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1. Physical Quantities and Units

1.1 Physical Quantities

- A physical quantity is made up of magnitude and unit

$2\ kg$

Magnitude ↗ ↖ Unit

1.2 Base Units

- The following are base units:

Quantity		Basic Unit	
Name	**Symbol**	**Name**	**Symbol**
Mass	m	Kilogram	kg
Length	l	Meter	m
Time	t	Second	s
Temperature	T	Kelvin	K
Electric Current	I	Ampere	A

- All units (not above) can be broken down to base units
- Homogeneity can be used to prove equations.
- An equation is homogenous if base units on left hand side are the same as base units on right hand side.
- This may not work every time due to the fact that it does not take pure numbers into account (E_k formula)

1.3 Multiples and Submultiples

Multiple	Prefix	Symbol
10^{12}	Tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
Submultiple	**Prefix**	**Symbol**
10^{-3}	Milli	m
10^{-6}	Micro	μ
10^{-9}	Nano	n
10^{-12}	Pico	p

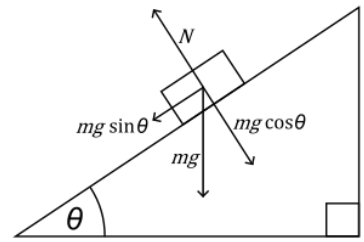
1.4 Estimations

Mass of a person	70 kg
Height of a person	1.5 m
Walking speed	1 ms^{-1}
Speed of a car on the motorway	30 ms^{-1}
Volume of a can of a drink	300 cm^3
Density of water	1000 kgm^{-3}
Density of air	1 kgm^{-3}
Weight of an apple	1 N
Current in a domestic appliance	13 A
e.m.f of a car battery	12 V
Hearing range	20 Hz to 20,000 Hz
Young's Modulus of a material	Something × 10^{11}

1.4 Scalar and Vector

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

1.5 Vectors

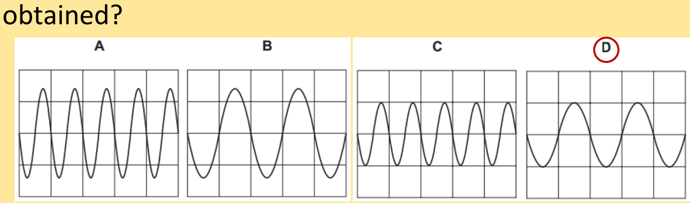


2. Measurement Techniques

Quantity	Accuracy	Instrument
Length	1 cm	Tape
	0.1 cm	Ruler
	0.01 cm	Vernier caliper
	0.001 cm	Micrometer screw gauge
Volume	1 cm^3	Measuring cylinder
	0.05 cm^3	Pipette/burette
Angle	0.5°	Protractor
Time	1 min	Clocks
	0.01 sec	Stopwatch
	x-axis scale	Time base of c.r.o
Temperature	1°C	Thermometer
	0.5°C	Thermocouple
P.d.	0.01 V	Voltmeter
Current	0.01 A	Ammeter
	0.0001 A	Galvanometer

2.1 Using a Cathode Ray Oscilloscope

Example: A supply of peak value 5.0 V and of frequency 50 Hz is connected to a c.r.o with time-base at 10 ms per division and Y-gain at 5.0V per division. Which trace is obtained?



Maximum value is 5.0V ∴ eliminate A and B

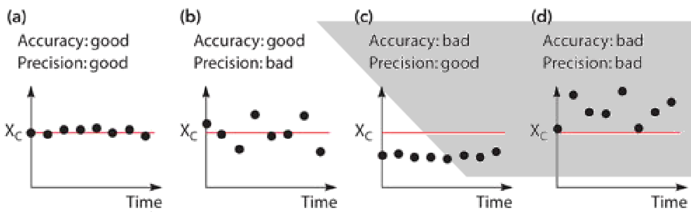
$F = \frac{1}{T}$ and $T = Timebase \times Divisions$ so $F = \frac{1}{Timebase \times Divisions}$

$$Divisions = \frac{1}{F \times Timebase} = \frac{1}{50 \times 10 \times 10^{-3}} = 2$$

Trace must have period of 2 divisions and height of 1 division ∴ D

2.1 Systematic and Random Errors

- **Systematic error:**
  - Constant error in one direction; too big or too small
  - Cannot be eliminated by repeating or averaging
  - If systematic error small, measurement accurate
  - **Accuracy:** refers to degree of agreement between result of a measurement and true value of quantity.
- **Random error:**
  - Random fluctuations or scatter about a true value
  - Can be reduced by repeating and averaging
  - When random error small, measurement precise
  - **Precision:** refers to degree of agreement of repeated measurements of the same quantity (regardless of whether it is correct or not)



2.1 Calculations Involving Errors

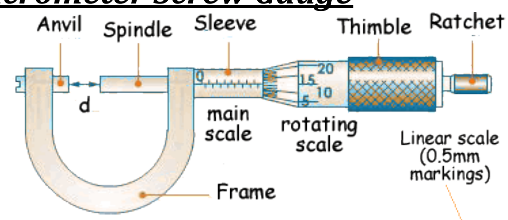
For a quantity $x = (2.0 \pm 0.1)mm$

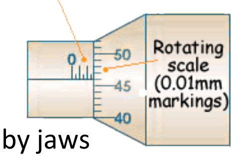
- **Absolute uncertainty** $= \Delta x = \pm 0.1mm$
- **Fractional uncertainty** $= \frac{\Delta x}{x} = 0.05$
- **Percentage uncertainty** $= \frac{\Delta x}{x} \times 100\% = 5\%$
- **Combining errors:**
  - When values **added or subtracted**, add absolute error
    If $p = \frac{2x+y}{3}$ or $p = \frac{2x-y}{3}$, then $\Delta p = \frac{2\Delta x + \Delta y}{3}$
  - When values **multiplied or divided**, add % errors
  - When values are **powered** (e.g. squared), multiply percentage error with power
    If $r = 2xy^3$ or $r = \frac{2x}{y^3}$, then $\frac{\Delta r}{r} = \frac{\Delta x}{x} + \frac{3\Delta y}{y}$

2.3 Treatment of Significant Figures

- **Actual error:** recorded to only 1 significant figure
- Number of decimal places for a calculated quantity is equal to number of decimal places in actual error.
- During a practical, when calculating using a measured quantity, give answers to the same significant figure as the measurement or one less

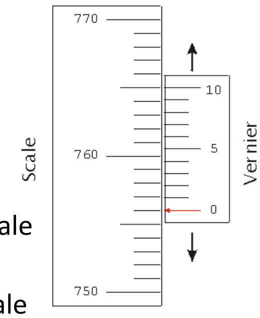
2.4 Micrometer Screw Gauge





- Measures objects up to 0.01mm
- Place object between **anvil** & **spindle**
- Rotate **thimble** until object firmly held by jaws
- Add together value from main scale and rotating scale

2.5 Vernier Scale



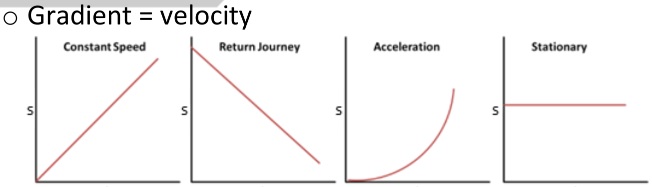
Measures objects up to 0.1mm

- Place object on rule
- Push slide scale to edge of object.
- The sliding scale is 0.9mm long & is divided into 10 equal divisions.
- Check which line division on sliding scale matches with a line division on rule
- Subtract the value from the sliding scale $(0.09 \times Divisions)$ by the value from the rule.

3. Kinematics

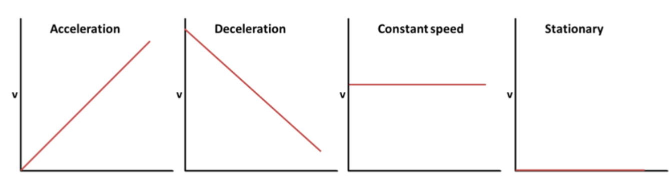
3.1 Linear Motion

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



3.2 Non-linear Motion

- **Velocity-time graph:**
  - Gradient = acceleration
  - Area under graph = change in displacement



- Uniform acceleration and straight line motion equations:

$$v = u + at$$

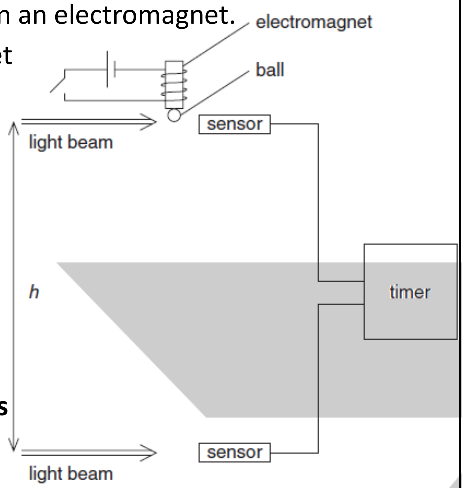
$$s = ut + \frac{1}{2}at^2 \qquad s = vt - \frac{1}{2}at^2$$

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

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

3.3 Determining Acceleration of Free Fall

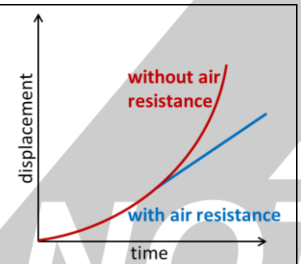
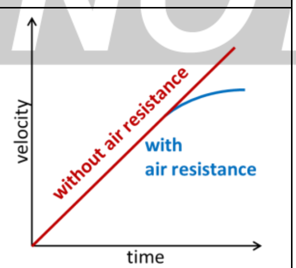
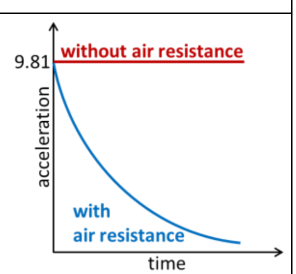
- A steel ball is held on an electromagnet.
- When electromagnet switched off, ball interrupts a beam of light and a timer started.
- As ball falls, it interrupts a second beam of light & timer stopped
- Vertical distance ***h*** **is plotted against t^2**



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

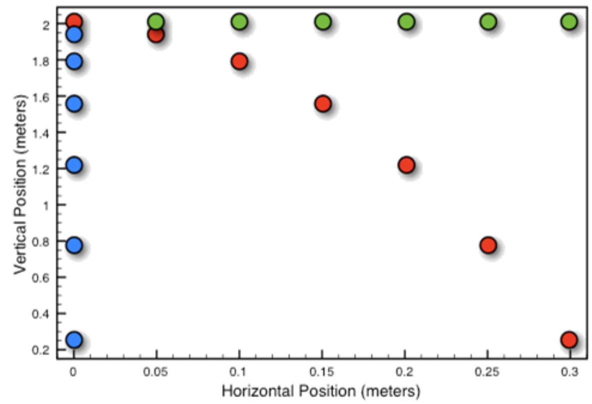
$Gradient = \frac{h}{t^2} = \frac{1}{2}g \qquad Accel. = 2 \times Gradient$

3.4 Motion of Bodies Free Falling

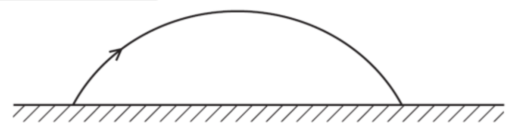
displacement	• Continues to curve as it accelerate • Graph levels off as it reaches terminal velocity	
velocity	• Continues to accelerate constantly • Graph curves as it decelerates and levels off to terminal velocity	
acceleration	• Straight line • Graph curves down to zero because resultant force equals zero	

3.5 Projectile motion

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

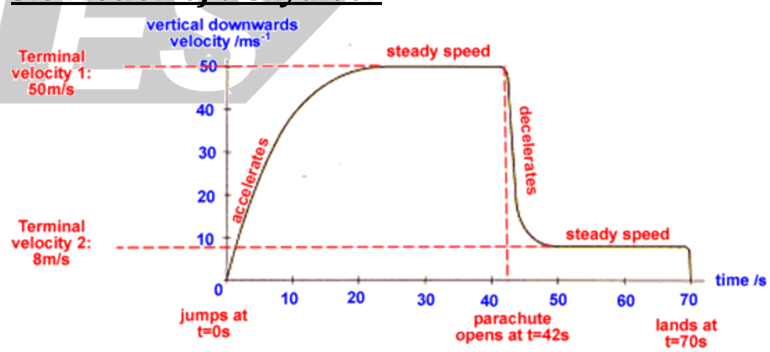


- Horizontal motion = constant velocity (speed at which projectile is thrown)
- Vertical motion = constant acceleration (cause by weight of object, constant free fall acceleration)
- Curved path – parabolic ($y \propto x^2$)



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

3.6 Motion of a Skydiver



4. Dynamics

4.1 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

4.2 Mass and Weight

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

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

4.3 Momentum

- **Linear momentum:** product of mass and velocity

$$p = mv$$

- **Force:** rate of change of momentum

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

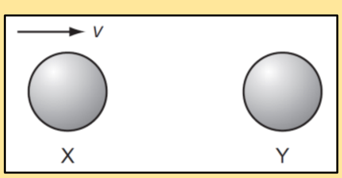
- **Principle of conservation of linear momentum:** when bodies in a system interact, total momentum remains constant provided no external force acts on the system.

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

4.4 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

$$\begin{pmatrix}\text{relative velocity}\\ \text{before collision}\end{pmatrix} = -\begin{pmatrix}\text{relative velocity}\\ \text{after collision}\end{pmatrix}$$

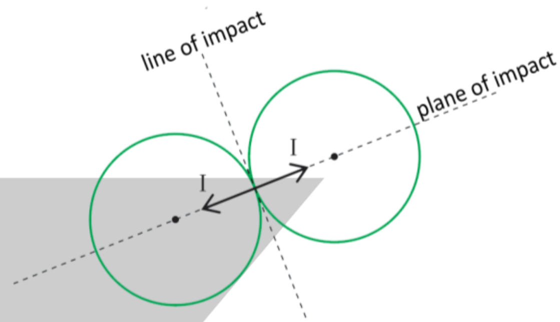
$$u_A - u_B = v_B - v_A$$

4.5 Inelastic Collisions

relative speed of approach > relative speed of separation

- ○ Total momentum is 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 E_k may be converted into other forms of energy e.g. heat

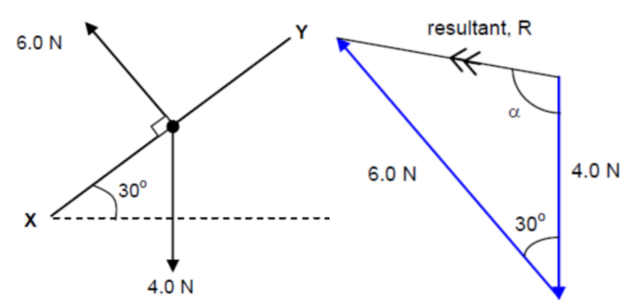
4.6 Collisions in Two Dimensions



- 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

5. Forces, Density, Pressure

- **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:**
  - Resultant force acting on it in any direction equals zero
  - 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.

5.1 Pressure in Fluids

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

5.2 Derivation of Pressure in Fluids

$$\text{Volume of water} = A \times h$$

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

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

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

$$\text{Pressure} = \rho g h$$

6. Work, Energy, Power

- **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

6.1 Work Done

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

$$W = Fs$$

- **Work done by an expanding gas:** the product of the force and the change in volume of gas

$$W = p.\delta V$$

  - **Condition for formula:** temperature of gas is constant
  - The change in distance of the piston, δx, is very small therefore it is assumed that p remains constant

6.2 Deriving Kinetic Energy

$$W = Fs \qquad \& \qquad F = ma$$

$$\therefore W = ma.s$$

$$v^2 = u^2 + 2as \Longrightarrow as = {}^{1}/_{2}\,(v^2 - u^2)$$

$$\therefore W = m.{}^{1}/_{2}\,(v^2 - u^2) \qquad u = 0$$

$$\therefore W = {}^{1}/_{2}\,mv^2$$

6.3 g.p.e and e.p

- **Gravitational Potential Energy:** arises in a system of masses where there are attractive gravitational forces between them. The g.p.e of an object is the energy it possesses by virtue of its position in a gravitational field.
- **Elastic potential energy:** this arises in a system of atoms where there are either attractive or repulsive short-range inter-atomic forces between them.
- **Electric potential energy:** arises in a system of charges where there are either attractive or repulsive electric forces between them.

6.4 Deriving Gravitational Potential Energy

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

$$\therefore W = mg.s$$

s in direction of force = h above ground

$$\therefore W = mgh$$

6.5 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 $= k.e.$
  - Intermolecular force present and keep shape $= p.e.$
- **Solids:** $k.e. < p.e.$
  - Molecules can only vibrate $\therefore$ $k.e.$ very little
  - Strong intermolecular forces $\therefore$ high $p.e.$

6.6 Power and a Derivation

- **Power:** work done per unit of time

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

- Deriving it to form $P = fv$

$$P = {}^{W.d}/_{T} \quad \& \quad W.d. = Fs$$

$$\therefore P = {}^{Fs}/_{T} = F({}^{s}/_{t}) \quad \& \quad v = {}^{s}/_{t}$$

$$\therefore P = Fv$$

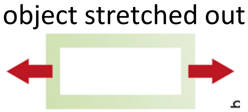
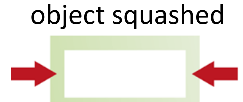
- **Efficiency:** ratio of (useful) output energy of a machine to the input energy

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

7. Deformation of Solids

7.1 Compressive and Tensile Forces

- Deformation is caused by a force

Tensile	Compressive
a pair of forces that	
act away from each other, object stretched out	act towards each other, object squashed
	

7.2 Hooke's Law

- A spring produces an extension when a load is attached
- According to Hooke's law, the extension produced is proportional to the applied force (due to the load) as long as the elastic limit is not exceeded.

$$F = ke$$

Where k is the spring constant; force per unit extension

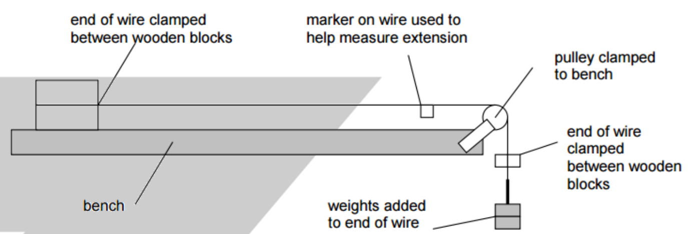
- Calculating effective spring constants:

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

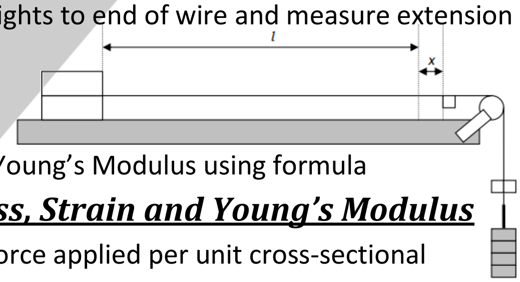
7.3 Determining Young's Modulus

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

7.4 Stress, Strain and Young's Modulus

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

$$\sigma = \frac{F}{A} \quad \text{in Nm}^{-2} \text{ or Pascals}$$

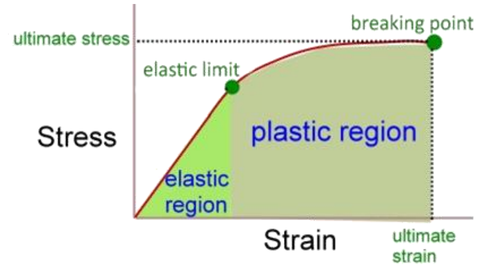
- **Strain:** fractional increase in original length of wire

$$\varepsilon = \frac{e}{l} \quad \text{no units}$$

- **Young's Modulus:** ratio of stress to strain

$$E = \frac{\sigma}{\varepsilon} \quad \text{in Nm}^{-2} \text{ or Pascals}$$

- **Stress-Strain Graph:**



Gradient = Young's modulus

- **Elastic deformation:** when deforming forces removed, spring returns back to original length
- **Plastic deformation:** when deforming forces removed, spring does not return back to original length

- **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

$$W = {}^{1}/_{2}\, k\Delta L^2$$

8. Waves

- **Displacement:** distance of a point from its undisturbed position
- **Amplitude:** maximum displacement of particle from 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 exactly 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

8.1 Deducing Wave Equation

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

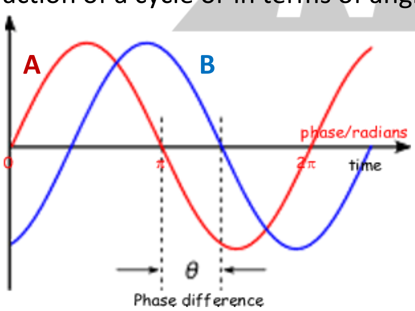
- Distance of 1 wavelength is λ and time taken for this is T

$$\therefore\ v = \frac{\lambda}{T} = \lambda\left(\frac{1}{T}\right)$$

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

8.2 Phase Difference

- Phase difference between two waves is the difference in terms of fraction of a cycle or in terms of angles



Wave **A** leads wave **B** by θ or Wave **B** lags wave **A** by θ

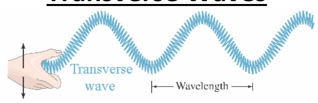
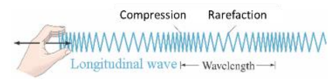
8.3 Intensity

- Rate of energy transmitted per unit area perpendicular to direction of wave propagation.

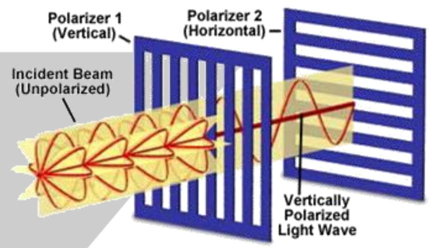
$$Intensity = \frac{Power}{Cross\ Sectional\ Area}$$

$$Intensity \propto (Amplitude)^2$$

8.4 Transverse and Longitudinal

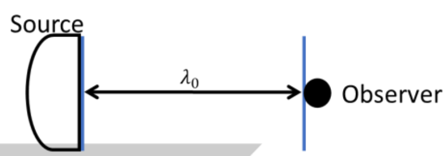
Transverse Waves	Longitudinal Waves
	
• **Oscillation of wave particles perpendicular to direction of propagation**	• **Oscillations of wave particle parallel to direction of propagation**
• Polarization can occur	• Polarization cannot occur
• E.g. light waves	• E.g. sound waves

- **Polarization:** vibration of particles is confined in one direction in the plane normal to direction of propagation

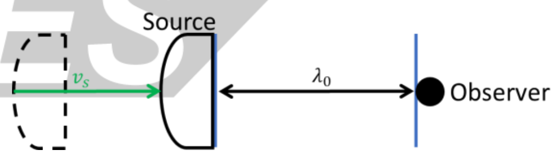


8.5 The Doppler Effect

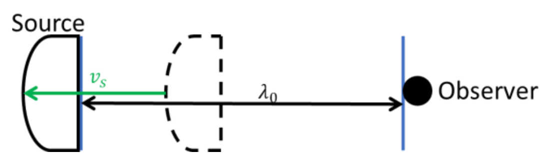
- Arises when source of waves moves relative to observer
- Can occur in all types of waves, including sound & light
- **Source stationary relative to Observer:**



- **Source moving towards Observer:**



- **Source moving away from Observer:**



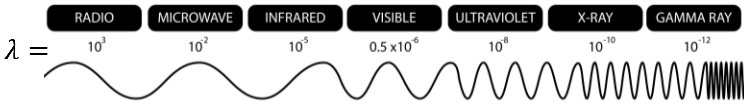
- Change in wavelength leads to change in frequency
- Observed frequency (f_0) is different from actual frequency (f_s); related by equation:

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

where v is speed of wave & v_s is speed of source relative to observer

8.6 Electromagnetic Waves

wavelength **decreases** and frequency **increases** →



All electromagnetic waves:

- All travel at the speed of light: 3×10^8m/s
- Travel in free space (don't need medium)
- Can transfer energy
- Are transverse waves

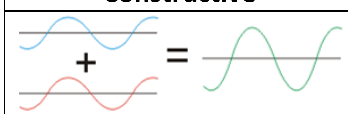
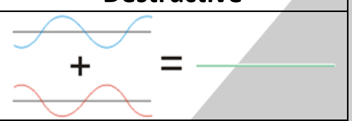
9. Superposition

9.1 Principle of Superposition

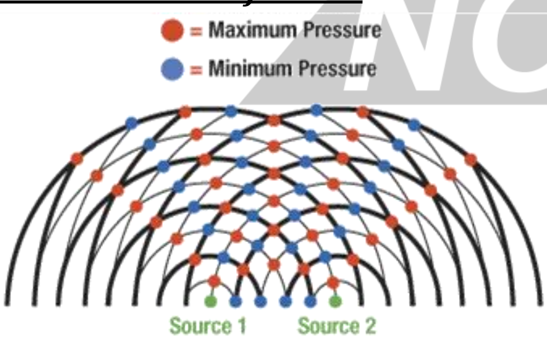
- When two or more waves of the same type meet at a point, the resultant displacement is the algebraic sum of the individual displacements

9.2 Interference and Coherence

- **Interference:** the formation of points of cancellation and reinforcement where 2 coherent waves pass each other
- **Coherence:** waves having a constant phase difference

Constructive	Destructive
	
Phase difference = even $\frac{\lambda}{2}$ **Path difference = even** $\frac{\lambda}{2}$	**Phase difference = odd** $\frac{\lambda}{2}$ **Path difference = odd** $\frac{\lambda}{2}$

9.3 Two-Source Interference

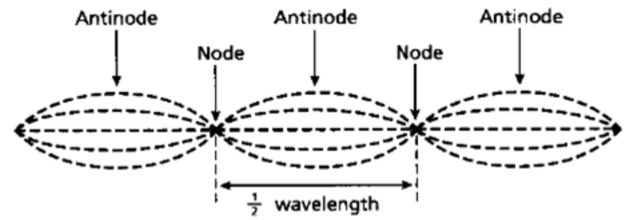


- **Conditions for Two-Source Interference:**
  - Meet at a point
  - Must be of the same type
  - Must have the same plane of polarization
- **Demonstrating Two-Source Interference:**

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

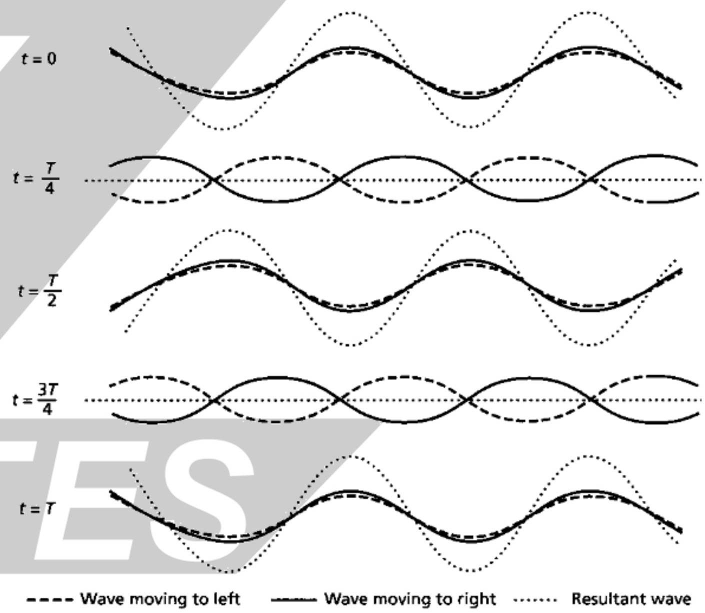
9.4 Formation of Stationary waves

- 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
- **Antinode:** region of constructive superposition where waves meet in phase ∴ particle vibrate with max amp



- Neighboring nodes & antinodes separated by $^1/_2\,\lambda$
- Between 2 adjacent nodes, particles move in phase and they are out of phase with the next two nodes by π

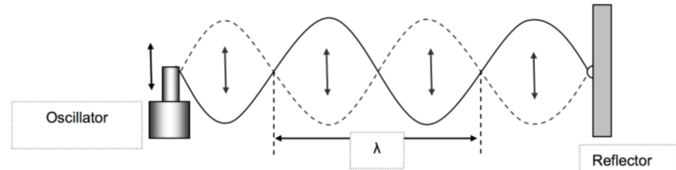
Stationary wave at different times:



9.5 Stationary Wave Experiments

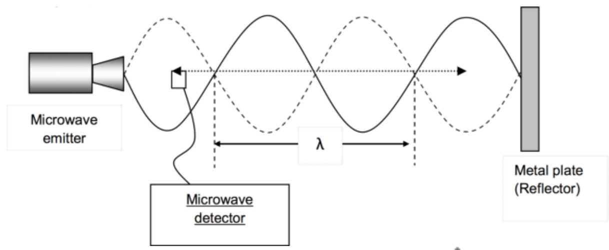
Stretched String:

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



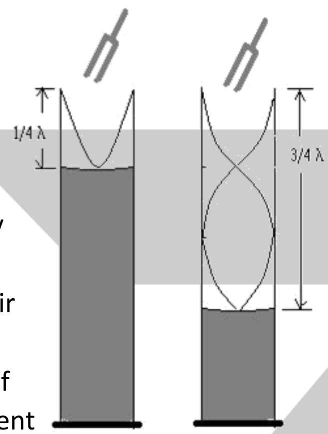
Microwaves:

- 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**

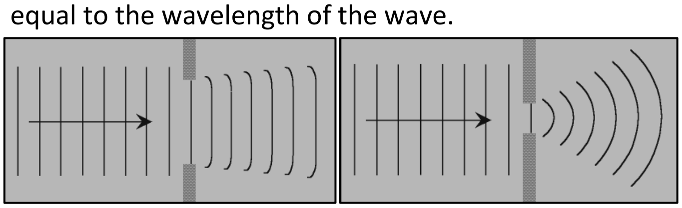


9.6 Stationary and Progressive Waves

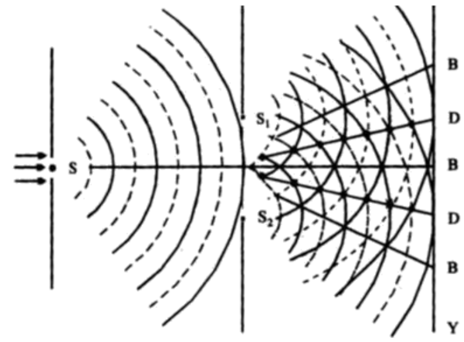
Stationary Waves	Progressive Waves
Stores energy	Transmits energy
Have nodes & antinodes	No nodes & antinodes
Amplitude increases from node to antinode	Amplitude constant along length of the wave
Phase change of π at node	No phase change

9.7 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.



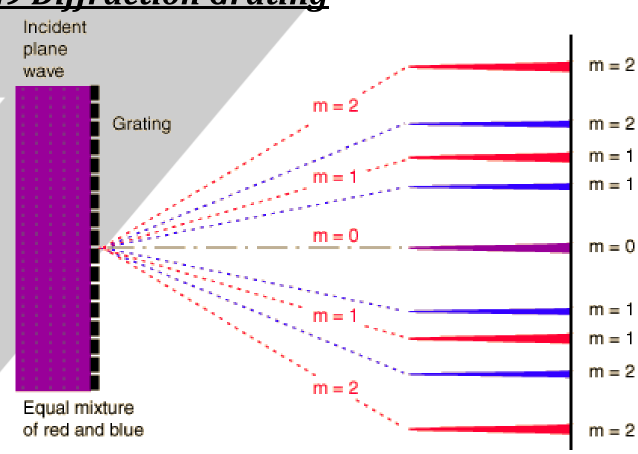
9.8 Double-Slit Interference



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

Where a = split separation
D = distance from slit to screen
x = fringe width

9.9 Diffraction Grating



$$d \sin\theta = n\lambda$$

Where d = distance between successive slits
= reciprocal of number of lines per meter
θ = angle from horizontal equilibrium
n = order number
λ = wavelength

Comparing to double-slit to diffraction grating:

- Maxima are sharper compared to fringes
- Maxima very bright; more slits, more light through

10. Electric Fields

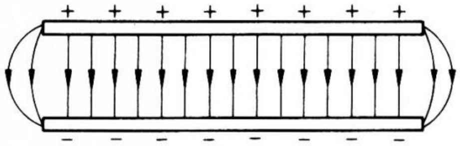
10.1 Concept of Electric Field

- Can be described as a field of force; it can move charged particles by exerting a force on them
- **Positive** charge moves in direction of the electric field: they **gain** E_K and **lose** E_P

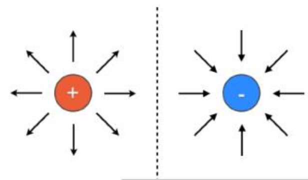
- **Negative** charge moves in opposite direction of the electric field: they **lose** E_K and **gain** E_P

10.2 Diagrammatic Representation

- **Parallel plates:**



- **Points:**



10.3 Electric Field Strength

- Force per unit positive charge acting at a point; a vector
- Units: NC^{-1} or Vm^{-1}

$$E = \frac{F}{q} \qquad E = \frac{V}{d}$$

- E is the electric field strength
- F is the force
- q is the charge
- V is potential difference
- d is distance between plates
- The higher the voltage, the stronger the electric field
- The greater the distance between the plates, the weaker the electric field

11. Current of Electricity

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

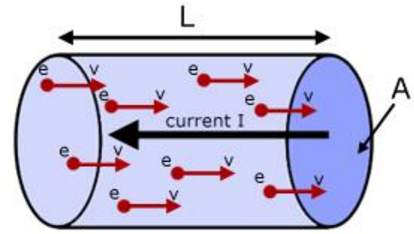
$$Q = It$$

- **Coulomb:** charge flowing per second pass a point at which the current is one ampere
- **Charge is quantized:** values of charge are not continuous they are discrete
- All charges are multiples of charge of 1e: 1.6x10^{-19}C
- **Potential Difference:** two points are a potential difference of 1V if the work required to move 1C of charge between them is 1 joule
- **Volt:** joule per coulomb

$$W = VQ$$

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

11.1 Current-Carrying Conductors



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

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

$$vol.of\ container = LA \qquad t = \frac{L}{v}$$

$$no.of\ free\ electrons = nLA$$

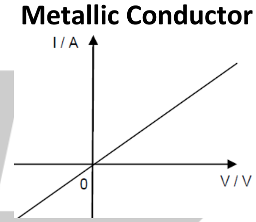
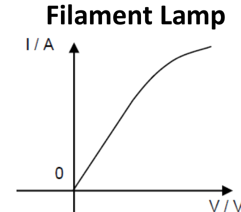
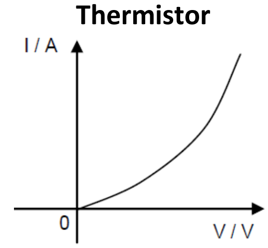
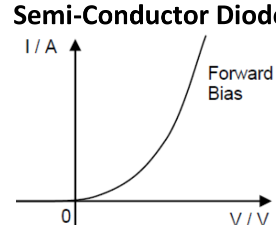
$$total\ charge = Q = nLAq$$

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

$$I = Anvq$$

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

11.2 Current-P.D. Relationships

Metallic Conductor	Filament Lamp
 **Ohmic conductor** V/I ratio constant	 **Non-ohmic conductor** Volt ↑, Temp. ↑, Vibration of ions ↑, Collision of ions with e⁻ ↑, Resistance ↑
Thermistor  **Non-ohmic conductor** Volt ↑, Temp. ↑, Released e⁻ ↑, Resistance ↓	**Semi-Conductor Diode**  **Non-ohmic conductor** Low resistance in one direction & infinite resistance in opposite

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

11.3 Resistance

- **Resistance:** ratio of potential difference to the current
- **Ohm:** volt per ampere

$$V = IR$$

- **Resistivity:** the resistance of a material of unit cross-sectional area and unit length

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

12. D.C. Circuits

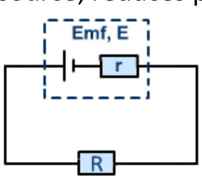
- **Electromotive Force:** the energy converted into electrical energy when 1C of charge passes through the power source

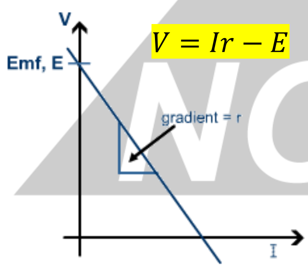
12.1 p.d. and e.m.f

Potential Difference	Electromotive Force
work done per unit charge	
energy transformed **from electrical to other** forms per unit charge	energy transformed **from other forms to electrical**

12.2 Internal Resistance

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





$V = Ir - E$

Voltage across resistor: $V = IR$
Voltage lost to internal resistance: $V = Ir$
Thus e.m.f.: $E = IR + Ir$

$$E = I(R + r)$$

12.3 Kirchhoff's 1st Law

Sum of currents into a junction
IS EQUAL TO
Sum of currents out of junction.

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

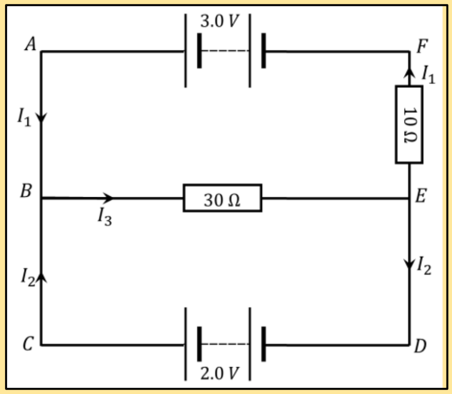
12.4 Kirchhoff's 2nd Law

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

12.5 Applying Kirchhoff's Laws

Example: Calculate the current in each of the resistors



Using Kirchhoff's 1st Law:

$$I_3 = I_1 + I_2$$

Using Kirchhoff's 2nd Law on loop $\boldsymbol{ABEF}$:

$$3 = 30I_3 + 10I_1$$

Using Kirchhoff's 2nd Law on loop $\boldsymbol{CBED}$:

$$2 = 30I_3$$

Using Kirchhoff's 2nd Law on loop $\boldsymbol{ACDF}$:

$$3 - 2 = 10I_1$$

Solve simulataneous equations:

$$I_1 = 0.100 \qquad I_2 = -0.033 \qquad I_3 = 0.067$$

12.6 Deriving Effective Resistance in Series

From Kirchhoff's 2nd Law:

$$E = \sum IR$$
$$IR = IR_1 + IR_2$$

Current constant therefore cancel:

$$R = R_1 + R_2$$

12.7 Deriving Effective Resistance in Parallel

From Kirchhoff's 1st Law:

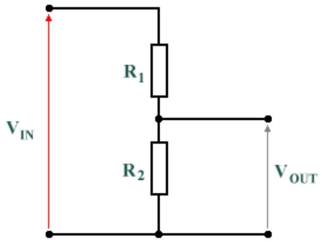
$$I = \sum I$$
$$I = I_1 + I_2$$
$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2}$$

Voltage constant therefore cancel:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

12.8 Potential Divider

- A potential divider divides the voltage into smaller parts.



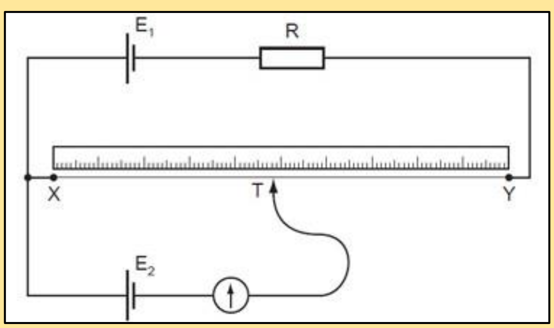
$$\frac{V_{out}}{V_{in}} = \frac{R_2}{R_{Total}}$$

- Usage of a thermistor at R_1:
  - Resistance decreases with increasing temperature.
  - Can be used in potential divider circuits to monitor and control temperatures.
- Usage of an LDR at R_1:
  - Resistance decreases with increasing light intensity.
  - Can be used in potential divider circuits to monitor light intensity.

12.9 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
- 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: E_1 is 10 V, distance XY is equal to 1m. The potentiometer is balanced at point T which is 0.4m from X. Calculate E_2



$$\frac{E_1}{E_2} = \frac{L_1}{L_2}$$

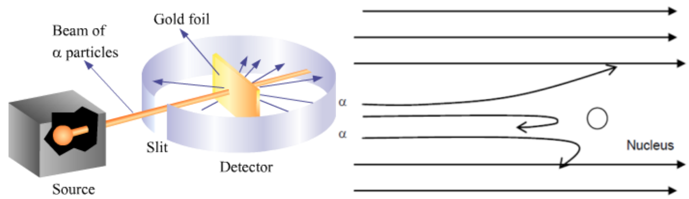
$$\frac{10}{E_2} = \frac{1}{0.4}$$

$$E_2 = 4V$$

13. Nuclear Physics

13.1 Geiger-Marsden α-scattering

- 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:
  - 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

13.2 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

13.3 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.

13.4 Radiations

	α-particle	β-particle β^-	β-particle β^+	γ-ray
Identity	Helium nucleus	Fast-moving electron/positron		Electro-magnetic
Symbol	${}^4_2He$	${}^{0}_{-1}e$	${}^{0}_{+1}e$	γ
Charge	$+2$	-1	$+1$	0
Relative Mass	4	$\frac{1}{1840}$		0
Speed	Slow (10^6 ms^{-1})	Fast (10^8 ms^{-1})		V of Light (3×10^8 ms^{-1})
Energy	Discrete	Varying		
Stopped by	Paper	Few mm of aluminum		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	Attracted to -ve	Undeflected

13.5 Types of Decays

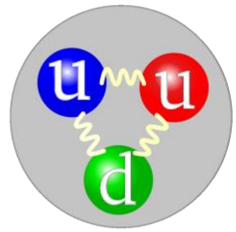
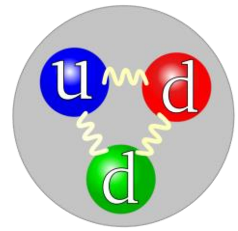
- **α-decay:** loses a helium proton
- **β^--decay:** neutron turns into a proton and an electron & electron antineutrino are emitted
- **β^+-decay:** proton turns into a neutron and a positron & electron neutrino are emitted
- **γ-decay:** a nucleus changes from a higher energy state to a lower energy state through the emission of electromagnetic radiation (photons)

13.6 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	$+2/3$
Down	d	$-1/3$
Strange	s	$+1/3$

- **Quark Models:**

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

- All particles have their corresponding **antiparticle**
- A particle and its antiparticle are essentially the same except for their charge
- **Table of Antiquarks**:

Antiquark	Symbol	Charge
Anti-Up	$\bar{u}$	$-2/3$
Anti-Down	$\bar{d}$	$+1/3$
Anti-Strange	$\bar{s}$	$-1/3$

- These antiquarks combine to similarly form respective antiprotons and antineutrons

13.7 Quark Nature of β-decay

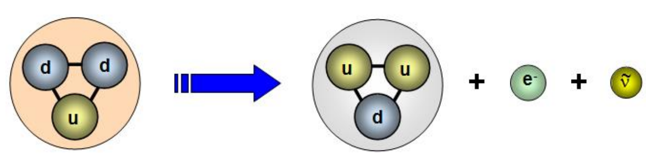
- Conventional model of β-decay:
  - **β^--decay:**

$$n \rightarrow p + \beta^- + \bar{v}$$

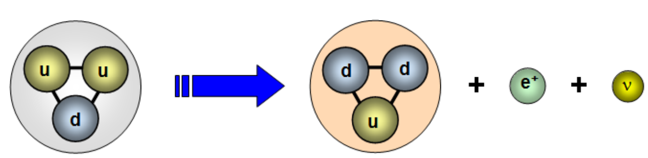
  - **β^+-decay:**

$$p \rightarrow n + \beta^+ + v$$

- Quark model of β-decay:
  - **β^--decay:**

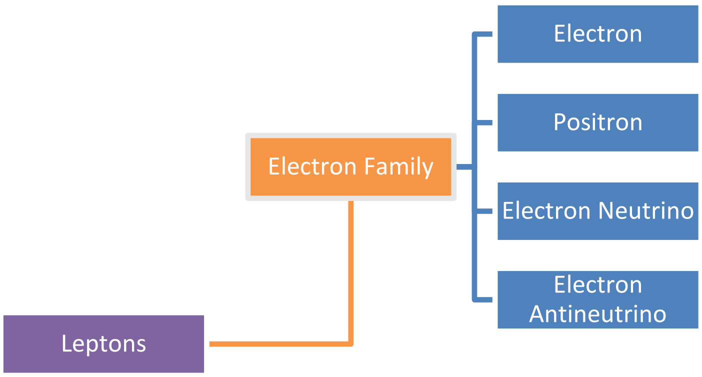


  - **β^+-decay:**



- Quarks undergo change to another quark in what is called a **'weak interaction'**

13.8 Particle Families



- There are other families under Leptons
- Leptons are a part of elementary particles

- There are other families under Hadrons too
- Hadrons are a part of composite particles