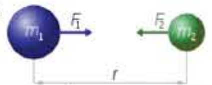
Gravitational Fields

Kepler's 3rd Law

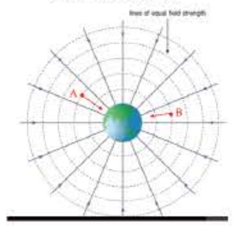
$$\frac{GM_s}{4\pi^2} = \frac{r^3}{T^2}$$

Newton's Law of Universal Gravitation states that:

"Any objects that possesses mass experience a force of attraction, called gravity."



Non-uniform



Uniform

$$F_g = \frac{Gm_1m_2}{r^2}$$

Where F represents the force due to gravity (N)
m_1 represents 1st mass (kg)
m_2 represents 2nd mass (kg)
r represents the radius of separation (m)
G represents the universal gravitational constant $= 6.67 \times 10^{-11}$ (Nm²kg⁻²)

$$g = \frac{GM}{r^2}$$

Where g represents the gravitational field strength (Nkg⁻¹)
M represents mass of Earth (kg)
r represents the radius of separation (m)
G represents the universal gravitational constant (6.67×10^{-11} Nm²kg⁻²)

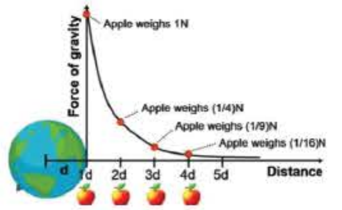
$$g \propto \frac{1}{r^2}$$

For same m1

$$\frac{g_1}{g_2} = \left(\frac{r_2}{r_1}\right)^2$$

Circular Orbits

$$a = \frac{4\pi^2 r}{T^2},\quad v = \frac{2\pi r}{T},\ \text{and,}\quad F_C = \frac{mv^2}{r}$$

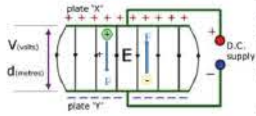


Equations of force upon a satellite:

$$F = \frac{GMm}{r^2} = \frac{mv^2}{r} = \frac{4\pi^2 rm}{T^2} = mg$$

Equations of acceleration of a satellite:

$$a = \frac{GM}{r^2} = \frac{v^2}{r} = \frac{4\pi^2 r}{T^2} = g$$



$F = Eq$

$E = \frac{V}{d}$

$W = Vq$

Work done (W) = Change in Energy (ΔE)

$Vq = \frac{1}{2}mv^2$

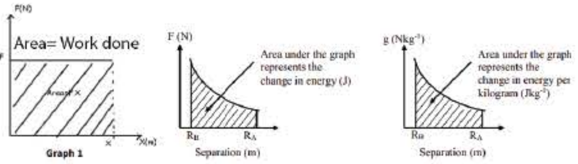
Energy changes in gravitational field

$W = Fs\cos\theta$

Where W represents Work (Joules)
F represents Force (N)
s represents displacement (m)
θ represents the angle between the force and displacement (°)

$E_{gp} = mgh$ or $\Delta E_{gp} = mg\Delta h$

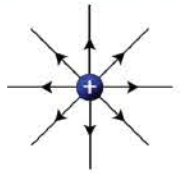
Where E_{gp} represents gravitational potential energy (J)
m represents mass (kg)
g represents the gravitational field strength (Nkg⁻¹)
h represents the elevated height (m)

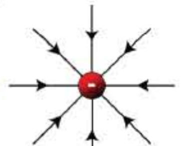


Electric Fields

Unlike gravitational fields which only create attraction between object, an electric field can create both an **attractive** or **repulsive force** depending on the charge located within the field. An electric field is a **vector**, it has both **magnitude and direction.**

Electric field lines travel from a **positive charge to a negative charge.**





Coulomb's Law

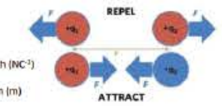
$$F = \frac{kq_1q_2}{r^2}$$

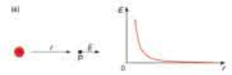
Where F represents the Coulomb force (N)
q_1 represents 1st charge (C)
q_2 represents 2nd charge (C)
r represents the radius of separation (m)
k represents Coulomb's constant $= 8.99 \times 10^9$ (Nm2C-2)

Electric Field Strength

$$E = \frac{kQ}{r^2}$$

Where E represents the electric field strength (NC⁻¹)
Q represents the charge (C)
r represents the radius of separation (m)
k represents Coulomb's constant $= 8.99 \times 10^9$ (Nm²C⁻²)

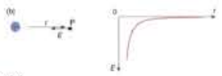




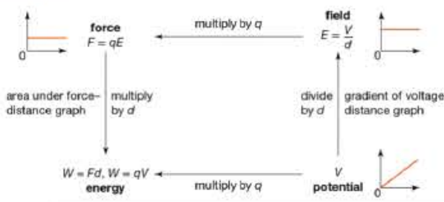
$E = \frac{F}{q}$ or $F = Eq$

Where E represents the electric field strength (NC⁻¹)
F represents the force (N)
q represents the charge (C)

Graph A
When the central charge is positive, then the electric field radiates away from the central charge in the same vector direction as the radius. Accordingly both the electric field and radius are graphed as positive quantities.



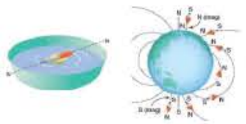
Graph B
When the central charge is negative, then the electric field radiates towards the central charge in the opposite vector direction to the radius. Accordingly the electric field is a graphed as a positive quantity and the radius as a positive quantities.



Magnetic Fields

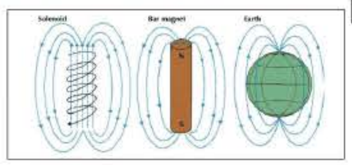
Aligned domains

- North seeking pole (**North pole**)
- South seeking pole (**South pole**)

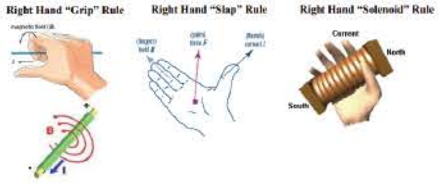


"A magnetic field describes the property of the space around a magnet that causes an object in that space to experience a force due only to the presence of the magnet."

Magnetic field strength (B) is measured in **Tesla (T).**



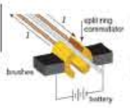
Right Hand "Grip" Rule **Right Hand "Slap" Rule** **Right Hand "Solenoid" Rule**



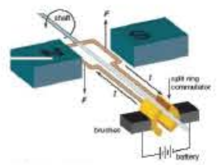
DC Motors

$F = BIl$

Where F = Force (N)
B = Magnetic field strength (T)
I = Current (A)
l = Length (m)



Split Ring Commutator
This device alters the direction of the supply DC current entering into the coil every 180° rotation. It does so when the coil is perpendicular to the magnetic field. Thereby allows a continuous rotation in one direction.



Magnetic Forces on Charged Particles

Fingers – in the direction of the magnetic field (B) [North → South]
Thumb – in the direction of the charge velocity
Palm – in the direction of the force upon the positive charged particle

$F = Bqv$

Where F represents Force (N)
B represents the magnetic field strength (T)
q represents charge (C)
v represents velocity (ms⁻¹)

$$r = \frac{mv}{Bq}$$

Where r represents the radius of the circular motion (m)
m represents the mass of the charged particle (kg)
v represents the velocity of the charged particle (ms⁻¹)
B represents the magnetic field strength (T)
q represents the charge of the particle (C)

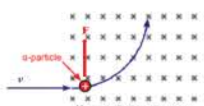


Figure 1

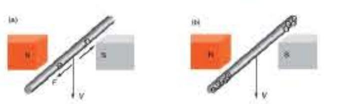
Making Electricity

$\varepsilon = Blv$

Where ε represents the induced emf (Volts)
B represents the magnetic field strength (T)
l represents the length of the rod in the magnetic field (m)
v represents the speed of the rod (ms-1)

$\Phi_B = BA$

Where Φ_B = Magnetic flux (Wb)
B = Magnetic field strength (T)
A = Area (m²)



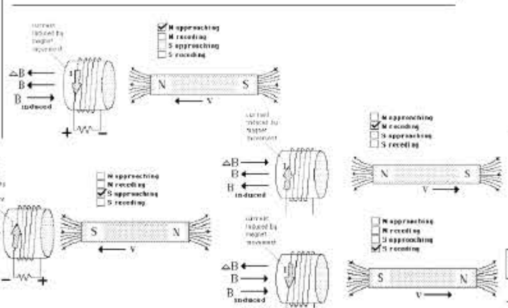
Electrons are free to move and create a negative end. However, cations are fixed within the lattice, but the lack of electrons present result in a positive end.
This charge separation, caused by a magnetic field, results in an **induced voltage** or **EMF.**

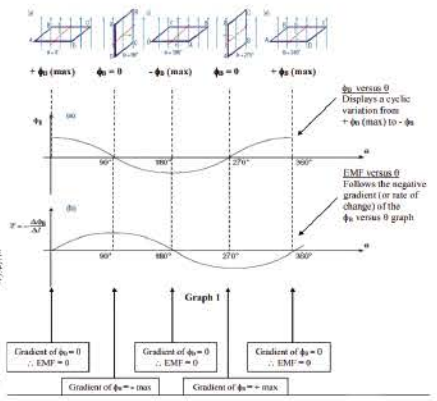
Induced EMF

$$\varepsilon_{avg} = -\frac{N\Delta\Phi_B}{\Delta t}$$

Where ε_{avg} = Average electromotive force (V)
N = No. of turns in coil
$\Delta\Phi_B$ = Change in magnetic flux (Wb)
Δt = Change in time (sec)

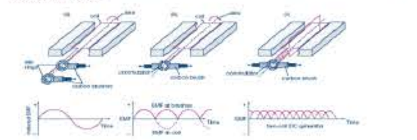
Lenz's Law



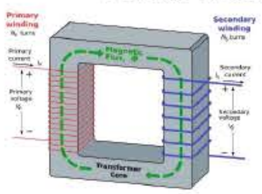


Alternators and DC Generators

A rotating coil in a magnetic field induces a sinusoidal EMF. This EMF can be can be used to either produce an AC output voltage or a DC output voltage depending on the connection between the coil and the external circuit.



Transformers



$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$$

Where V_s = Voltage in the secondary coil
V_p = Voltage in the primary coil
N_s = Number of turns in the secondary coil
N_p = Number of turns in the primary coil
I_p = Current in the primary coil
I_s = Current in the secondary coil

Power in the primary coil = Power in the secondary coil
$P_p = P_s$

∴ $V_pI_p = V_sI_s$

If $V_s > V_P$
If $V_s < V_P$

Transformer is classified as a **"Step-Up"** transformer
Transformer is classified as a **"Step-Down"** transformer

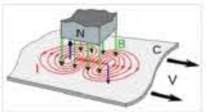
A transformer as shown in **Figure 1** is a device that consists of an **iron core** and an input and output, or rather a **primary coil** and a **secondary coil**. When an **AC voltage** is applied to the primary coil an **alternating magnetic field** is established within the **iron core**. This in turn will induce an **alternating voltage** in the **secondary coil.**

The induced voltage (or current) located at the secondary coil depends upon the:

- input voltage
- number of turns in both the primary and secondary coils

Eddy Currents

Eddy currents can cause **heating** in the **soft iron core** of a transformer. To overcome this, transformers are often made of **thin layers of soft iron** separated by **insulated layers**, as shown in **Figure 3**. This reduces the build-up of eddy currents and reduces the heating effect within the transformer.



Power Transmission

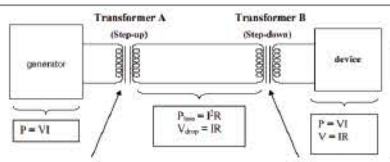
$$R = \frac{\rho L}{A}$$

Where R = Resistance of cable (Ω)
ρ = Resistivity of cable (Ωm)
L = Length of cable (m)
A = Cross sectional area (m²)

$$\%P_{loss} = \frac{P_{loss}}{P_s} \times 100$$

$P_{loss} = I^2R$

Where P_{loss} = Power loss in cable (W)
I = Current (A)
R = Resistance of cable (Ω)



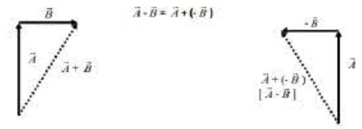
As $P_{loss} \propto I^2$, transmission of power over considerable distances is optimised at relative **high voltages** and **low currents**. The standard arrangement used consists of a pair of transformers:

Transformer A
$N_s/N_P = V_s/V_P = I_P/I_s$
$P_P = P_S$
$V_P = V_{gen}$
$I_P = I_{gen}$
$V_S = V$ @ start of transmission on line
$I_S = I$ on transmission line

Transformer B
$N_s/N_P = V_s/V_P = I_P/I_s$
$P_P = P_S$
$V_P = V$ @ end of transmission on line $= V_S(A) - V_{drop}$
$I_P = I_S(A)$
$V_S = V_{device}$
$I_S = I_{device}$

$$\%P_{loss} = \frac{P_{loss}}{P_s} \times 100$$

Vectors

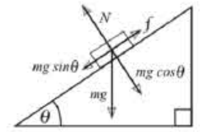


Newton's Laws of Motion

#1 "A body will travel at a constant speed in a constant direction, unless acted upon by an external force" (Inertia)

#2 "An objects acceleration is proportional to the applied force and inversely proportional to its mass."
F = ma, or more accurately; a = F/m

#3 "Every force has an equal & opposite force"
Eg. A Person leaning upon a wall applies a force which is equal, but in the opposite direction, as the force applied by the wall upon the person.
$F_{of\ person\ on\ wall} = -F_{of\ wall\ on\ person}$



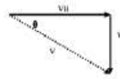
All object "sliding" down a **frictionless** inclined plane have an acceleration of:
a = g sin θ

Horizontal Projectile Motion

Horizontal motion
There is **no horizontal force** acting upon the vehicle, therefore **no acceleration.**
∴ horizontal velocity (v_H) remains constant for the entire motion.

Vertical motion
Weight force of the vehicle (due to gravity) is present, therefore an **acceleration of 10 ms⁻² (g).**
∴vertical velocity (v_v) increases with time (accelerates)
∴vertical motion can be analysed using the various equations of constant acceleration.

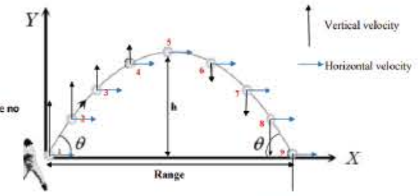
Add the vertical and horizontal velocity vectors



$v^2 = v_H^2 + v_v^2$
$v = \sqrt{v_H^2 + v_v^2}$
$= \sqrt{40^2 + 31.3^2}$
$= 51.0$ ms⁻¹

$\tan\theta = v_v/v_H$
$\therefore \theta = \tan^{-1}(v_v/v_H)$
$\theta = \tan^{-1}(31.3/40)$
$\theta = 38.0°$

Oblique Projectile Motion



Horizontal motion
Upon leaving the bat, there is **no horizontal force** acting upon the ball, therefore **no acceleration.**
∴ horizontal velocity (v_H) remains constant for the entire motion.

Vertical motion
From projection to position.5
Upon leaving the bat, gravity decelerates the ball at a rate of **9.8 ms⁻² (g).**
∴vertical velocity (v_v) decreases with time

At position.5
At the highest displacement, the v_v is 0 ms⁻¹

From position.5 to impact
Gravity now accelerates the cannon ball at a rate of **9.8 ms⁻² (g).**
∴v_v increases with time

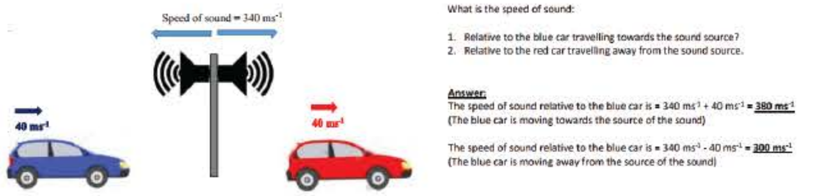
Horizontal initial velocity: $u_H = u\cos\theta$
Vertical initial velocity: $u_v = u\sin\theta$

Time of flight, $t = \frac{2u\sin\theta}{g}$

Max height reached, $h = \frac{(u\sin\theta)^2}{2g}$

Horizontal range, $R = \frac{u^2\sin 2\theta}{g}$

Classical Relativity



What is the speed of sound:

1. Relative to the blue car travelling towards the sound source?
2. Relative to the red car travelling away from the sound source.

Answer:
The speed of sound relative to the blue car is = 340 ms⁻¹ + 40 ms⁻¹ = **380 ms⁻¹**
(The blue car is moving towards the source of the sound)

The speed of sound relative to the blue car is = 340 ms⁻¹ - 40 ms⁻¹ = **300 ms⁻¹**
(The blue car is moving away from the source of the sound)

Mass - Energy

$E = mc^2$

Where E represents energy (Joules)
M represents mass (kilograms)
c represents the speed of light (3.0×10^8 ms⁻¹)

$E_{total} = E_k + E_{rest} = mc^2$

Where E_{total} represents the objects total energy (Joules)
E_k represents the objects kinetic energy (Joules)
E_{rest} represents the rets energy of an object (Joules)

When objects are rest
If an object is not moving in the reference frame of an observer there is no kinetic energy and $E = mc^2$ is equal to the **rest-energy** of an object.

$m = m_0\gamma$

Where m represents the relativistic mass (kg)
m_0 represents the rest mass (kg)
γ represents the Lorentz factor

Special Relativity

Einstein's two postulates for his theory of special relativity that:

1. *the laws of physics are the same in all inertial (non-accelerated) frames of reference*
2. *the speed of light has a constant value for all observers regardless of their motion or the motion of the source*

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Where γ represents the Lorentz factor
v represents the speed (ms⁻¹)
c represents the speed of light (3.0×10^8 ms⁻¹)

Time Dilation

$$t_0 = \frac{2L}{c}$$

Where t_0 represents proper time (sec)
L represents the length between mirrors A & B (m)
c represents the speed of light (3.0×10^8 ms⁻¹)

$t = t_0\gamma$

Where t represents the dilated time (sec)
t_0 represents the proper time (sec)
γ represents the Lorentz factor

Length Contraction

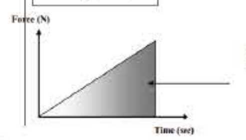
$$L = \frac{L_0}{\gamma}$$

Where L represents the contracted length (m)
L_0 represents the proper length (m)
γ represents the Lorentz factor

Momentum (P)

P = mv, where
P is momentum (kgms⁻¹)
m is mass (kg)
v is velocity (ms⁻¹)

Impulse = force x time
I = Ft (Ns)



The area under a Force – Time graph represents the: impulse delivered & change of momentum

Circular Motion

$$v = \frac{2\pi r}{T}$$

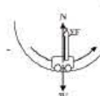
Where v represents speed (ms⁻¹)
r represents radius (m)
T represents period (s)

$$a = \frac{v^2}{r}$$

Where a represents centripetal acceleration (ms⁻²)
v represents speed (ms⁻¹)
r represents radius (m)

$$a = \frac{4\pi^2 r}{T^2}$$

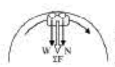
$$F_{net} = \Sigma F = ma = \frac{mv^2}{r}$$



$\Sigma F = F_C = \frac{mv^2}{r} = N + W$ (as a vector addition)

$\Sigma F = F_C = \frac{mv^2}{r} = N - W$ (taking towards the centre as positive)

ie. The normal reaction force is greater than your weight force (N > W)
∴ you feel your seat is **pushing against you** and you **feel heavier**



$\Sigma F = F_C = \frac{mv^2}{r} = N + W$ (as a vector addition)

$\Sigma F = F_C = \frac{mv^2}{r} = N + W$ (taking towards the centre as positive)

ie. The weight force is greater than your normal reaction force (W > N)
∴ you feel your **little force** from your seat, therefore you **feel lighter.**

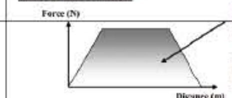
Collisions

Elastic & Inelastic Collisions
Nearly all collisions on Earth are **inelastic**, very few even approach being truly **elastic.**
In an **elastic collision**, kinetic energy (E_k) **is conserved.**
E_k (before collision) = E_k (after collision)

In an **inelastic collision**, kinetic energy (E_k) **is not conserved**
E_k (before collision) ≠ E_k (after collision)

FΔt = mΔv
[Change of impulse = Change of momentum]

Force – Distance Graph



The area under a Force v Distance graph represents the work done and the change of energy (Joules).

To calculate the area under the graph, either use area equations (ie. squares, triangles or trapezoids) or the "counting squares" technique.

NB: 1 Joule = 1 Nm

W = ΔE = Fx

Where:
W represents Work (Joules)
ΔE represents Change in energy (Joules)
F represents Force (Newtons)
x represents Distance (Meters)

P = W/Δt

Where:
P represents Power (Watts)
W represents Work done (Joules)
Δt represents Change in time (Seconds)

Hooke's Law

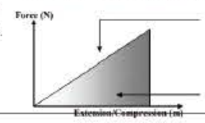
F = kΔx

Where:
F represents Force (Newtons)
Δx represents Extension/Compression (Meters)
k represents Spring Constant (N/m)

$E_s = \frac{1}{2}k\Delta x^2$

$E_s = \frac{1}{2}F\Delta x$

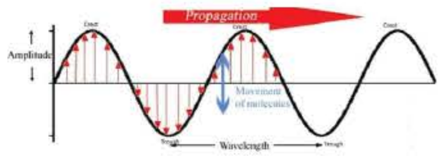
Where:
E_s represents Elastic Potential Energy (Joules)

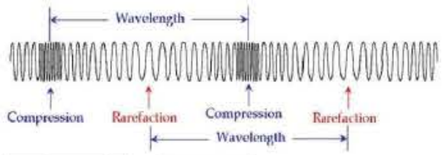


The gradient (rise/run) represents the **spring constant (k).**
It provides a measure of the amount of force required to extend or compress a spring a unit length (ie. meter).

The area represents the elastic potential energy stored in the spring.

Wave Model





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

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

Interference

Superposition Waves pass through each other without being disturbed. The net displacement of the medium at any point in space or time, is simply the sum of the individual wave displacements

Constructive interference
Constructive interference occurs when two pulses superimpose to give a maximum disturbance of a medium.
In such a case, two crests or troughs overlap or superimpose to create a single resultant pulse of larger amplitude.

Destructive interference
Destructive interference occurs when two pulses superimpose cancel one another.
In such a case, a crests and trough overlap or superimpose to completely cancel one another out.

Two wave sources are **coherent** if they are creating waves with the **same frequency** and a **constant phase difference**.

An **antinode** is a point where **constructive interference** always occurs.
A **node** is a point where **destructive interference** always occurs.

Path Difference = $|S_1P - S_2P|$

Constructive interference occurs if

Path Difference (PD) = $n\lambda$

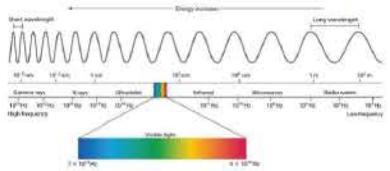
Destructive interference occurs if

Path Difference (PD) = $(n - \frac{1}{2})\lambda$

Doppler Effect

	Moving detector		Moving source	
	Speed of wave relative to detector	Detected frequency	Wavelength	Detected frequency
Towards	↑	↑	↓	↑
Away	↓	↓	↑	↓

When the **wavelength of light increases** (↑ λ), this is known as **redshift**.
When the **wavelength of light decreases** (↓ λ), this is known as **blueshift**.

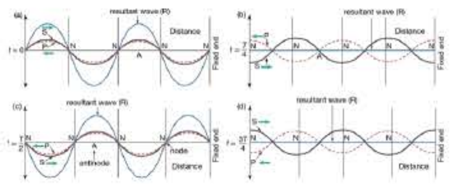


Resonance

Resonance is the vibration of an object caused when a forced oscillation matches the object's natural frequency of vibration.

Standing Waves

A **standing wave** is the result of the **superposition** of two waves with the same **amplitude and frequency** travelling in **opposite directions** within the same medium.

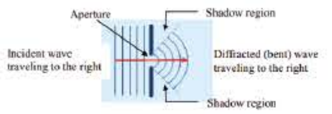


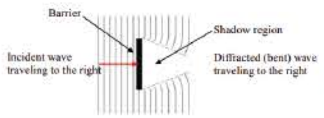
$L = \frac{n\lambda}{2}$ $\lambda = \frac{2L}{n}$ $f = \frac{nv}{2L}$

$L = \frac{n\lambda}{4}$ $\lambda = \frac{4L}{n}$ $f = \frac{nv}{4L}$

Where L is the length of the string (m)
λ is the wavelength (m)
F is the frequency of the string (Hz)
n is the integer representing the mode of vibration (ie. 1, 2, 3, 4 …)

Diffraction





Extent of diffraction $\propto \frac{1}{w}$ Where w represents the gap size

Extent of diffraction $\propto \lambda$ Where λ represents the wavelength (m)

If the ratio of $\frac{\lambda}{w} \geq 1$, diffraction **will be significant**.
If the ratio of $\frac{\lambda}{w} < 1$, diffraction **will not be significant**.

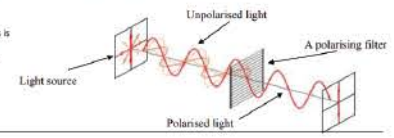
Electro-magnetic Waves

$c = \lambda f$ Where c is the speed of light in a vacuum (3.0×10^8 ms^{-1})
λ is the wavelength (m)
f is the frequency (Hz)

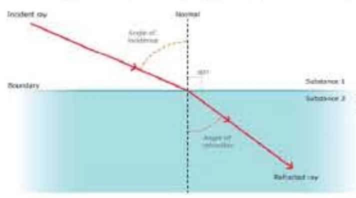
Colour	Violet	Blue	Green	Yellow	Orange	Red
Wavelength (nm)	400	460	525	580	625	700
Frequency [$\times 10^{12}$ (Hz)]	750					429

A **polarised wave** describes a transverse wave for which the oscillations occur in a single plane.

The **polarisation of light** is a property of **transverse waves**. Light from most sources is unpolarised. This means the oscillations in the electric field occur in multiple planes. Polarising filters for light allow **oscillations of the electric field in only one plane**, and absorb oscillations in other planes.



Refraction of Light



$n_{medium} = \frac{v_{light\ in\ vacuum}}{v_{light\ in\ medium}}$

$n_1 \sin(i) = n_2 \sin(r)$ $i_c = \sin^{-1}\left(\frac{n_2}{n_1}\right)$

Where n_1 is the refractive index of the incident medium (medium 1)
n_2 is the refractive index of the refractive medium (medium 2)
i is the angle of incidence (°)
r is the angle of refraction (°)

Total Internal Reflection and Critical Angle
It is possible for light travelling from one medium into a second, **of less optical density**, to refract to such an extent that it **does not escape** out of the second medium, but rather "grazes" along the surface of the material.

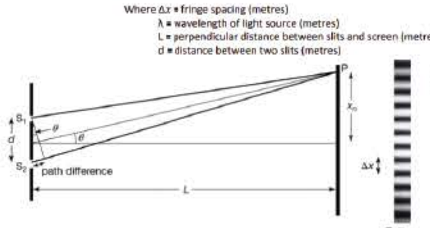
Convex lenses are thick in the middle and thin at the top and bottom.
Concave lenses are thin in the middle and thick at the top and bottom.

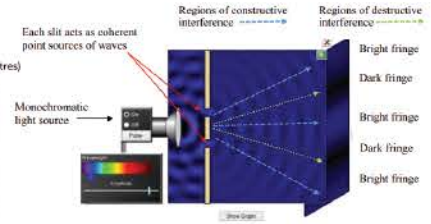
Young's Double Slit

$\Delta x = \frac{\lambda L}{d}$

Path difference (pd) = $d\sin(\theta)$
For bright fringes $n\lambda = d\sin(\theta)$

Where Δx = fringe spacing (metres)
λ = wavelength of light source (metres)
L = perpendicular distance between slits and screen (metres)
d = distance between two slits (metres)





Practical Investigation

the physics concepts specific to the investigation and their significance, including definitions of key terms, and physics representations
the characteristics of scientific research methodologies and techniques of primary qualitative and quantitative data collection relevant to the selected investigation, including experiments (gravity, magnetism, electricity, Newton's laws of motion, waves), and/or the evaluation of a device; precision, accuracy, reliability and validity of data; and distinction between, uncertainty and error
identification and application of relevant health and safety guidelines
methods of organising, analysing and evaluating primary data to identify patterns and relationships including sources of error and uncertainty, and limitations of data and methodologies
independent, dependent and controlled variables

Types of errors

1) Instrumental limitations
Any measuring device can only be used to measure to with a certain degree of fineness.
Our measurements are no better than the instruments we use to make them.

2) Systematic errors and blunders
These are caused by a mistake which does not change during the measurement. For example, if the platform balance you used to weigh something was not correctly set to zero with no weight on the pan, all your subsequent measurements of mass would be too large. Systematic errors do not enter into the uncertainty. They are either identified and eliminated or lurk in the background producing a shift from the true value.

3) Random errors
These arise from unnoticed variations in measurement technique, tiny changes in the experimental environment, etc. Random variations affect precision. Truly random effects average out if the results of a large number of trials are combined.

Repeatability
Completion of experiment more than once to obtain closely agreeing results.
Good practice in improving experimental precision.

Reliability:
Likelihood that another experimenter with different/similar equipment will obtain the same results

Rules for Significant Figures
1. All non-zero digits are significant
2. Zeros between two significant digits are significant
3. A zero after the decimal point that is at the end of a number is significant
4. Zeros that are used only to space a decimal point are not considered significant

Validity
Validity describes "How well do the findings provide a response to research question?"
Generally if a single variable has been manipulated and an accurate outcome has been measured then the experiment would have high validity.

In order to present your findings well, be sure to:

- Provide a clear statement of what was found
- Acknowledge limitations to validity and recommendations for future experimentation, either methodology or development of experiment
- Explain how uncertainties were allocated
- State how your findings answer the research question – link to hypothesis if one was formulated
- State all risks, safety and ethical considerations (working with people/animals) should be acknowledged where appropriate
- Include referencing of research and supporting theory must be included

The Error is the difference between the measured and true value for c
Error = $C_{measured} - C_{true}$

The uncertainty ranges from $C_{measured}$ - Uncertainty to $C_{measured}$ + Uncertainty

1. **Addition and Subtraction: ADD the Absolute Uncertainties**:

$(x \pm \Delta x) - (y \pm \Delta y) = (x - y) \pm (\Delta x + \Delta y)$
$(x \pm \Delta x) + (y \pm \Delta y) = (x + y) \pm (\Delta x + \Delta y)$

2. **Multiplication and Division: ADD the Percentage Uncertainties**:

$(x \pm \Delta x) / (y \pm \Delta y) = (x / y) \pm (\Delta x + \Delta y)$
$(x \pm \Delta x) \times (y \pm \Delta y) = (x \times y) \pm (\Delta x + \Delta y)$

3. **For a number raised to a power**: **MULTIPLY the Percentage Uncertainty by the power**.

$(x \pm \Delta x)^n = (x^n \pm n\Delta x)$

4. **For multiplying a number by a constant** (there are 2 options)

Absolute Uncertainty:
$c(x \pm \Delta x) = cx \pm c(\Delta x)$

Example.10
Consider: 1.5(2.0 ± 0.2) m = (3.0 ± 0.3) m

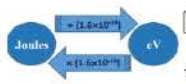
Percentage Uncertainty:
$c(x \pm \Delta x) = cx \pm \Delta x$

Example.11
Consider: 1.5(2.0 m ± 1.0%) = 3.0 m ± 1.0%)

Photoelectric Effect

$E_k = E_{light} - \phi$

1 eV = 1.6×10^{-19} Joules



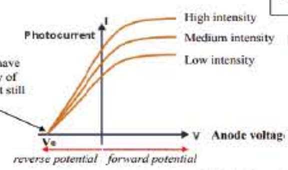
Photocurrent
If a photoelectron has enough kinetic energy to reach the other side (anode) a current will form in the circuit. This current is called a **photocurrent**.

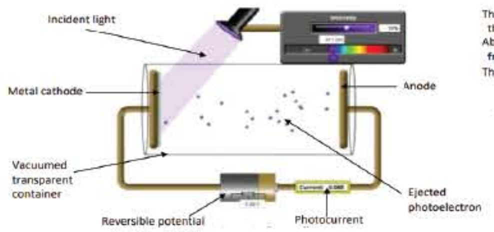
$W = \Delta E_k = qV$ Where W is the work done (Joules or eV)
ΔE_k is the change in kinetic energy (Joules or eV)
q is the charge (Coulombs)
V is the potential difference (Volts)

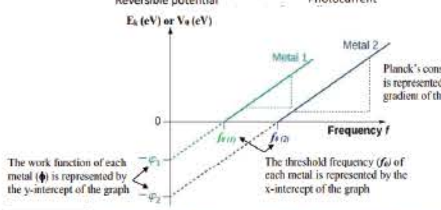
$E_k(max) = eV_0$ Where $E_k(max)$ is the maximum kinetic energy of a photoelectron (Joules or eV)
e is the charge of an electron (Coulombs)
V_0 is the stopping voltage (Volts)

The photocurrent is directly proportional to the intensity: $(I_{ph}) \propto$ Intensity

As all light intensities have the same V_0, the energy of the photoelectrons must still be the same.







Planck's constant (h) is represented by the gradient of the graph

The work function of each metal (ϕ) is represented by the y-intercept of the graph

The threshold frequency (f_0) of each metal is represented by the x-intercept of the graph

$E_k = hf - hf_0$ Where E_k is the kinetic energy of the photoelectron (Joules or eV)
h is Planck's constant (6.63×10^{-34} Js or 4.14×10^{-15} eVs)
f is the frequency (Hz)
f_0 is the threshold frequency (Hz)
ϕ is the work function (Joules or eV)

There is a minimum frequency below which no photocurrent is measured. This is called the **threshold frequency (f_0)**
Above f_0, the **kinetic energy** of photoelectrons **increases proportionally** with the **frequency**: $E_k \propto f$
The photocurrent is not affected by the frequency: $I_{ph} \not\propto f$

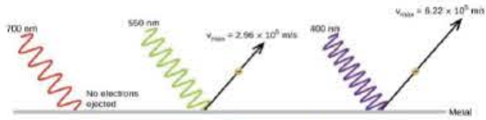
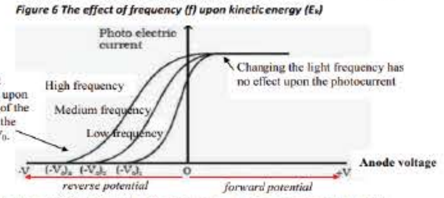


Figure 6 The effect of frequency (f) upon kinetic energy (E_k)

Changing the light frequency impacts upon the kinetic energy of the photoelectron and the stopping voltage V_0.



So in terms of the Photoelectric Effect investigation, the wave model incorrectly predicts that:
- Increasing the intensity of light should result in greater kinetic energy of photoelectrons
- Any frequency of light should be able to overcome the work function to eject electrons, as long as the intensity is great enough and/or the light shines for a long enough time

The wave model falls short in its explanation of the Photoelectric Effect as it cannot explain:
- Independence of photoelectron kinetic energy and light intensity
- Existence of a threshold frequency
- No time delay for electron ejection

The "frequency" (or colour) of light is a property of each photon. The **energy of a photon is determined by its frequency.**

$E_{photon} = hc$ or $\frac{hc}{\lambda}$

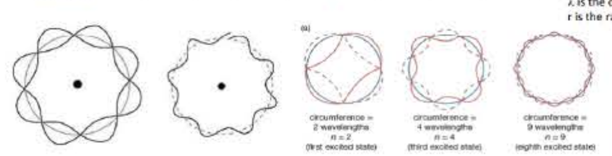
Point 1 - Independence of photoelectron EK and light intensity
- Increasing the intensity of light at the same frequency only increases the number of photons.
- It does not change the energy of each photon.
- This means more electrons will absorb energy and be released, but each electron absorbs the same amount of energy.
- Greater photocurrent, but E_k does not change

Point 2 - Threshold frequency
- An electron is released only if it absorbs at least as much energy as the work function.
- This means the photon energy must be greater than or equal to the work function.
- Photon energy is determined by its frequency.
- So a minimum (or threshold) frequency exists which is required to release a photon.

Point 3 - No time delay
- A photon either has more energy than the work function or it does not.
- Electrons are released immediately if they absorb a photon with more energy than the work function or they are not released at all if there is insufficient energy.
- It does not take time for the electron to gather enough energy.

Photons	Both	Matter
$p = \frac{E}{c}$ $p = \frac{hf}{c}$ $E = hf$	$p = \frac{h}{\lambda}$ $\lambda = \frac{h}{p}$	$p = mv$ $p = \sqrt{2mE_k}$ $E_k = \frac{1}{2}mv^2$

	Momentum (p)	Wavelength (λ)	Mass (m)	Frequency (f)
Matter	✓	✓	✓	✗
Photons	✓	✓	✗	✓



De Broglie Wavelength

$\lambda = \frac{h}{p} = \frac{h}{mv}$ Where λ is the de Broglie wavelength (m)
h is Planck's constant (6.63×10^{-34} Js) **NOT in eV**
p is momentum (kgms^{-1})
m is mass (kg)
v is speed (ms^{-1})

$p = \frac{h}{\lambda} = \frac{E}{c} = \frac{hf}{c}$ Where p is momentum (kgms^{-1})
h is Planck's constant (6.63×10^{-34} Js)
λ is the wavelength of the photon (m)
E is the energy of the photon (Joules)
f is the frequency of the photon (Hz)

Figure 2a
X-Ray diffraction

Figure 2b
Electron diffraction

Figure 2c
Electron diffraction (more mon

- If an electron absorbs light then it will move up to a higher energy level
- If an electron emits light then it will move down to a lower energy level

Electrons have a **de Broglie wavelength** and they exist as **circular waves** around a nucleus. Refer to Figure 1a below.

An electron will only be stable if it forms a **standing wave** in its orbit. This means the circumference of its orbit must be an integer multiple of the electron's de Broglie wavelength.

Hence only specific wavelengths are allowed.

$n\lambda = 2\pi r$

Where n is the energy level number (ie. n=1 for the 1st energy level)
λ is the de Broglie wavelength of the electron (m)
r is the radius of the energy level

$\Delta x \Delta p_x \geq \frac{h}{4\pi}$

Where Δx is the uncertainty in x-position
Δp_x is the uncertainty in x-momentum

If Δx ↑, then Δp_x ↓
If Δx ↓, then Δp_x ↑

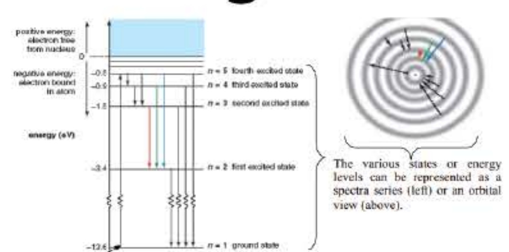


Figure 7 - Atomic energy level view of the spectral series of hydrogen

The first line (directed upwards) on the energy diagram indicates the energy **received** by an electron which has been **excited** from its **ground state** to a higher **excited state** (ie. fourth excited state)

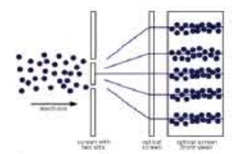


Figure 4a *– Interference pattern with electrons*

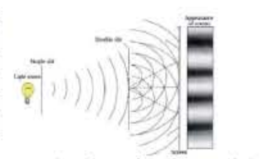


Figure 4b *– Interference pattern with photons*

Comparison of light sources

Light Source	Cause of light production	Features of the light
Laser	Electron transitions in atoms in a gas due to stimulated emission	Coherent, polarised
Synchrotron	Acceleration (deflection) of charged particles (electrons) due to magnetic fields	Wide range of wavelengths, polarised, very intense (can be coherent)
LED	Electron transition in semiconducting material from conduction band to valence band	Can be monochromatic (single wavelength)
Incandescent	Acceleration of charged particles due to thermal vibrations	Continuous spectrum