor
  - Volt ↑
  - Temp. ↑
  - Released e- ↑
  - Resistance ↓



- Semi-Conductor Diode
  - Non-ohmic conductor
  - Low resistance in one direction and infinite resistance in opposite
  - Threshold voltage: the voltage at which the diode suddenly starts to conduct \n



- Light Dependent Resistor (LDR)
  - Light intensity ↑
  - Resistance ↓

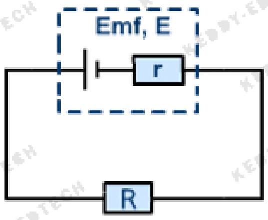
10. D.C. Circuits

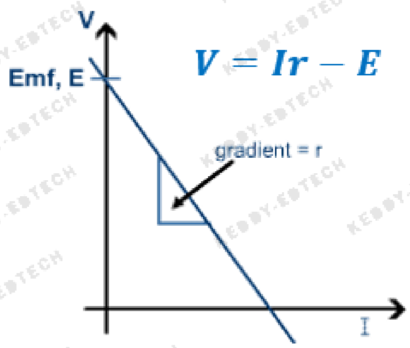
10.1. Potential Difference and Electromotive Force

- Electromotive Force: the amount of energy given to each coulomb of charge to go around the circuit once.
- Potential difference (work done per unit charge)
  - energy transformed from electrical to other forms per unit charge
- Electromotive force (work done per unit charge)
  - energy transformed from other forms to electrical

10.2. Internal Resistance

Internal Resistance: resistance to current flow within the power source; reduces p.d. when delivering current





The voltage across resistor: $V = IR$

Voltage lost to internal resistance: $V = E - Ir$

Thus e.m.f.: $E = IR + Ir$

$E = I(R + r)$

10.3. Kirchhoff's 1st Law

The sum of currents in a junction
IS EQUAL TO
The sum of currents out of the junction.

- Kirchhoff's 1st law is another statement of the law of conservation of charge

10.4. Kirchhoff's 2nd Law

Sum of e.m.f.s in a closed circuit
IS EQUAL TO
Sum of potential differences

- Kirchhoff's 2nd law is another statement of the law of conservation of energy

10.5. Deriving Effective Resistance in Series

From Kirchhoff's 2nd Law:

$E = \sum IR$

$IR = IR_1 + IR_2$

Current constant therefore cancel:

$R = R1 + R_2$

10.6. Deriving Effective Resistance in Parallel

From Kirchhoff's 1st Law:

$I = \sum I$

$I = I_1 + I_2$

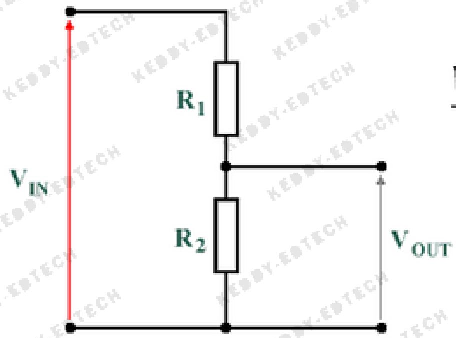
$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$

Voltage constant therefore cancel:

$\frac{1}{R} = \frac{1}{R^1} + \frac{1}{R2}$

10.7. Potential Divider

- A potential divider divides the voltage into smaller parts.



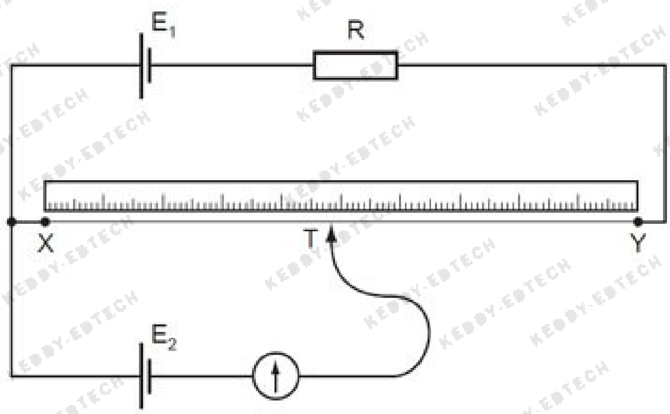
$$\frac{V_{out}}{V_{in}} = \frac{R_2}{R_{Total}}$$

- Usage of a thermistor at R1:
  - Resistance decreases with increasing temperature.
  - It can be used in potential divider circuits to monitor and control temperatures.
- Usage of an LDR at R1:
  - Resistance decreases with increasing light intensity.
  - It can be used in potential divider circuits to monitor light intensity.

10.8. Potentiometers

- A potentiometer is a continuously variable potential divider used to compare potential differences
- Potential difference along the wire is proportional to the length of the wire
- It can be used to determine the unknown e.m.f. of a cell
- This can be done by moving the sliding contact along the wire until it finds the null point that the galvanometer shows a zero reading; the potentiometer is balanced

Example: E1 is 10 V, and and distance XY equals 1m. The potentiometer is balanced at point T, which is 0.4m from X. Calculate E2

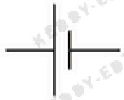
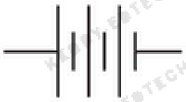
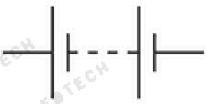
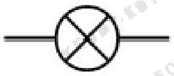
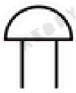
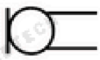
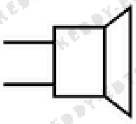
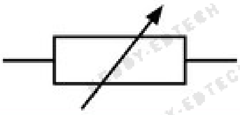
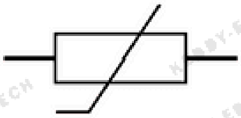
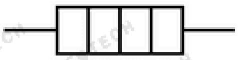
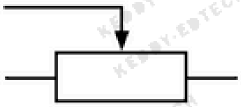
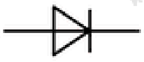
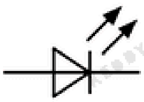


$\frac{E1}{E2} = \frac{L_{XY}}{L_{XT}}$

$\frac{10}{E2} = \frac{1}{0.4}$

$E2 = 4V$

10.9. Circuit Symbols

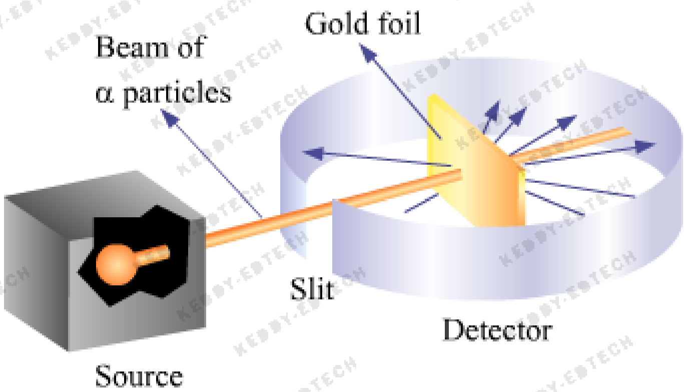
cell	
battery of cells	 or 
power supply	
switch	
lamp	
electric bell	
buzzer	
microphone	
loudspeaker	
fixed resistor	
variable resistor	
thermistor	
light-dependent resistor	
heater	
potentiometer	
diode	
light-emitting diode	

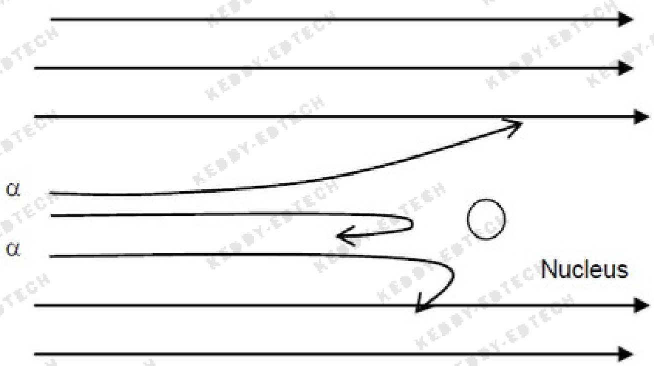
ammeter	
voltmeter	
galvanometer	

11. Nuclear Physics

11.1. Geiger-Marsden α

- Experiment: a beam of α-particles is fired at thin gold foil





- Results of the experiment:
  - Most particles pass straight through
  - Some are scattered appreciably
  - Very few – 1 in 8,000 – suffered deflections > 90°
- Conclusion:
  - Most of an atom is empty space
  - All mass and charge concentrated in the center of atom ∴ nucleus is small and very dense
  - Nucleus is positively charged as α-particles are repelled/deflected

11.2. The Nuclear Atom

- Nucleon number: total number of protons and neutrons
- Proton/atomic number: total number of protons
- Isotope: atoms of the same element with a different number of neutrons but the same number of protons
- Simple model:
  - The nucleus is made of protons and neutrons.
  - Electrons move around the nucleus in a cloud, some closer to and some further from the nucleus.
- Nuclide notation: $^{A}_{Z}X$
  - A: nucleon number
  - Z: proton number
  - X: element
- Unified atomic mass unit: u
  - 1 u = 112 mass of a carbon-12 atom

11.3. Nuclear Processes

- During a nuclear process, nucleon number, proton number and mass-energy are conserved

Radioactive process are random and spontaneous

- Random: impossible to predict and each nucleus has the same probability of decaying per unit time
- Spontaneous: not affected by external factors such as the presence of other nuclei, temperature and pressure
- Evidence on a graph:
  - Random; graph will have fluctuations in count rate
  - Spontaneous; graph has same shape even at different temperatures, pressure etc.

11.4. Radiations

	α-particle	β-particle	γ-ray
Identity	Helium nucleus	Fast-moving electron/positron	Electromagnetic
Symbol	$^{4}_{2}He$	$^{0}_{-1}e$ − / $^{0}_{+1}e$ +	$^{0}_{0}\gamma$
Charge	+ 2	− 1	0
Relative Mass	4	1/1840	0
Speed	Slow ($10^{6} ms^{-1}$)	Fast ($10^{8} ms^{-1}$)	v of light ($3 \times 10^{8} ms^{-1}$)
Energy	Discrete	Continuous range (because (anti)neutrinos are emitted in β-decay)	
Stopped by	Paper	Few mm of aluminium	Few cm of lead
Ionizing power	High	Low	Very Low
Effect of Magnetic	Deflected slightly	Deflected greater	Undeflected
Effect of Electric	Attracted to -ve	Attracted to +ve	Undeflected
Force	Strong interaction	Weak interaction	

11.5. Types of Decays

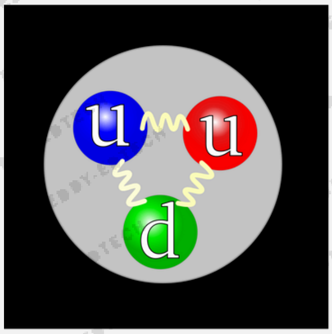
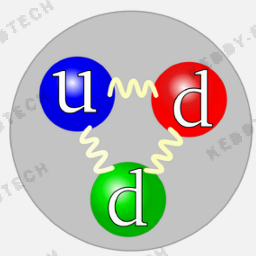
- α decay: loses a helium nucleus
  - $^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}X + ^{4}_{2}\alpha$
- $\beta-$ decay: neutron turns into a proton and an electron & electron antineutrino are emitted
  - $^{A}_{Z}X \rightarrow ^{A}_{Z+1}X + ^{0}_{-1}e + \bar{\nu}$
  - $d \rightarrow u + ^{0}_{-1}e + \bar{\nu}$
- $\beta+$ decay: proton turns into a neutron and a positron & electron neutrino are emitted
  - $^{A}_{Z}X \rightarrow ^{A}_{Z-1}X + ^{0}_{+1}e + \nu$
  - $u \rightarrow d + ^{0}_{+1}e + \nu$
- γ decay: a nucleus changes from a higher energy state to a lower energy state through the emission of electromagnetic radiation (photons)

11.6. Fundamental Particles

- Fundamental Particle: a particle that cannot be split up into anything smaller
- Electron is a fundamental particle but protons and neutrons are not
- Protons and neutrons are made up of different combinations of smaller particles called quarks
- Table of Quarks:

Quark	Symbol	Charge
Up	u	$+\frac{2}{3}e$
Down	d	$-\frac{1}{3}e$
Charm	c	$+\frac{2}{3}e$
Strange	s	$-\frac{1}{3}e$
Top	t	$+\frac{2}{3}e$
Bottom	b	$-\frac{1}{3}e$

- Quark Models:

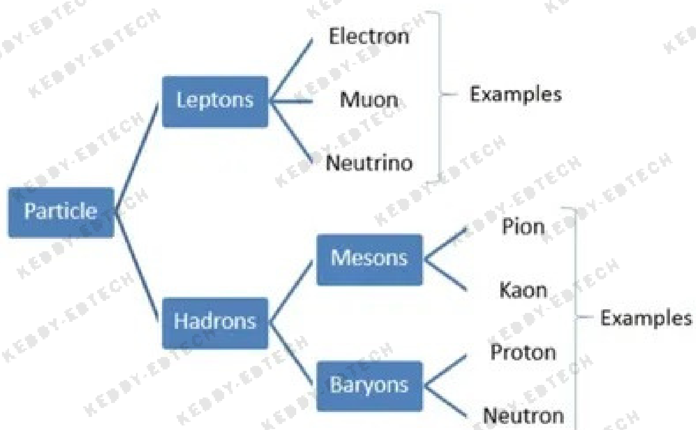
Proton	Neutron
	
2 Up & 1 Down	1 Up & 2 Down
$+\frac{2}{3}e + \frac{2}{3}e - \frac{1}{3}e = +e$	$+\frac{2}{3}e - \frac{1}{3}e - \frac{1}{3}e = 0$

- All particles have their corresponding antiparticle (same mass, opposite charge)
- Table of Antiquarks:

Antiquark	Symbol	Charge
Anti-Up	$\bar{u}$	$-\frac{2}{3}e$
Anti-Down	$\bar{d}$	$+\frac{1}{3}$

- These antiquarks combine to similarly form respective antiprotons and antineutrons

11.7. Particle Families



- Hadrons: made up of quarks
- Leptons: fundamental particles

- Baryons: made up of 3 quarks
- Mesons: made up of 1 quark & 1 antiquark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