Wallace Hall Academy

CfE Advanced Higher Physics

Notes

Name ___________________

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	*Symbol*	*Value*	*Quantity*	*Symbol*	*Value*
Gravitational acceleration on Earth	g	$9\cdot8\ \mathrm{m\,s^{-2}}$	Mass of electron	m_e	$9\cdot11\times10^{-31}\ \mathrm{kg}$
Radius of Earth	R_E	$6\cdot4\times10^{6}\ \mathrm{m}$	Charge on electron	e	$-1\cdot60\times10^{-19}\ \mathrm{C}$
Mass of Earth	M_E	$6\cdot0\times10^{24}\ \mathrm{kg}$	Mass of neutron	m_n	$1\cdot675\times10^{-27}\ \mathrm{kg}$
Mass of Moon	M_M	$7\cdot3\times10^{22}\ \mathrm{kg}$	Mass of proton	m_p	$1\cdot673\times10^{-27}\ \mathrm{kg}$
Radius of Moon	R_M	$1\cdot7\times10^{6}\ \mathrm{m}$	Mass of alpha particle	m_α	$6\cdot645\times10^{-27}\ \mathrm{kg}$
Mean Radius of Moon Orbit		$3\cdot84\times10^{8}\ \mathrm{m}$	Charge on alpha particle		$3\cdot20\times10^{-19}\ \mathrm{C}$
Solar radius		$6\cdot955\times10^{8}\ \mathrm{m}$	Planck's constant	h	$6\cdot63\times10^{-34}\ \mathrm{J\,s}$
Mass of Sun		$2\cdot0\times10^{30}\ \mathrm{kg}$	Permittivity of free space	ε_0	$8\cdot85\times10^{-12}\ \mathrm{F\,m^{-1}}$
1 AU		$1\cdot5\times10^{11}\ \mathrm{m}$	Permeability of free space	μ_0	$4\pi\times10^{-7}\ \mathrm{H\,m^{-1}}$
Stefan-Boltzmann constant	σ	$5\cdot67\times10^{-8}\ \mathrm{W\ m^{-2}K^{-4}}$	Speed of light in vacuum	c	$3\cdot0\times10^{8}\ \mathrm{m\,s^{-1}}$
Universal constant of gravitation	G	$6\cdot67\times10^{-11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$	Speed of sound in air	v	$3\cdot4\times10^{2}\ \mathrm{m\,s^{-1}}$

REFRACTIVE INDICES

The refractive indices refer to sodium light of wavelength 589 nm and to substances at a temperature of 273 K.

Substance	*Refractive index*	*Substance*	*Refractive index*
Diamond	2·42	Glycerol	1·47
Glass	1·51	Water	1·33
Ice	1·31	Air	1·00
Perspex	1·49	Magnesium Fluoride	1·38

SPECTRAL LINES

Element	*Wavelength/nm*	*Colour*
Hydrogen	656	Red
	486	Blue-green
	434	Blue-violet
	410	Violet
	397	Ultraviolet
	389	Ultraviolet
Sodium	589	Yellow

Element	*Wavelength/nm*	*Colour*
Cadmium	644	Red
	509	Green
	480	Blue

Lasers

Element	*Wavelength/nm*	*Colour*
Carbon dioxide	9550, 10590	Infrared
Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	*Density/* $\mathrm{kg\ m^{-3}}$	*Melting Point/* K	*Boiling Point/*K	*Specific Heat Capacity/* $\mathrm{J\,kg^{-1}\,K^{-1}}$	*Specific Latent Heat of Fusion/* $\mathrm{J\,kg^{-1}}$	*Specific Latent Heat of Vaporisation/* $\mathrm{J\,kg^{-1}}$
Aluminium	$2\cdot70\times10^{3}$	933	2623	$9\cdot02\times10^{2}$	$3\cdot95\times10^{5}$	....
Copper	$8\cdot96\times10^{3}$	1357	2853	$3\cdot86\times10^{2}$	$2\cdot05\times10^{5}$	....
Glass	$2\cdot60\times10^{3}$	1400	....	$6\cdot70\times10^{2}$	....	....
Ice	$9\cdot20\times10^{2}$	273	....	$2\cdot10\times10^{3}$	$3\cdot34\times10^{5}$	....
Glycerol	$1\cdot26\times10^{3}$	291	563	$2\cdot43\times10^{3}$	$1\cdot81\times10^{5}$	$8\cdot30\times10^{5}$
Methanol	$7\cdot91\times10^{2}$	175	338	$2\cdot52\times10^{3}$	$9\cdot9\times10^{4}$	$1\cdot12\times10^{6}$
Sea Water	$1\cdot02\times10^{3}$	264	377	$3\cdot93\times10^{3}$	....	....
Water	$1\cdot00\times10^{3}$	273	373	$4\cdot19\times10^{3}$	$3\cdot34\times10^{5}$	$2\cdot26\times10^{6}$
Air	1·29	....	....	....	....	....
Hydrogen	$9\cdot0\times10^{-2}$	14	20	$1\cdot43\times10^{4}$	....	$4\cdot50\times10^{5}$
Nitrogen	1·25	63	77	$1\cdot04\times10^{3}$	....	$2\cdot00\times10^{5}$
Oxygen	1·43	55	90	$9\cdot18\times10^{2}$	....	$2\cdot40\times10^{4}$

The gas densities refer to a temperature of 273 K and a pressure of $1\cdot01\times10^{5}$ Pa.

$$v = \frac{ds}{dt}$$

$$a = \frac{dv}{dt} = \frac{d^2 s}{dt^2}$$

$$v = u + at$$

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

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

$$\omega = \frac{d\theta}{dt}$$

$$\alpha = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2}$$

$$\omega = \omega_o + \alpha t$$

$$\theta = \omega_o t + \frac{1}{2}\alpha t^2$$

$$\omega^2 = \omega_o{}^2 + 2\alpha\theta$$

$$s = r\theta$$

$$v = r\omega$$

$$a_t = r\alpha$$

$$a_r = \frac{v^2}{r} = r\omega^2$$

$$F = \frac{mv^2}{r} = mr\omega^2$$

$$T = Fr$$

$$T = I\alpha$$

$$L = mvr = mr^2\omega$$

$$L = I\omega$$

$$E_K = \frac{1}{2}I\omega^2$$

$$F = G\frac{Mm}{r^2}$$

$$V = -\frac{GM}{r}$$

$$v = \sqrt{\frac{2GM}{r}}$$

$$\text{apparent brightness}, b = \frac{L}{4\pi r^2}$$

$$\text{Power per unit area} = \sigma T^4$$

$$L = 4\pi r^2 \sigma T^4$$

$$r_{Schwarzschild} = \frac{2GM}{c^2}$$

$$E = hf$$

$$\lambda = \frac{h}{p}$$

$$mvr = \frac{nh}{2\pi}$$

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

$$\Delta E \, \Delta t \geq \frac{h}{4\pi}$$

$$F = qvB$$

$$\omega = 2\pi f$$

$$a = \frac{d^2 y}{dt^2} = -\omega^2 y$$

$y = A\cos\omega t$ or $y = A\sin\omega t$

$v = \pm\omega\sqrt{(A^2 - y^2)}$

$E_K = \frac{1}{2}m\omega^2(A^2 - y^2)$

$E_P = \frac{1}{2}m\omega^2 y^2$

$y = A\sin 2\pi(ft - \frac{x}{\lambda})$

$\phi = \frac{2\pi x}{\lambda}$

optical path difference $= m\lambda$ or $\left(m + \frac{1}{2}\right)\lambda$

where $m = 0, 1, 2....$

$\Delta x = \frac{\lambda l}{2d}$

$d = \frac{\lambda}{4n}$

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

$n = \tan i_P$

$F = \frac{Q_1 Q_2}{4\pi\varepsilon_o r^2}$

$E = \frac{Q}{4\pi\varepsilon_o r^2}$

$V = \frac{Q}{4\pi\varepsilon_o r}$

$F = QE$

$V = Ed$

$F = IlB\sin\theta$

$B = \frac{\mu_o I}{2\pi r}$

$c = \frac{1}{\sqrt{\varepsilon_o \mu_o}}$

$t = RC$

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

$X_C = \frac{1}{2\pi fC}$

$\mathcal{E} = -L\frac{dI}{dt}$

$E = \frac{1}{2}LI^2$

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

$X_L = 2\pi fL$

$\frac{\Delta W}{W} = \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\Delta Z}{Z}\right)^2}$

$\Delta W = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$

$d = \bar{v}t$

$s = \bar{v}t$

$v = u + at$

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

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

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

$W = mg$

$F = ma$

$E_W = Fd$

$E_P = mgh$

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

$P = \frac{E}{t}$

$p = mv$

$Ft = mv - mu$

$F = G\frac{Mm}{r^2}$

$t' = \frac{t}{\sqrt{1-\left(\frac{v}{c}\right)^2}}$

$l' = l\sqrt{1-\left(\frac{v}{c}\right)^2}$

$f_o = f_s\left(\frac{v}{v \pm v_s}\right)$

$z = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$

$z = \frac{v}{c}$

$v = H_0 d$

$E_W = QV$

$E = mc^2$

$E = hf$

$E_K = hf - hf_0$

$E_2 - E_1 = hf$

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

$v = f\lambda$

$d\sin\theta = m\lambda$

$n = \frac{\sin\theta_1}{\sin\theta_2}$

$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$

$\sin\theta_c = \frac{1}{n}$

$I = \frac{k}{d^2}$

$I = \frac{P}{A}$

path difference $= m\lambda$ or $\left(m + \frac{1}{2}\right)\lambda$ where $m = 0,\ 1,\ 2...$

random uncertainty $= \frac{\text{max. value - min. value}}{\text{number of values}}$

$V_{peak} = \sqrt{2}V_{rms}$

$I_{peak} = \sqrt{2}I_{rms}$

$Q = It$

$V = IR$

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

$R_T = R_1 + R_2 + ...$

$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + ...$

$E = V + Ir$

$V_1 = \left(\frac{R_1}{R_1 + R_2}\right)V_S$

$\frac{V_1}{V_2} = \frac{R_1}{R_2}$

$C = \frac{Q}{V}$

$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$

Additional Relationships

Circle

$circumference = 2\pi r$

$area = \pi r^2$

Sphere

$area = 4\pi r^2$

$volume = \frac{4}{3}\pi r^3$

Trigonometry

$\sin\theta = \dfrac{opposite}{hypotenuse}$

$\cos\theta = \dfrac{adjacent}{hypotenuse}$

$\tan\theta = \dfrac{opposite}{adjacent}$

$\sin^2\theta + \cos^2\theta = 1$

Moment of inertia

point mass
$I = mr^2$

rod about centre
$I = \frac{1}{12}ml^2$

rod about end
$I = \frac{1}{3}ml^2$

disc about centre
$I = \frac{1}{2}mr^2$

sphere about centre
$I = \frac{2}{5}mr^2$

Table of standard derivatives

$f(x)$	$f'(x)$
$\sin ax$	$a\cos ax$
$\cos ax$	$-a\sin ax$

Table of standard integrals

$f(x)$	$\int f(x)dx$
$\sin ax$	$-\frac{1}{a}\cos ax + C$
$\cos ax$	$\frac{1}{a}\sin ax + C$

Electron Arrangements of Elements

Key

Atomic number Symbol Electron arrangement Name

Transition Elements

Group 1 (1)	Group 2 (2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Group 3 (13)	Group 4 (14)	Group 5 (15)	Group 6 (16)	Group 7 (17)	Group 0 (18)
1 **H** 1 Hydrogen																	2 **He** 2 Helium
3 **Li** 2,1 Lithium	4 **Be** 2,2 Beryllium											5 **B** 2,3 Boron	6 **C** 2,4 Carbon	7 **N** 2,5 Nitrogen	8 **O** 2,6 Oxygen	9 **F** 2,7 Fluorine	10 **Ne** 2,8 Neon
11 **Na** 2,8,1 Sodium	12 **Mg** 2,8,2 Magnesium											13 **Al** 2,8,3 Aluminium	14 **Si** 2,8,4 Silicon	15 **P** 2,8,5 Phosphorus	16 **S** 2,8,6 Sulfur	17 **Cl** 2,8,7 Chlorine	18 **Ar** 2,8,8 Argon
19 **K** 2,8,8,1 Potassium	20 **Ca** 2,8,8,2 Calcium	21 **Sc** 2,8,9,2 Scandium	22 **Ti** 2,8,10,2 Titanium	23 **V** 2,8,11,2 Vanadium	24 **Cr** 2,8,13,1 Chromium	25 **Mn** 2,8,13,2 Manganese	26 **Fe** 2,8,14,2 Iron	27 **Co** 2,8,15,2 Cobalt	28 **Ni** 2,8,16,2 Nickel	29 **Cu** 2,8,18,1 Copper	30 **Zn** 2,8,18,2 Zinc	31 **Ga** 2,8,18,3 Gallium	32 **Ge** 2,8,18,4 Germanium	33 **As** 2,8,18,5 Arsenic	34 **Se** 2,8,18,6 Selenium	35 **Br** 2,8,18,7 Bromine	36 **Kr** 2,8,18,8 Krypton
37 **Rb** 2,8,18,8,1 Rubidium	38 **Sr** 2,8,18,8,2 Strontium	39 **Y** 2,8,18,9,2 Yttrium	40 **Zr** 2,8,18, 10,2 Zirconium	41 **Nb** 2,8,18, 12,1 Niobium	42 **Mo** 2,8,18,13, 1 Molybdenum	43 **Tc** 2,8,18,13, 2 Technetium	44 **Ru** 2,8,18,15, 1 Ruthenium	45 **Rh** 2,8,18,16, 1 Rhodium	46 **Pd** 2,8,18, 18,0 Palladium	47 **Ag** 2,8,18, 18,1 Silver	48 **Cd** 2,8,18, 18,2 Cadmium	49 **In** 2,8,18, 18,3 Indium	50 **Sn** 2,8,18, 18,4 Tin	51 **Sb** 2,8,18, 18,5 Antimony	52 **Te** 2,8,18, 18,6 Tellurium	53 **I** 2,8,18, 18,7 Iodine	54 **Xe** 2,8,18, 18,8 Xenon
55 **Cs** 2,8,18,18, 8,1 Caesium	56 **Ba** 2,8,18,18, 8,2 Barium	57 **La** 2,8,18,18, 9,2 Lanthanum	72 **Hf** 2,8,18,32, 10,2 Hafnium	73 **Ta** 2,8,18, 32,11,2 Tantalum	74 **W** 2,8,18,32, 12,2 Tungsten	75 **Re** 2,8,18,32, 13,2 Rhenium	76 **Os** 2,8,18,32, 14,2 Osmium	77 **Ir** 2,8,18,32, 15,2 Iridium	78 **Pt** 2,8,18,32, 17,1 Platinum	79 **Au** 2,8,18, 32,18,1 Gold	80 **Hg** 2,8,18, 32,18,2 Mercury	81 **Tl** 2,8,18, 32,18,3 Thallium	82 **Pb** 2,8,18, 32,18,4 Lead	83 **Bi** 2,8,18, 32,18,5 Bismuth	84 **Po** 2,8,18, 32,18,6 Polonium	85 **At** 2,8,18, 32,18,7 Astatine	86 **Rn** 2,8,18, 32,18,8 Radon
87 **Fr** 2,8,18,32, 18,8,1 Francium	88 **Ra** 2,8,18,32, 18,8,2 Radium	89 **Ac** 2,8,18,32, 18,9,2 Actinium	104 **Rf** 2,8,18,32, 32,10,2 Rutherfordium	105 **Db** 2,8,18,32, 32,11,2 Dubnium	106 **Sg** 2,8,18,32, 32,12,2 Seaborgium	107 **Bh** 2,8,18,32, 32,13,2 Bohrium	108 **Hs** 2,8,18,32, 32,14,2 Hassium	109 **Mt** 2,8,18,32, 32,15,2 Meitnerium	110 **Ds** 2,8,18,32, 32,17,1 Darmstadtium	111 **Rg** 2,8,18,32, 32,18,1 Roentgenium	112 **Cn** 2,8,18,32, 32,18,2 Copernicium						

Lanthanides	57 **La** 2,8,18, 18,9,2 Lanthanum	58 **Ce** 2,8,18, 20,8,2 Cerium	59 **Pr** 2,8,18,21, 8,2 Praseodymium	60 **Nd** 2,8,18,22, 8,2 Neodymium	61 **Pm** 2,8,18,23, 8,2 Promethium	62 **Sm** 2,8,18,24, 8,2 Samarium	63 **Eu** 2,8,18,25, 8,2 Europium	64 **Gd** 2,8,18,25, 9,2 Gadolinium	65 **Tb** 2,8,18,27, 8,2 Terbium	66 **Dy** 2,8,18,28, 8,2 Dysprosium	67 **Ho** 2,8,18,29, 8,2 Holmium	68 **Er** 2,8,18,30, 8,2 Erbium	69 **Tm** 2,8,18,31, 8,2 Thulium	70 **Yb** 2,8,18,32, 8,2 Ytterbium	71 **Lu** 2,8,18,32, 9,2 Lutetium
Actinides	89 **Ac** 2,8,18,32, 18,9,2 Actinium	90 **Th** 2,8,18,32, 18,10,2 Thorium	91 **Pa** 2,8,18,32, 20,9,2 Protactinium	92 **U** 2,8,18,32, 21,9,2 Uranium	93 **Np** 2,8,18,32, 22,9,2 Neptunium	94 **Pu** 2,8,18,32, 24,8,2 Plutonium	95 **Am** 2,8,18,32, 25,8,2 Americium	96 **Cm** 2,8,18,32, 25,9,2 Curium	97 **Bk** 2,8,18,32, 27,8,2 Berkelium	98 **Cf** 2,8,18,32, 28,8,2 Californium	99 **Es** 2,8,18,32, 29,8,2 Einsteinium	100 **Fm** 2,8,18,32, 30,8,2 Fermium	101 **Md** 2,8,18,32, 31,8,2 Mendelevium	102 **No** 2,8,18,32, 32,8,2 Nobelium	103 **Lr** 2,8,18,32, 32,9,2 Lawrencium

Unit 0

Uncertainties

Uncertainties

Scale and reading uncertainty – a measure of how well an instrument scale can be read. ±1 division for digital, ±½ division for analogue.

Calibration uncertainty – a measure of how well a measurement instrument has been calibrated against a known standard. Manufacturers will usually quote this for you.

Systematic uncertainty – occurs when all readings are too small or too big due to a calibration error or poor experimental technique. E.g. measuring from the edge of a ruler rather than the 0 cm point. A systematic uncertainty often causes a graph to not go through the origin.

Random uncertainty – occurs when an experiment is repeated and slight variations occur. Can be reduced by repeating the experiment.

<u>Combining uncertainties</u>

At AH uncertainties are combined by adding the squares and square rooting.

Example

1. A race is 50 ± 5 m long. Joe takes 10.3 ± 0.2 s to run the race. Calculate his average speed and the absolute uncertainty in his average speed.

Combining uncertainties with powers

When a value is raised to a power, the percentage uncertainty of the value needs to be multiplied by the power.

For example, if the uncertainty in v is 4 % then the uncertainty in v^2 is 8% or $\sqrt{v}$ is 2%.

Example

1. A car has a mass of 800 ± 20 kg and a top speed of 42 ± 4 ms^{-1}. Calculate its maximum kinetic energy and the absolute uncertainty in kinetic energy.

Unit 1

Section 1

Rotational motion

Kinematic relationships

Velocity is rate of change of displacement

Acceleration is rate of change of velocity

This means by differentiating displacement equations containing t we can determine velocity or acceleration

Examples

1. The displacement of an object is described below.

Calculate the velocity at t = 2 s.

Calculate the acceleration at t = 2 s.

2. Calculate the velocity and acceleration in the following examples.

   a.

b.

c.

3. Determine an expression an expression for displacement from the following equation.
   s = 0 at t = 0.

Deriving the equations of motion

Equations 1 and 2 occur regularly in exams

In graphs of motion

Velocity = gradient of displacement-time graph
Acceleration = gradient of a velocity-time graph

<u>You can now complete tutorial 1</u>

Angular motion

Radians

1 radian = 360/2π degrees = 57.3 degrees

Degrees are often used by younger pupils as 360 degrees can be split into 1, 2, 3, 4, 5, 6, 8, 9, 10 and 12 etc. segments quite easily. In AH Physics radians must be used.

The easiest way to understand angular (rotational) motion is to link it to linear motion from Higher.

Linear quantity	Angular quantity
Displacement	angular displacement
initial velocity	initial angular velocity
final velocity	final angular velocity
acceleration	angular acceleration
time	time

The same is true for the equations

Linear	Angular

For the $\omega = d\theta/dt$ equation we also see that if $d\theta = 2\pi$ (1 complete rotation) then $dt = T$ (1period)

Examples

1. A CD starts spinning at 3 revolutions per second and 4 s later is spinning at 7 revolutions per second. Calculate its angular acceleration.

2. A tyre is rolling down a hill at 2.4 revolutions per second and 8 s later is spinning at 6.2 revolutions per second. Calculate its angular acceleration.

3. A barrel is rolled up a hill. It starts at 1.6 revolutions per second and undergoes 4 rotations before coming to rest. Calculate its angular acceleration.

4. A CD starts spinning from rest and accelerates at 9 $rads^{-2}$ to spin 20 complete revolutions. Calculate how long this will take.

Linking linear and angular quantities.

Linear = radius x angular

Examples

1. A tyre of radius 40 cm completes 3 revolutions. Calculate how far it will travel in this time.

2. A ball of radius 5 cm is rolling down a slope at 0.8 revolutions per second. Calculate its linear velocity?

<u>You can now complete tutorial 2.0 and 2.1</u>

Central Motion

Label all the forces acting on an unpowered object in orbit.

.

It is accelerating towards the centre of Earth but its tangential velocity stops it falling towards Earth. All objects in radial motion accelerate towards the centre of rotation due to a central force being applied. This is not a magical extra force you don't know about it is just the label given to an already existing force.

Eg. Weight (gravity) causing the moon to orbit the Earth
Friction causing a stone to stay stuck in a car tyre and rotate
Tension causing a hammer attached to a rope to keep spinning
Magnetic fields causing a charged particle to travel in a circle

Radial acceleration (central acceleration)

Angular or tangential acceleration is the rate of change of angular velocity

Radial or central acceleration is the rate of change of linear velocity

If the applied force is greater than the central force needed then an object will remain in circular motion. If it is not then the object leaves tangentially.

Examples

1. Calculate the central force needed to keep us rotating around the centre of the Earth.

2. A hammer thrower spins a 12 kg mass at a radius of 80 cm, twice per second. Calculate the central force he is providing.

Central motion – resolving forces (1)

A car on a banked track

Calculate the angle of track needed to keep the car in circular motion without friction.

Central motion – resolving forces (2)

A pendulum swinging about its centre

Calculate the angle of the pendulum for the bob to continue in circular motion.

You can now complete tutorial 3.0 and 3.1

Rotational Dynamics

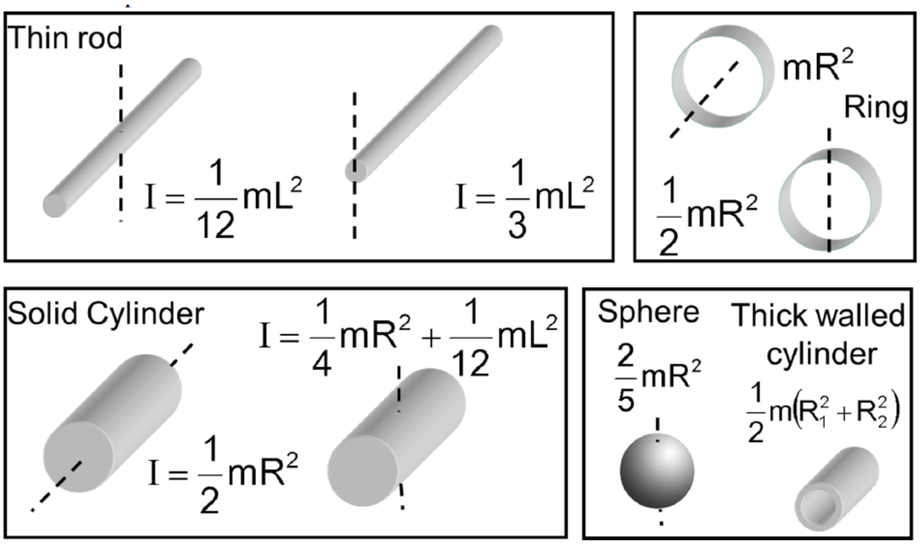
Torque – the turning effect which results from the application of a force at a radius r.

If the torque is unbalanced it will cause an acceleration.

mr^2 is called the moment of inertia.

Moment of inertia (mr^2) is dependent on the mass and the radial distribution of the mass around the centre of rotation. Moment of inertia describes how much an object will resist changes in its angular velocity.

mr^2 is the moment of inertia of a mass rotating about a centre or of a hoop. A solid disk has a moment of inertia of ½ mr^2. There are others in the data booklet.

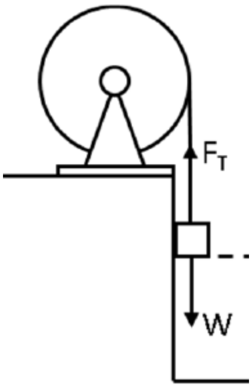


Examples

1. A 12 N force is applied to a 1.4 kg mass 50 cm from its centre of rotation. All of the 1.4 kg of mass is at 50 cm from the centre. Calculate its angular acceleration.

2. A 400 kg solid disc roundabout is accelerated by applying a 600 N force at a radius of 1.2 m. The roundabout itself has a radius of 1.4 m. Calculate the angular acceleration of the roundabout.

3. A 3 kg mass is hung from a flywheel. Calculate the angular acceleration of the flywheel. (Weight of mass causes its own acceleration and the acceleration of the flywheel)

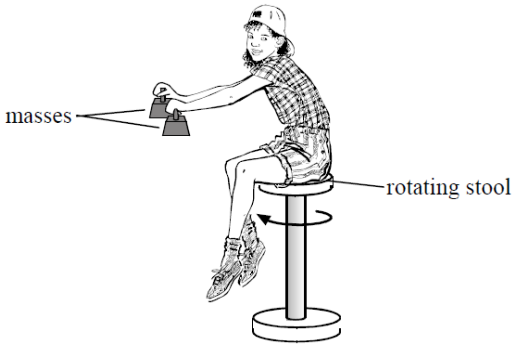


<u>You can now complete tutorial 4.0</u>

Angular momentum

In collisions the total angular momentum before a collision is equal to the total angular momentum after a collision in the absence of external torques.

Consider a pupil spinning in a chair while holding masses. As the masses are extended I increases so ω decreases and vice versa.



There isn't usually a need for a bigger equation as one object is usually stationary beforehand and afterwards both objects have the same angular velocity.

Examples

1. A 6 kg solid disc of radius 80 cm is rotating about its centre at 4 rads^{-1}. A 1 kg mass is dropped onto the disc 55 cm from the centre. Calculate the new angular velocity of the disc and mass.

2. A 500 kg roundabout of radius 1.1 m is rotating about its centre at 0.6 $rads^{-1}$. Two 70 kg boys jump onto the roundabout at a radius of 60 cm. Calculate the new angular velocity of the roundabout.

3. Explain what would have happened to the angular velocity if the boys had jumped on at a smaller radius in example 2.

Rotational Kinetic Energy

The cylinders have equal mass but the distribution of the masses about the centre is different. Which cylinder will reach the bottom first?

You can now complete tutorial 5.0 and 5.1

Rotational Motion

Explain what is meant by the term ‘angular acceleration’.
Rate of change of angular velocity.

Explain what is meant by the term ‘central acceleration’.
Rate of change of linear/tangential velocity.

An object is moving in a circular path at a constant speed, explain how it is accelerating.
The object is changing direction and hence its velocity is changing.

An object is moving in a circular path and the central force causing this is removed. State the direction the object will now move.
The object moves in a straight line tangentially.

State what is meant by a central force.
A central force is a force which causes on object to remain in circular motion. It is usually provided by tension, gravitational force, a magnetic field or friction.

Explain why an object can move faster around a banked circular track than on a flat circular track.
On a flat circular track only friction provides a central force. On a banked circular track there is also the reaction force of the track providing a central force.

State what is meant by ‘Torque’.
The turning effect which results from the application of a force at a radius r.

A system rotates because a force is applied at a radius ‘r’ from the centre of rotation. An identical force is applied to the system but at a greater radius. Explain what effect this will have on the angular acceleration of the system.
The radius has increased meaning the torque ($T = Fr$) has increased. This means the angular acceleration increases as $T = I\alpha$.

State the law of conservation of angular momentum.
The total angular momentum before a collision is equal to the total angular momentum after a collision in the absence of external torques.

State what is meant by the term ’moment of inertia’.
A measure of the resistance an object has to changing its angular velocity.

Explain what is meant by the term ’moment of inertia’.
A measure of the mass of an object and the distribution of that mass around the centre of rotation.

Unit 1

Section 2

Astrophysics

Gravitation

Newton's inverse square law of gravitation

r is the distance between the centre of objects. Certain distances are often quoted as height above the surface. Therefore r = R+h where R is the radius of the planet and h is the height above the surface. Values quoted in the data booklet are distances between the centres. h often given as 2×10^5 km so be careful when converting.

Example

1. Calculate the mass of the Earth.

2. Calculate the force of attraction between you and the person sitting next to you.

3. Calculate how long it takes for the Earth to orbit the Sun.

Gravitational field strength

The gravitational field strength (g) is weight per mass.

Gravitational field lines

Equipotential lines – where g is equal

Single mass 2 equal masses

2 unequal masses (Eg. Earth and moon)

Example

1. Calculate the distance between the Earth and moon where the gravitational attractions from each body are equal.

Gravitational potential

The gravitational potential (Vp) at a point in a field is the work done in bringing a unit mass from infinity to the point.

V_p = 0 at infinity so work must be done against the attractive fields to get it back there, hence the -ve in the above equation.

Conservative fields

A gravitational field is a conservative field. This means an objects' potential energy depends on where is it, not how it got there.

Potential Energy

An object in a gravitational field has potential energy

Ep = 0 at infinity so work must be done against the attractive fields to get it back there, hence the -ve in the above equation.

Satellite motion

Gravitation provides the central force for satellite motion.

Examples

1. Calculate the period of orbit of a geostationary satellite 36000km above the Earth.

2. Calculate how fast the satellite is travelling?

A satellite in orbit has both kinetic and potential energy.

Kinetic energy

Potential energy

Total energy

Escape velocity

Escape velocity is the minimum velocity needed to escape from a gravitational field to infinity.

Example

1. Calculate the escape velocity of the Earth

2. Calculate the escape velocity of the moon.

The moon has a smaller escape velocity than the Earth and this is why it has no atmosphere, the particles in the atmosphere can escape.

Black Holes

A black hole is created when the escape velocity of a star is greater than the speed of light. The radius of a star which becomes a black hole is called the Swarzschild radius.

Example

1. Calculate the radius at which our sun would become a black hole.

(It would fit between here and Auldgirth) – it's not actually possible for our sun to do this due to what it is made of.

Photons in gravitational fields

Photons can be deflected by large gravitational fields and objects may appear in a different position as a result.

Observers at different distances from a star would observe the emitted photons at different frequencies. The photons lose energy as they move away from the star and become redshifted. This is “gravitational red shift” and is different to the redshift observed as galaxies move away from us.

You can now complete tutorial 1.0 and 1.1

Relativity

Special relativity – time dilating and length contracting at high speed. Not covered here.

General relativity – combines special relativity and Newtonian mechanics to describe gravity as a property of space and time.

Non-inertial and inertial frames of reference

Non-inertial frames of reference are frames of reference that are **accelerating** with reference to an inertial frame of reference. **Inertial** frames of reference are frames of reference that are moving with a **constant velocity** relative to each other.

Equivalence principle

If a physics experiment is conducted in a reference frame accelerating at 9.8 ms^{-2} it would yield the same results as if it were completed on the surface of the earth. It is impossible to tell the difference between acceleration and the effects of gravity.

Space – time

There are 3 spatial dimensions (x, y and z) and a fourth time dimension (t). It is impossible to draw 4 dimensions on a page. It is possible to show two dimensions (x and y) with time (t) as the third dimension.

A is an event in space time

B is an event which could be influenced by A as it occurred after it.

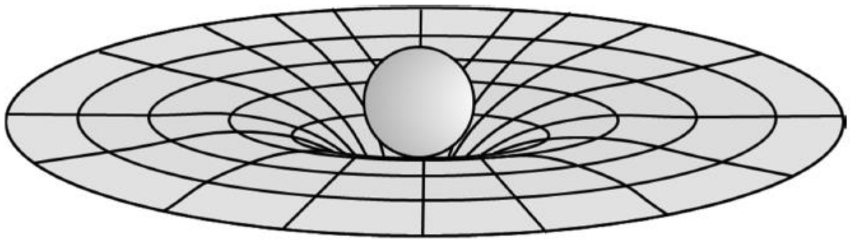
C is an event which could have influenced A as it occurred before it.

D could not have influenced or be influenced by A as nothing can travel faster than the speed of light to exist outside of the light cones.

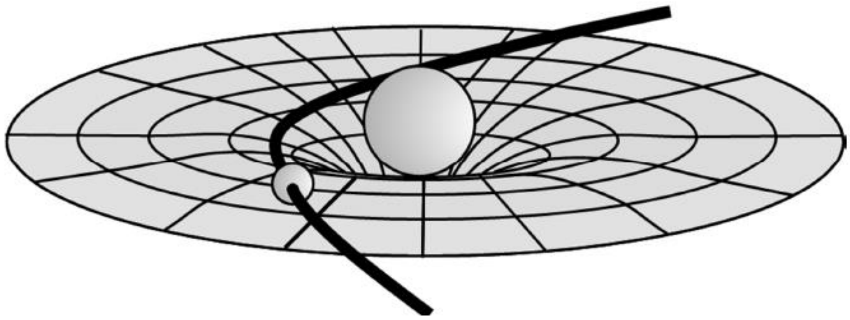
Principle of covariance

In order to explain space – time with general relativity we must allow space – time to curve. The amount of curving it does will depend on the size of the masses involved. The bigger the masses, the more curving.

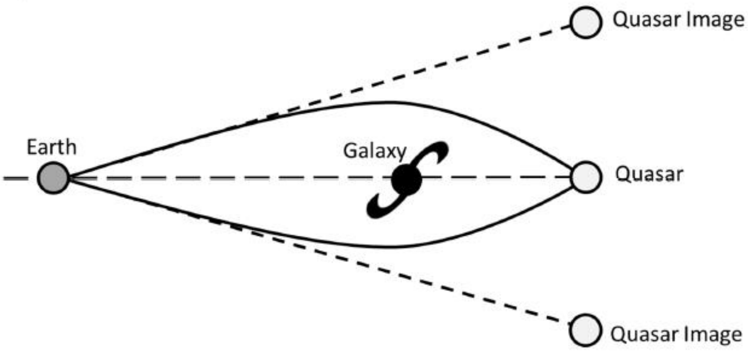
Matter tells space how to curve:



Space tells matter how to move:



As a result light will appear to be bend as it passes massive objects.



This effect is called gravitational lensing where gravitational fields act like a lens to alter the direction of light.

Masses are also affected in this way and Mercury’s orbit is changing angle (precessing) by 1/180th of a degree per century as it orbits so close to the sun.

Event horizon

As previously mentioned a star will become a black hole when it becomes so dense not even light can escape. The radius at which this occurs is the Schwarzchild radius. The edge of a black hole is called the “event horizon”.

Gravitational red – shift

As previously mentioned light reduces in frequency and energy when moving away from a star. This is called gravitational redshift. Imagine the 3 stars below of equal mass but different radii.

High frequency – not much gravitational red shift

Lower frequency – lots of gravitational red shift

No frequency – total gravitational red shift

Gravitational field strength

The value of g reduces as you increase distance from a planet or star. As a result time speeds up when you are further from a planet or star. GPS satellites have to connect for this as they experience less g. If you were on a satellite or at the top of a mountain then your clocks would run faster.

You can now complete tutorial 2.0

Stellar physics

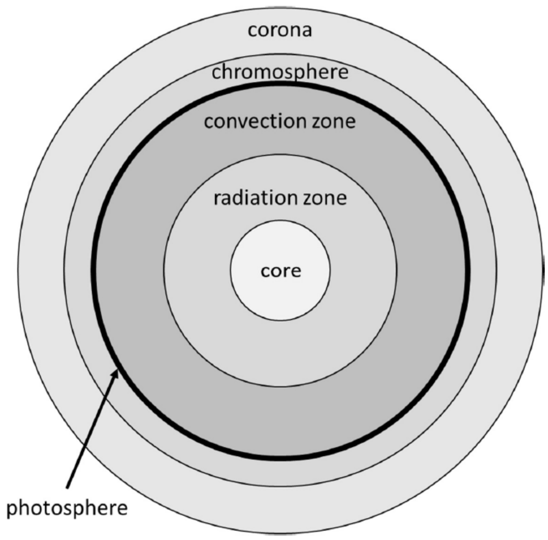
The Physics of stars from birth to death and everything in between. There are 10^{22} stars, of which we can see 2000 or so with the naked eye. Active stars produce energy through nuclear fusion.

Nuclear fusion

Nuclear fusion is a 3 stage process

This can be summarised as the proton - proton chain reaction.

Structure of our sun

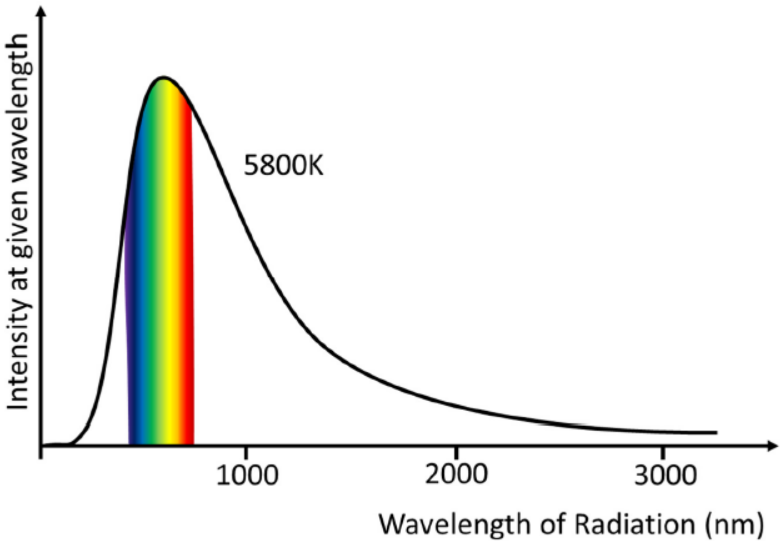


The solar zones

Fusion happens in the core and it takes hundreds of thousands of years for the photons (energy) to reach the surface.

Surface temperature of our sun

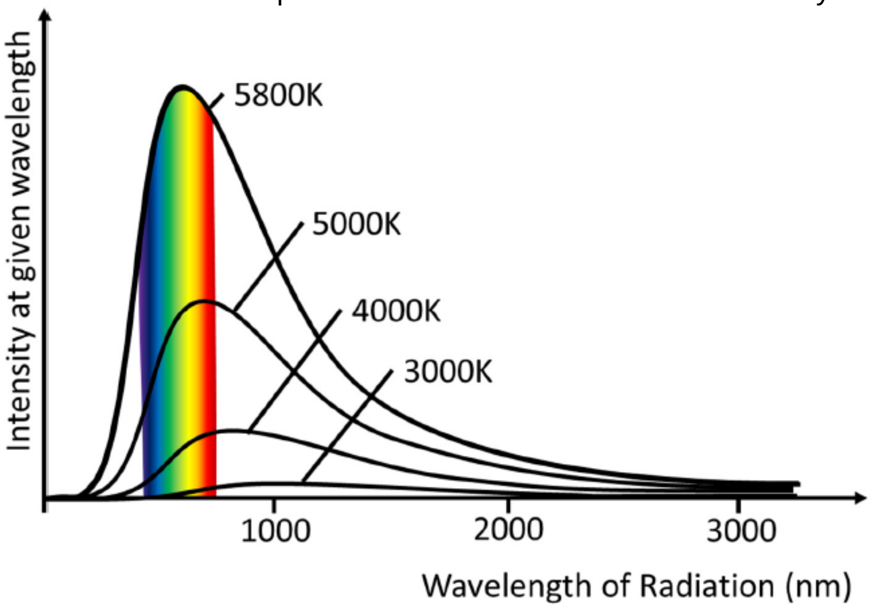
A black body diagram shows the intensity of different wavelengths emitted from a star and is related to it temperature.



It is not a coincidence that humans have evolved to have good eye sensitivity where the sun emits most of its light.

Black body diagrams – star temperatures

Different stars have different temperatures and so have different black body diagrams.



Cooler stars emit higher wavelengths.

Mass of stars

Our sun has a mass of 1.99 x 10^{30} kg = 1 solar mass.
Stars range from 0.08 to 150 solar masses and cannot exist outside this range.

Light years

Distances are often measured in light years when they are very large. 1 light year is the distance light travels in 1 year.

Example

1. Calculate how far (in m) light would travel in 3.6 light years.

Star brightness

Brightness – power per unit area from a star

Example

1. Calculate how bright our sun is (T = 5800 K).

Star luminosity

Luminosity – total rate at which energy is radiated by a star across all wavelengths.

Example

1. Calculate the luminosity of our sun?

Apparent brightness

All stars are obviously vastly different distances from us and you would expect the closer stars to appear brighter as they are nearer. To take account of this we can calculate apparent brightness

Example

1. Calculate the apparent brightness of our sun.

The actual measured brightness is less than this due to atmospheric absorption and other effects.

Measuring values

Absolute magnitude – a value measured a set distance from a star (32.6 light years).
Apparent magnitude – a value measured from Earth.

Classification

All stars have been classified into 7 spectral types.

Modern stellar classification

Spectral type	Temperature (K)	Examples	Colour
O	> 30,000	Orion's Belt stars	Blue
B	30,000–10,000	Rigel	Blue-white
A	10,000–7,500	Sirius	White
F	7,500–6000	Polaris	Yellow-white
G	6000–5000	Sun	Yellow
K	5000–3500	Arcturus	Orange
M	<3500	Proxima Centauri, Betelgeuse	Red

To remember the order of the 7 types use the mnemonic.

Oh, Be A Fine Girl/Guy, Kiss Me.

There are 10 sections (0 to 9) within each of the 7 spectral types. Our sun is a G2.

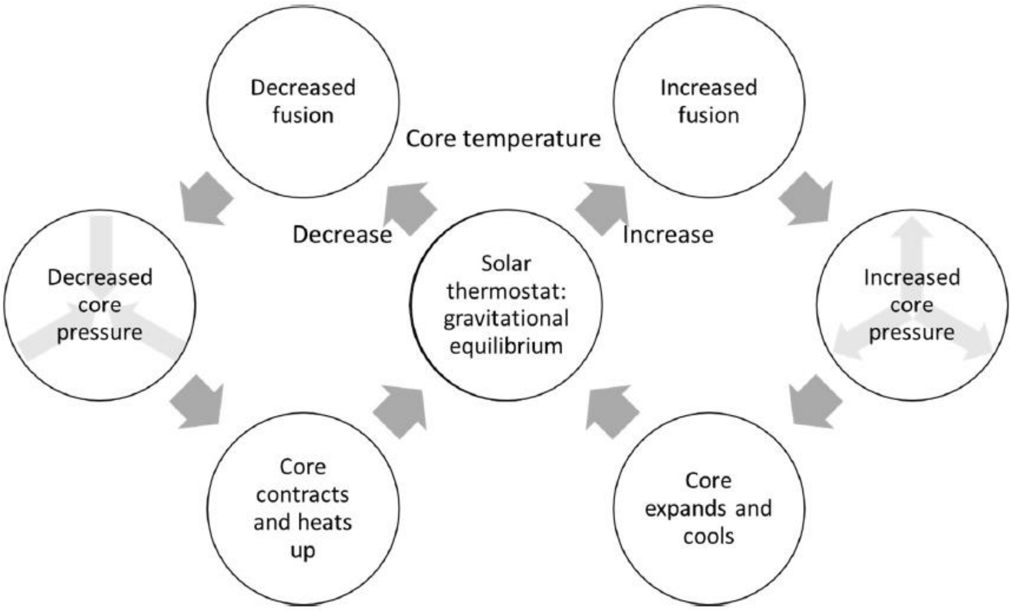
Star activity

Sunspots – darker regions where cooler plasma is sinking back into the sun. Lasts hours to weeks.

Solar flares – large quantities of x-rays emitted. Lasts minutes to hours.

Stellar equilibrium

All stars balance the inward gravitational attraction with the outward pressure produced from fusion.



Evolution – stellar nucleosynthesis

In the late 1940's Fred Hoyle summarised the fusion reactions occurring in stars.

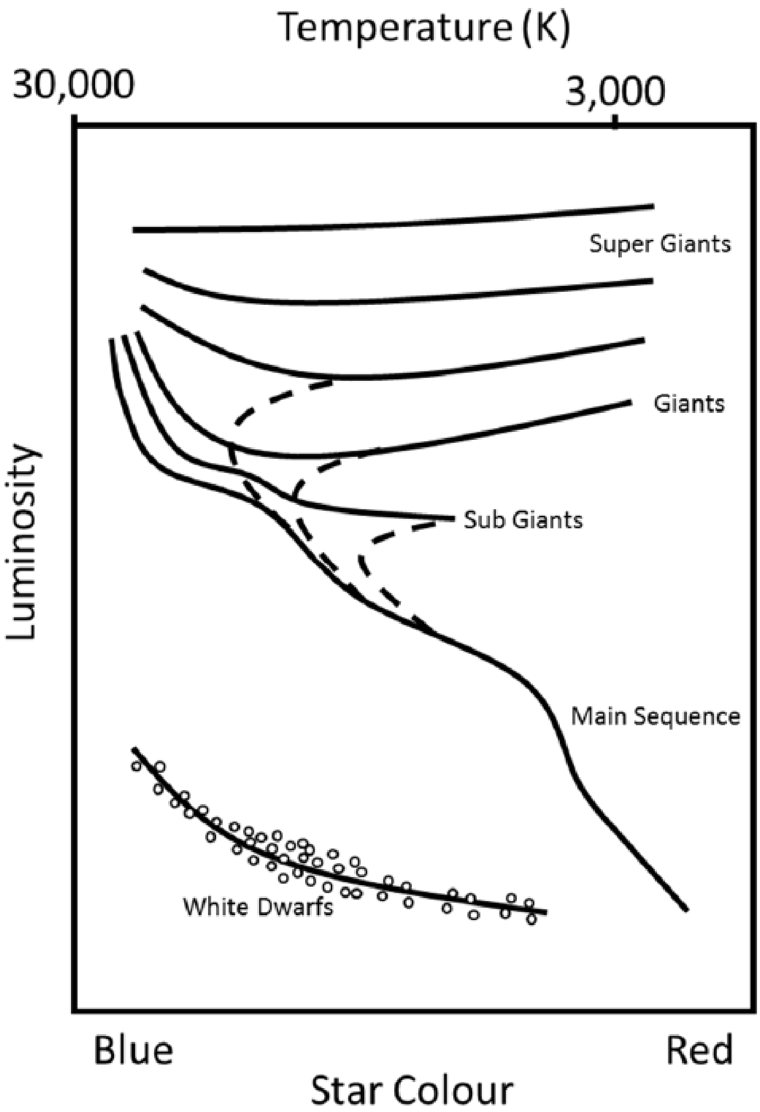
Summary of nucleosynthesis occurring in a star of mass $25M_{Sun}$.

Stage	Temperature (K)	Density (g cm^{-3})	Duration
Hydrogen → helium	4×10^7	5	10^7 years
Helium → carbon	2×10^8	7×10^2	10^6 years
Carbon → neon + magnesium	6×10^8	2×10^5	600 years
Neon → oxygen + magnesium	1.2×10^9	5×10^5	1 year
Oxygen → sulphur + silicon	1.5×10^9	1×10^7	6 months
Silicon → iron	2.7×10^9	3×10^7	1 day

We are all made of stars – all elements up to iron are made in this way. Increases in temperature and density led to heavier elements.

Hertzsptrung – Russell (H – R) diagrams

Plots of luminosity versus temperature.



Neutron stars

Stars which collapse in on themselves and form an iron core are called neutron stars. They eventually become black holes.

You can now complete tutorial 3.0

Astrophysics

Describe what a gravitational field is.
A place where a mass experiences a force.

State what is meant by the term gravitational field strength.
Weight per unit mass.

State what is meant by the term gravitational potential.
The gravitational potential (Vp) at a point in a field is the work done in bringing a unit mass from infinity to the point. $V_p = 0$ at infinity.

Describe what is meant by a conservative field.
In a conservative field the journey an object takes is not important, it is the starting and finishing positions which determine physical values.

State what is meant by 'escape velocity'.
The minimum velocity required to escape a gravitational field to infinity.

Describe what causes a star to become a black hole.
It contracts causing its escape velocity to increase to a value bigger than the speed of light meaning not even light can escape.

State what the event horizon is.
The event horizon is the edge of a black hole.

State what the Schwarzchild radius is.
The minimum radius required of a star for it to become a black hole.

Describe what happens to photons in gravitational fields.
Photons are deflected by gravitational fields and objects can appear in different positions in the sky because of this.

State how many dimensions there are in space-time.
4 (x, y, z and time)

Describe what gravitational redshift is.
Photons emitted from stars lose energy as they escape from the star meaning they are redshifted. (This is different from the redshift associated with stars moving away from us)

Describe what special relativity is.
Time dilates and length contracts when observing objects moving at speeds close to the speed of light.

Describe what general relativity is.
Includes special relativity and Newtonian mechanics to describe gravity as a property of space-time.

Describe the principle of covariance.

Space-time is curved due to the large masses in the universe. This curved space-time then affects all photons and masses travelling through it.

With reference to general relativity explain why planets orbit stars.

Space-time is curved due to the star. Planets follow this curved space-time and orbit the star.

State what is meant by non-inertial frames of reference.

Frames of reference that are **accelerating** with reference to an inertial frame of reference.

State what is meant by inertial frames of reference.

Frames of reference that are moving at a **constant velocity** relative to each other.

State the equivalence principle.

If a physics experiment is conducted in a reference frame accelerating at 9.8 ms^{-2} it would yield the same results as if it were completed on the surface of the earth. It is impossible to tell the difference between acceleration and the effects of gravity.

Two clocks are placed in 2 different gravitational fields. Clock A experiences a greater g than clock B. Explain which clock runs more slowly.

Clock A would run more slowly as it experiences a greater gravitational field strength.

Explain why a star expands and contracts during its life cycle.

Thermal pressure in the star is large and it overcomes the gravitational pull causing it to expand. This expansion reduces the thermal pressure in the star meaning the gravitational pull overcomes it and contracts the star. This cycle continues.

State what is released in a proton-proton chain reaction.

Positrons, neutrinos, Helium nucleus and energy.

State what is meant by the ‘brightness’ of a star.

Power per unit area emitted.

State what is meant by the ‘luminosity’ of a star.

Total rate at which energy is radiated by a star across all wavelengths.

Describe what the ‘apparent brightness’ of a star is.

The brightness of a star in the sky depends on 2 things; how bright the star is and how far away it is. Apparent brightness takes account of how far away the star is so it can be compared with other stars.

State what ‘absolute magnitude’ is.

The brightness of a star measured at a set distance from the star (32.6 light years).

State what ‘apparent magnitude’ is.

The brightness of a star measured from Earth.

Describe what a sunspot is.
A dark region where cooler plasma sinks back into the sun.

Describe what a solar flare is.
An emission of X-rays from the sun.

State what type of star is found in the bottom left hand corner of a Hertzsprung-Russell diagram.
White dwarf.

State what type of star is found in the top right hand corner of a Hertzsprung-Russell diagram.
Red giant.

State what the region from the top left to the bottom right of a Hertzsprung-Russell diagram is known as.
The main sequence where stars spend a large portion of their life cycle expanding and contracting.

State what a neutron star is.
A star which collapses in on itself and becomes a black hole.

State what is meant by 1 Solar mass.
1 Solar mass is the mass of the sun. E.g. 4.2 Solar masses is equal to 4.2 x the mass of the sun.

State what is meant by 1 Astronomical unit (1 a.u.).
1 Astronomical unit is the distance between the Earth and the sun. E.g. 6.5 a.u. is equal to 6.5 x the distance between the Earth and the sun.

State what is meant by 1 Light year (1 ly).
1 Light year is the distance travelled by light in 1 year. E.g. 7.4 ly is equal to 7.4 x the distance travelled by light in 1 year.

Unit 2

Section 1

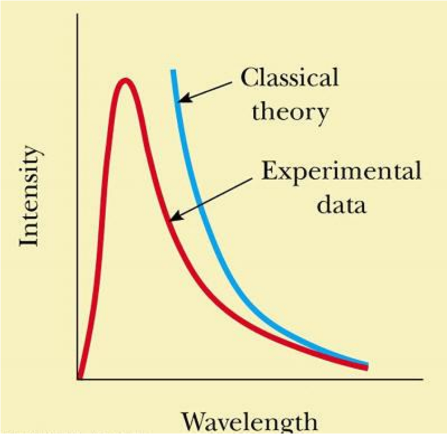
Quanta

Quantum mechanics

Quantum mechanics was developed in the early 20th century to explain experimental observations that could not be explained by classical Physics. Quantum mechanics is used to help explain blackbody radiation, the photoelectric effect, emission and absorption spectra, atomic structure and electron diffraction.

Blackbody radiation

The amount of radiation emitted at a given frequency or wavelength depends on temperature not on the type of material. This can only be explained by light existing as photons.



Photoelectric effect

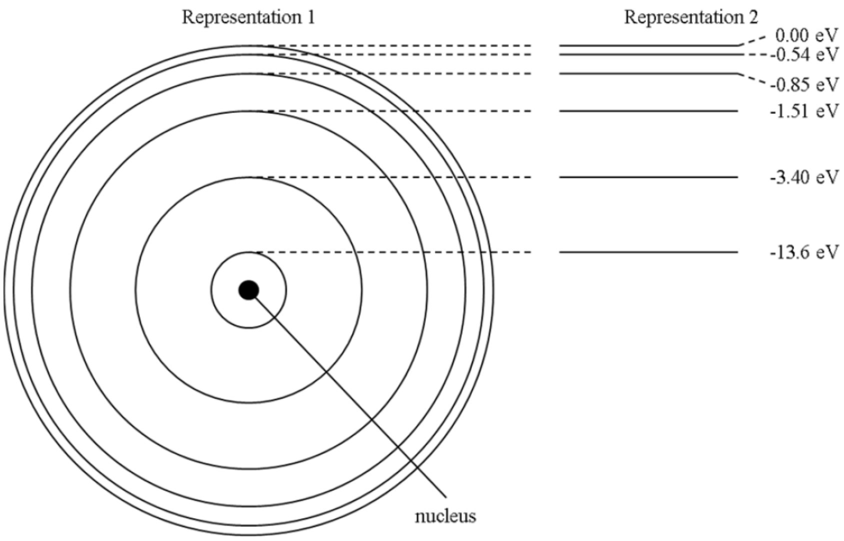
Photons cause emission of electrons from metals but only if the photons have high frequency.

Number of UV photons affects the number of emitted electrons.
Energy of UV photons affects the energy of the emitted electrons.

Again only possible if light exists as photons.

Atomic structure – Bohr model

Bohr model – electrons orbit the nucleus but only in certain discrete orbitals.



The allowed orbitals are quantised in terms of angular momentum.

Example

1. Calculate the speed of an electron in the 1st Bohr orbit of hydrogen where r = 5.3×10^{-11} m.

Wave – particle duality

Particles can behave like a wave or like particles.
Waves can behave like a wave or like particles.
The particle most likely to exhibit wave like properties is the electron.

	Particle nature	Wave nature
Electron	cathode ray tube (old T.V.)	electron microscope
Light	photoelectric effect	double slit interference

De Broglie wavelength of particles

The de Broglie wavelength of a particle tells us how likely it is to demonstrate wave like properties. For a particle to exhibit wave like properties its de Broglie wavelength must be similar in size to the objects it scatters off.

Examples

1. Calculate the de Broglie wavelength of an electron moving at 1.8×10^7 ms^{-1}.

This is between the size of a nucleus and an atom so electrons will show wave like properties when scattering off atoms, like in an electron microscope.

2. Calculate the de Broglie wavelength of a 70 kg pupil running at 6 ms^{-1}.

We know of nothing this small that a pupil could scatter off so you do not exhibit wave like properties.

Quantum mechanics and probability

Consider young slits experiment with laser

Now consider the same experiment but with a really weak laser which only emits one photon at a time. Any individual photon can obviously only go through 1 slit.

How does a single photon know the other slit exists to create an interference pattern?

If we try to interrogate this and find out what is going on then the interference pattern breaks down. This is why we can only talk about probabilities in quantum mechanics rather than exact measurements. All of the equations in quantum mechanics agree very well with theory and experiment but if we interrogate too much they break down.

<u>Heisenberg uncertainty principle</u>

On the atomic scale by measuring one value very **<u>precisely</u>** it means a second value is difficult to measure **<u>precisely</u>**. Position and momentum are linked, as are energy and time. Heisenberg's uncertainty principle is concerned with **precision not accuracy**.

If we measure x then our ability to measure p is affected. If we measure E then our ability to measure t is affected.

Consider measuring the temperature of a beaker of water. As soon as you put the thermometer in the water you have affected its temperature and your ability to measure it accurately. Such effects are even more common on the atomic scale.

Examples

1. During an experiment the position of an electron is measured to within $\pm 3 \times 10^{-12}$ m. Calculate the minimum uncertainty in the measurement of momentum.

2. During an experiment the uncertainty in the exact energy of an electron ± 1.4 x 10^{-20} J in a given energy level. Calculate how long the electron is likely to exist in this energy level.

Don't get too hung up on these calculations, just pop the numbers in. You may be asked for uncertainty in velocity. For this just use $\Delta p = m\Delta v$ as m is usually known exactly.

Quantum tunnelling

In the real world the ball could not get from A to B unless it was given enough energy to overcome h.

In the quantum world it is possible due to quantum tunnelling.

Notice the amplitude at B is much less than at A to indicate it is unlikely to make it across, but it is possible.

Alpha decay

Some radioactive elements should not be able to emit α particles as the α particles in the nucleus do not have enough energy to escape. Quantum tunnelling allows them to escape and this is one of the ways we know quantum tunnelling is possible.

Scanning Tunnelling Microscope (STM)

Electrons in the STM shouldn't have enough momentum to cover this gap.

Because of the Heisenberg uncertainty principle if momentum is known accurately then the uncertainty in position can be big enough for electrons to exist on the other side of the gap to build up a picture of the surface.

Virtual particles

In a vacuum, virtual particles of energy ΔE can appear for a short time Δt according to the Heisenberg uncertainty principle. It is difficult to observe these particles as Δt will be small but they play an important role in nuclear decay and high energy particle collisions.

You can now complete tutorial 1.0

Particles from space

In 1936 Victor Hess won the Nobel prize for discovering Cosmic rays.

Cosmic rays

Cosmic rays are high energy particles from space which are usually absorbed by the atmosphere. They are usually generated by stars. As shown in the table below cosmic rays are mostly protons or alpha particles. From our sun cosmic rays are also called a solar wind.

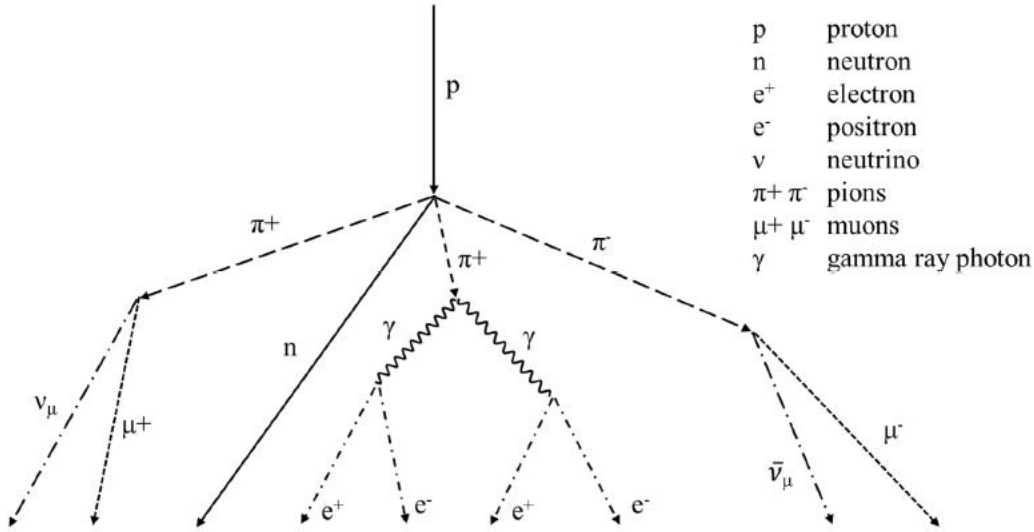
Protons	89%
Alpha particles (Helium nuclei)	9%
C, N, O nuclei	1%
Electrons	<1%
Gamma rays	<0.1%

Electron volts

Energies of cosmic rays often quoted in electron volts (eV).

Cosmic air shower

When particles from space hit the atmosphere they are involved in a number of reactions resulting in many other particles being created. This is called a cosmic air shower.



Detection of cosmic rays

Above atmosphere – primary cosmic rays detected by satellites.

On Earth – cosmic air showers detected. Particles moving very fast through fluids (e.g. water) emit radiation (Cherenkov radiation). This is why nuclear reactors have a blue tinge. Particles in the cosmic ray move close to atoms in the atmosphere and cause electrons to be excited to higher energy levels. As the electrons move back to the lower energy levels light is emitted and detected as atmospheric fluorescence. This is what causes the aurora.

Our sun

Comet tails

Comet tails in our solar system always point away from the sun. This is due to the solar wind or cosmic rays it is emitting.

Coronal holes

Coronal holes are magnetic field lines which don't loop back towards the sun and instead spew out charged particles away from the sun.

Solar flares

Solar flares are explosive releases of energy across the electromagnetic spectrum. They also contain cosmic rays and cause disruption to communications on Earth.

Sun spots

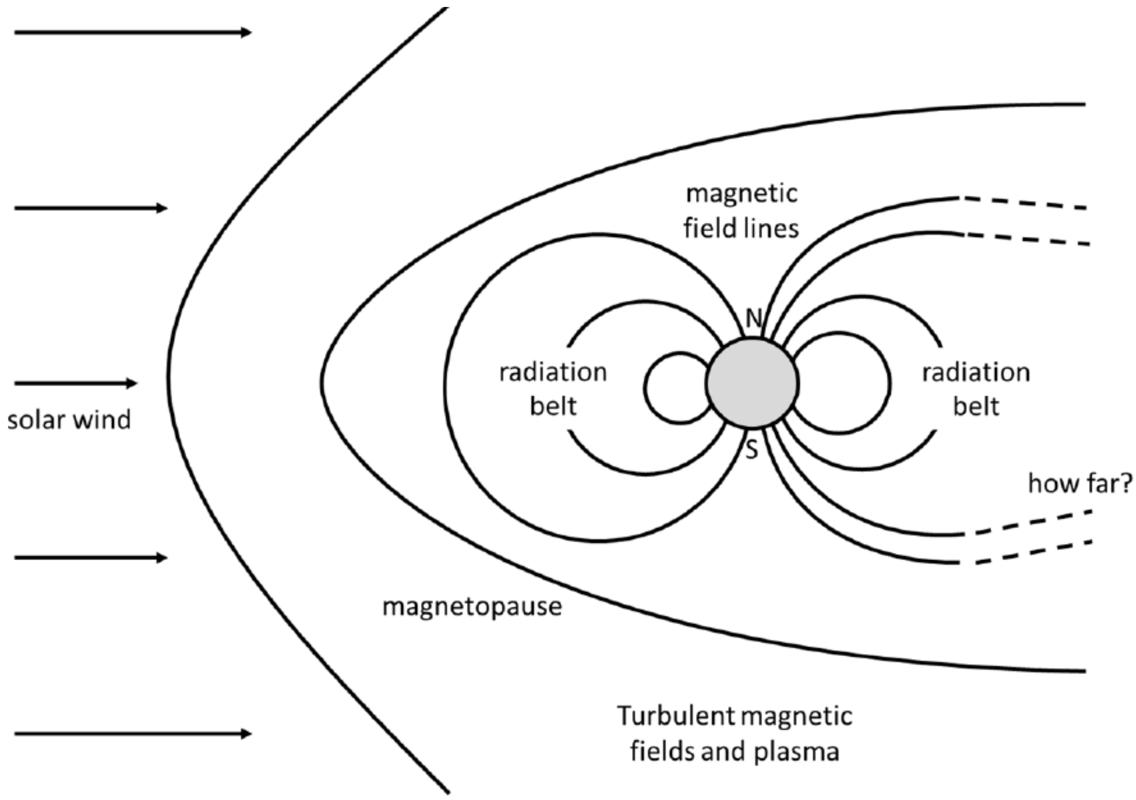
Areas where cooler plasma sinks back to the centre of the sun. Every 11 years the suns sunspots undergo a solar cycle.

This affects the

- number of sunspots
- mean latitude of sunspots
- magnetic polarity of sunspot groups

Earth’s magnetosphere

This is the part of the Earth’s atmosphere dominated by the Earth’s magnetic field. It deflects much of the Sun’s solar winds away from the surface.



Particles approaching at an angle which do leak into the magnetosphere become trapped in either the inner or outer Van-Allen belts.

Aurorae

Particles which are trapped in the inner or outer Van-Allen belts interact with particles in the atmosphere as they come closer to the Earth at the North or South Pole. These interactions cause light to be emitted. We know this light as the Aurora Borealis (Northern Lights) or the Aurora Australis (Southern Lights).

This is why Aurorae are only visible nearer the poles as the particles from the solar wind interact with particles in the atmosphere.

Particles in magnetic fields

A fuller note on this will be done in the Electromagnetism topic. Charges particles in a magnetic field experience a force.

Examples

1. An electron is moving perpendicular to the Earth's magnetic field lines at a velocity of 6.3×10^7 ms^{-1}. B = 4 mT at this altitude. Calculate the size of the force the electron experiences.

2. An electron is moving at an angle of 32^o to the Earth's magnetic field at a velocity of 0.08c. B = 16 mT at this altitude. Calculate the size of the force the electron experiences.

You can now complete tutorial 2.0

Quanta

Describe what quantum mechanics is.
Quantum mechanics explains the Physics behind anything which cannot be explained by classical Physics (blackbody radiation, the photoelectric effect, emission and absorption spectra, atomic structure and electron diffraction).

State what is meant by 'wave-particle duality'.
Under certain conditions particles can behave like waves and waves can behave like particles.

State an example of light behaving as a particle.
Photoelectric effect.

State an example of light behaving as a wave.
Youngs' double slits.

State an example of particles (electrons) behaving as a particle.
Cathode ray tube.

State an example of particles (electrons) behaving as a wave.
Electron microscope.

Explain why the de Broglie wavelength is important.
For a particle to exhibit wave like properties its de Broglie wavelength must be of comparable size to the object which it scatters from.

Describe what is meant by black body radiation.
The amount of radiation emitted at a given frequency or wavelength depends on temperature not on the type of material.

Explain how the photoelectric effect works.
High energy photons cause the ejection of electrons from metals. Increasing the energy of the photons increases the energy of the ejected electrons. Increasing the number of the photons increases the number of ejected electrons.

Describe what is meant by the phrase 'energy is quantised'.
Energy is emitted or absorbed in discrete packets and is not continuous.

Explain how the Bohr model of the atom accounts for line emission spectra.
Electrons orbit in discrete energy levels. Transitions between then levels emit photons of discrete/fixed energies.

Explain the Heisenberg uncertainty principle.
To measure one value precisely (momentum or energy) it means we are unable to measure a second value precisely (position or time).

Explain what quantum tunnelling is.
When a particle needs to get over a potential hill it looks impossible through classical Physics. Using quantum tunnelling it is possible, although not probable that a certain percentage of particles can overcome the hill by tunnelling. This is how alpha decay works and how a scanning tunnelling microscope works.

State what a ‘solar wind’ is.
Charged particles released from the sun.

Explain why comet tails always face away from the sun.
The solar wind from the sun blows the comet debris (tail) away from it.

Describe what a ‘coronal hole’ is.
Magnetic field lines which don’t loop back towards the sun and spew out charged particles.

Describe what a ‘solar flare’ is.
Explosive releases of light energy which also contain cosmic rays.

Describe what a ‘sun spot’ is.
An area where cooler plasma has sunk back to the centre of the sun.

Describe the origin and composition of cosmic rays.
High energy particles which come from space, mostly protons and alpha particles.

State how cosmic rays are detected.
Above the atmosphere cosmic rays are detected by satellites. Below the atmosphere cosmic rays cause a cosmic shower and the particles from the cosmic shower are detected as they give off light when passing through water.

Describe the path of a particle entering the Earth’s atmosphere directly towards one of the poles.
It would continue in a straight line along the magnetic field line heading towards the pole.

Describe the path of a particle entering the Earth’s atmosphere directly towards the equator.
It would be absorbed by the Earth’s atmosphere.

Describe the path of a particle entering the Earth’s atmosphere at an angle and between the equator and one of the poles.
It would follow a helical path around the magnetic field lines.

Describe how an aurorae is produced.
Particles from space follow helical paths around magnetic field lines. They interact with the atmosphere and emit light as they do this which is an aurorae.

Explain why the helical radius of particles caught in Van-Allen belts varies.
The nearer the particles are to the poles the stronger the magnetic field is so the smaller the radius of the helix. The further the particles are from the poles the weaker the magnetic field is so the larger the radius of the helix.

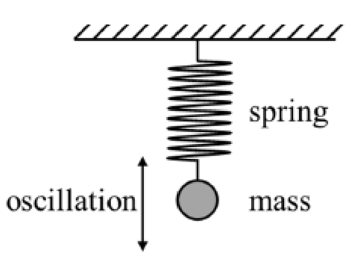
Unit 2

Section 2

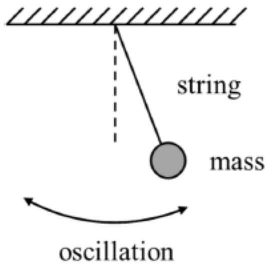
Waves

Simple harmonic motion SHM

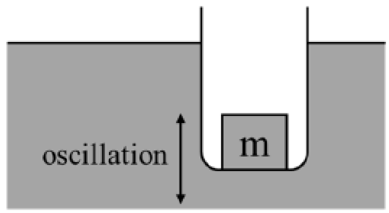
Examples of SHM



Mass on a spring



Simple Pendulum



Mass bobbing up and down in a fluid

An object displaced from its equilibrium position exhibits SHM if it is acted on by a **linear restoring** force.

Solutions to SHM equation

y = A$\sin\omega t$ and y = A$\cos\omega t$ are solutions of the SHM equation.

Velocity in SHM

Example

1. A 3 kg bob is in SHM as shown. It completes 4 oscillations per second.

Calculate its velocity at

a. y = 15 cm
b. y = 0 cm
c. y = -20 cm

a.

b.

c.

Graphs of SHM

displacement

velocity

acceleration

displacement – max at y=A (extreme of motion)

velocity – max at y=0 (middle of motion)

acceleration – max at y = A (extreme of motion)

Energy in SHM

Example

1. A 1.4 kg bob is in SHM as shown. It is oscillating at 0.5 Hz.

At a certain time y = 20 mm. Calculate E_k, E_p and E_t at this time.

a. E_k

b. E_p

c. E_t

Total energy =

Kinetic energy =

Potential energy =

Damping

SMH is often damped. This means energy is being removed from the system.

SHM – no damping SHM – with damping

Systems when there is a lot of damping are called critically damped.

You can now complete tutorial 1.0 and 1.1

The wave equation

Examples

1. A wave has the following equation (all distances in m)

a. Calculate the amplitude of the wave

b. Calculate the frequency of the wave

c. Calculate the wavelength of the wave

d. Calculate the speed of the wave

2. A wave has the following equation (all distances in cm)

a. Calculate the amplitude of the wave

b. Calculate the frequency of the wave

c. Calculate the wavelength of the wave

d. Calculate the speed of the wave

3. A wave has the following equation (all distances in mm)

a. Calculate the amplitude of the wave

b. Calculate the frequency of the wave

c. Calculate the wavelength of the wave

d. Calculate the speed of the wave

The intensity of a wave is proportional to the amplitude squared.

Examples

1. A wave has the following equation

Write down the equation of a wave travelling in the opposite direction with double the intensity and the same speed but double the frequency.

2. A wave has the following equation

Write down the equation of a wave with treble the intensity, travelling in the opposite direction, with double the speed but the same frequency.

Phase difference

A phase difference exists between 2 points on the same wave.

	Phase difference	Distance	Phase difference/distance
0 to A			
0 to B			
0 to C			
0 to D			

If waves are in-phase then they have a phase difference of

$0, 2\pi, 4\pi, 6\pi, 8\pi$ etc.

If waves are exactly out of phase then they have a phase difference of

$1\pi, 3\pi, 5\pi, 7\pi, 9\pi$ etc.

Example

1. Two points on a wave of wavelength 6 cm are 15 cm apart.

a. Calculate the phase difference between the two points.

b. State whether the points are in phase or out of phase.

<u>Stationary waves</u>

A stationary or standing wave is formed by the interference of two waves of equal wavelength and amplitude but travelling in opposite directions.

Remember when doing calculations that the distance between nodes is $\lambda/2$.

A travelling wave
- adjacent points out of phase
- adjacent points oscillate to same amplitude

A stationary wave
- adjacent points in phase
- adjacent points oscillate to different amplitudes

<u>You can now complete tutorial 2.0 and 2.1</u>

Interference

Interference can only occur between 2 waves which are coherent. Coherent waves have the same phase. The best way to achieve this is to split a single source in two.

Optical path difference and path difference

S1 and S2 are 2 coherent sources

A maxima will occur at Q when

A minima will occur at Q when

We have started using m as n is used for refractive index. We must take account of refractive index when travelling through glass or water.

Where optical path difference =

Path difference is also linked to phase.

The only difference is that we are taking account of refractive index.

Division of amplitude or wavefront

All examples of interference we will cover involve either interference by division of amplitude (Thin films, wedge fringes, Newtons' rings, non-reflective coatings) or interference by division of wavefront (Youngs' double slits, diffraction).

In division of amplitude an extended source of light can be used but in division of wavefront a single point source must be used.

In division of amplitude examples when light moves from a low to high refractive index then a π phase change occurs.

LOW TO HIGH GIVES π

Thin films (division of amplitude)

White light incident on a thin film (oil) above another medium (water) causes constructive and destructive interference.

The varying thickness of the thin film causes a colourful effect as different thicknesses produce different interference effects for different colours of light.

Example

1. Calculate the minimum thickness of oil ($n = 1.42$) which will produce constructive interference for red light ($\lambda = 633$ nm)

<u>Wedge fringes</u> (division of amplitude)

Fringes can be observed using a thin wedge of air. R_1 and R_2 interfere to produce constructive and destructive interference.

Example

1. During a wedge fringe experiment with green light (λ = 550 nm) and a 4 cm long wedge the following fringes are observed.

Calculate the height of the wedge.

<u>Non-reflective coating</u> (division of amplitude)

Some glasses and camera lenses have non-reflecting coatings on them. They often have a purple tinge. In non-reflective coatings R_1 and R_2 interfere to produce destructive interference.

We want destructive interference as we don't want light to be reflected.

d can be varied to produce destructive interference for different λ. They are usually set up to cancel the middle of the visible spectrum (green). This means the edges of the visible spectrum (red and blue) are not perfectly cancelled so mix to give the purple tinge.

Example

1. Calculate the thickness of coating n = 1.36 needed to cause destructive interference for green light (λ = 550 nm).

<u>You can now complete tutorial 3.0 and 3.1</u>

<u>Young slits</u> (division of wavefront)

Example

1. A 633 nm laser is shone through a set of slits 0.3 mm apart. The maxima produced are 4 cm apart. Calculate how far away the screen is.

<u>You can now complete tutorial 4.0 and 4.1</u>

Polarisation

We often draw the electric field vector of a light wave as a 2D wave.

In reality the electric field vector also oscillates along the z–axis.

We will now look at the electric field rector along the x axis in the yz plane.

In unpolarised light the electric field vector oscillates in many planes.

In polarised light the electric field vector oscillates in the same plane (not direction).

Polarising waves

Only transverse waves can be polarised, not longitudinal waves.

Most light is unpolarised but we can polarise it by absorbing all planes except 1. With polaroids there are large chains of molecules which absorb light. Light oscillating parallel to the chains of molecules is absorbed. Light oscillating perpendicular to the chains of molecules is transmitted.

For microwaves light oscillating parallel to the chains of molecules is absorbed. Light oscillating perpendicular to the chains of molecules is transmitted.

Polarisation by reflection

Light can be polarised by reflecting it from water or glass. If it is reflected at Brewster's angle it will be completely polarised in the direction parallel to the boundary.

You can now complete tutorial 5.0 and 5.1

Waves

Describe what is meant by 'simple harmonic motion'.
An object in simple harmonic motion oscillates due to a **linear** **restoring** force. (F= -ky)

State the two solutions to SHM.
$y = A\sin(\omega t)$ and $y = A\cos(\omega t)$

State what is meant by 'damping'.
A reduction in the **amplitude and energy** of an object in SHM.

Describe how a stationary wave is produced.
An incident wave and a reflected wave of equal amplitude and frequency interfere.

Describe what is meant by a 'node' on a stationary wave.
A point where there is no displacement.

Describe what is meant by an 'anti-node' on a stationary wave.
A point where there is maximum displacement.

State the condition for two waves to be coherent.
For waves to be coherent they must have equal phase.

Describe when a phase change will occur when light travels from one medium to another.
When light travels from a low to a high refractive index medium a π phase change occurs (**low to high gives π**). When going from high to low then no phase change occurs.

State three examples of interference by division of amplitude.
Thin films, wedge fringes and anti-reflective coatings.

State one example of interference by division of wavefront.
Youngs' double slits.

Explain how anti-reflective coatings work.
The ray of light reflected from the top surface of the coating interferes with the ray of light reflected from the bottom surface of the coating. **There is a π phase change for each reflection.** The thickness of the coating is chosen to allow **destructive interference** to occur.

Explain how thin films produce interference patterns.
The ray of light reflected from the top surface of the thin film interferes with the ray of light reflected from the bottom surface of the film. **There is a π phase change for the reflection off of the top surface only.** The thickness of the film determines which colours interfere constructively and which interfere destructively.

Explain how a wedge of air produces interference patterns.
The ray of light reflected from the bottom surface of the top slide interferes with the ray of light reflected from the top surface of the bottom slide. The thickness of the wedge of air varies along the length of the wedge and has thicknesses where constructive interference and destructive interference occur.

Explain why anti-reflective coatings have a purple tinge.
Anti-reflective coatings are set up to cause destructive interference in the middle of the visible spectra (green). The edges of the visible spectra (red and blue) do not destructively interfere and mix to give purple.

Describe why bright fringes can be observed on a far away screen if laser light is shone through a double slit.
Waves **meet** **in phase** and constructively interfere to produce maxima.

Describe why dark fringes can be observed on a far away screen if laser light is shone through a double slit.
Waves **meet** **exactly out of phase** and destructively interfere to produce minima.

Describe the effect of changing the wavelength of light on the spacing of fringes in a Youngs' double slit experiment.
Increasing the wavelength increases the space between fringes. Decreasing the wavelength decreases the space between fringes.

State what is meant by the term 'unpolarised'.
The electric field vector oscillates in **more than one** **plane**.

State what is meant by the term 'plane polarised'.
The electric field vector only oscillates in **one** **plane**.

Describe what is meant by 'Brewster's angle'.
When unpolarised light is incident on a glass or water surface if the incident angle is equal to Brewster's angle then the reflected component of light from the surface will be plane polarised.

Unit 3

Electromagnetism

Force in an electric field

The force will be attractive if the charges are different

The force will be repulsive if the charges are the same

Force is a vector quantity so vector diagrams are needed when solving problems.

Examples

1. A +3 mC charge and a -6 mC charge are 4 mm apart. Calculate the force of attraction between them.

2. Calculate the resultant force on charge A from B and C.

<u>You can now complete tutorial 1.0, 1.1</u>

Electric field patterns

Electric field patterns can be drawn around electric charges to indicate the direction a positive charge would move in an electric field. The closer together the field lines are, the stronger the electric field.

Field lines around a positive charge

Field lines around a negative charge

Field lines around two different charges

Field lines around two similar charges

Field lines between two parallel plates

Electric field strength

The electric field strength is the force experienced by a unit positive charge.

Electric field strength is a vector quantity so vector diagrams are needed when solving 2D problems.

Examples

1. Calculate the electric field strength at a distance of 8 cm from a 12 nC charge.

2. Calculate the electric field strength at points x and y in the diagram below.

The electric field strength around a hollow conductor varies as shown.

Electric field strength in a uniform field is given by

<u>You can now complete tutorials 2.0, 2.1</u>

<u>Electrostatic potential</u>

The electrostatic potential is the work done to bring a positive test charge from infinity to a point in an electric field.

Electrostatic potential is a scalar quantity and so requires no vector addition.

Examples

1. Calculate the electrostatic potential at a distance of 18 mm from a 4 nC charge.

2. Calculate the electrostatic potential be at point x in the diagram.

The electrostatic potential around a hollow conductor varies as shown.

<u>You can now complete tutorial 3.1</u>

Collisions between charges

If a positively charged particle is fired towards a positively charged nucleus it will turns its kinetic energy into potential energy.

Example

1. A proton is moving at 1.8×10^6 ms^{-1} towards a carbon nucleus (+12). Calculate how close it gets to the nucleus.

<u>Millikan's oil drop experiment</u>

A negatively charged oil drop can be suspended between charged plates as the electrostatic force (qE) is balanced by the weight (mg)

When Millikan did this experiment he found that all values of q were multiples of the charge on an electron. Eg 1.6 x 10^{-19}, 3.2 x 10^{-19}, 4.8 x 10^{-19}. This showed him that charge was quantised in chunks of 1.6 x 10^{-19} C.

Example

1. An oil drop of charge 4 e is suspended by a 6 kV potential produced between plates separated by 2 cm. Calculate the mass of the oil drop.

You can now complete tutorial 4.0,4.1

Magnetism

A magnetic field is a place where a **moving** charge experiences a force.

Ferromagnetism

Ferromagnetic materials like Iron, Nickel and Cobalt can be made into magnets. A magnet is held near them and the dipoles in the materials line up in the same direction.

Magnetic induction

The strength of a magnetic field is called the magnetic induction (B) and is measured in Tesla (T). 1 Tesla is the magnetic field in which a 1 m long wire carrying 1 A of current is acted on by a 1 N force.

Force on a current carrying wire

Example

1. A 60 cm long wire in a 14 mT field at an angle of 50^0 to the field experiences a force of 0.5 N. Calculate the current flowing in the wire.

Magnetic induction at a distance from a current carrying wire.

As well as experiencing a force in a magnetic field a current carrying wire can create its own magnetic field.

The left hand rule will tell you in which direction the magnetic field lines are.

Example

1. A magnetic induction of 0.6 mT is experienced next to a wire carrying a current of 88 A. Calculate the distance to the wire.

Force per unit length between 2 current carrying wires

If two current carrying wires are placed close to each other then their magnetic fields will interact.

Current in same direction – attraction
Current in opposite directions – repulsion

Example

1. 2 wires carrying 460 mA are placed 0.4 mm apart. The wires are 240 cm in length. Calculate the force experienced by each wire.

You can now complete tutorial 5.0, 5.1

Motion in a magnetic field

Charged particles also move through space as well as through wires. You saw this in unit 2 with the charged particles from the sun causing aurorae.

$\theta = 0^0$

F = 0 so particles move along field lines.

$\theta = 90^0$

F = qvB so particles move in circular path due to right hand rule.

Right hand rule is set up for negative particles.

The magnetic force provides the central force for the circular motion so

Example

1. An electron travelling at 3.2×10^7 ms^{-1} enters a 40 mT magnetic field. Calculate its radius of orbit.

Particles of opposite charge would orbit in opposite directions in a B – field. The radius of orbit is also dependent on the mass, velocity and charge of the particle.

θ between 0^0 and 90^0

The particle will move in a helical path around the B – field. Eg a charged particle trapped in a Van-Allen belt.

Angle of v to B field is important

vB – perpendicular =

vB – parallel =

Period of a helix

The period of a helix is the time to complete one rotation.

Pitch of a helix

The pitch of a helix is the distance between similar points.

Example

1. An electron moving at 6.2×10^6 ms^{-1} enters a 0.2 T B-field at an angle of 31^0 to the B-field. Calculate the period and pitch of the helical motion.

Combining E and B fields

A charged particle can be made to travel undeviated through balanced E and B fields.

Example

1. An electron moving 6.9×10^7 ms^{-1} enters a 600 mT B-field and travels undeviated. Calculate the strength of the E-field.

You can now complete tutorials 6.0, 6.1

<u>**Capacitors**</u>

In a dc circuit capacitors take time to charge or discharge.

The time to charge or discharge depends on the resistance and capacitance. The time constant is used to describe approximate charging times.

The time constant is the time taken to reach 0.63 (or 63 %) of the maximum value during the charging process or to fall to 0.37 (or 37 %) of the initial value during the discharging process.

Example

1. Calculate the time constant during the charging process for a 600 μF capacitor in series with an 8 kΩ resistor.

In a.c. circuits capacitors block low frequencies

The property of a capacitor which blocks low frequencies is its reactance. Reactance is measures in Ohms but it is not a resistance, although it does have the same effect on a circuit. Reactance is a measure of opposition to current in ac circuits.

Example

1. Calculate the reactance of an 80 μF capacitor at 3 kHz.

<u>You can now complete tutorial 7.0, 7,1</u>

Inductors

An inductor is a coil of wire with a soft iron cone.

Electromagnetic induction involves kinetic energy being transformed into electrical energy. Eg. A magnet moving near a coil of wire. When the current is induced in the coil of wire it too will have a magnetic field around it which will oppose the original magnet used to create the induced current in the first place.

In a dc circuit an inductor causes a delay in changing the current due to this effect.

Closing a switch (completing a circuit)	opening a switch (breaking a circuit)

Growth – induced emf opposes increase in current
Decay – induced emf opposes decrease in current.

Back emf

The opposition to changing current is often called a back emf. This can be thought of as a large voltage used to oppose the change in current.

In the circuit above the neon lamp needs 80 V to light. When the switch is opened a large back emf (80 V) is produced as the current tries to go back to zero and the lamp lights.

Any induced emf will always oppose the change which produced it. An inductor always tries to maintain the current at its present value.

Magnitude of induced emf

The inductance of an inductor is 1 H when 1 V of emf is induced across the inductor when the current changes at a rate of 1 As^{-1}.

Example

1. A current changes at 3 As^{-1} to produce a back emf of 6 V. Calculate the inductance of the inductor.

Energy stored in inductor

Examples

1. 42 mJ of energy is stored on a 100 mH inductor. Calculate the current.

2. A circuit is shown below.

a. Calculate the back emf when I = 3 A.

b. Calculate the inductance of the inductor.

c. Calculate the energy stored in the inductor when I = 3 A.

In a.c. circuits inductors block high frequencies

The property of an inductor which blocks high frequencies is its reactance, measured in Ohms. Reactance is a measure of opposition to current in ac circuits.

Example

1. Calculate the reactance of a 90 mH inductor with a frequency of 8 kHz.

Combining capacitors and inductors

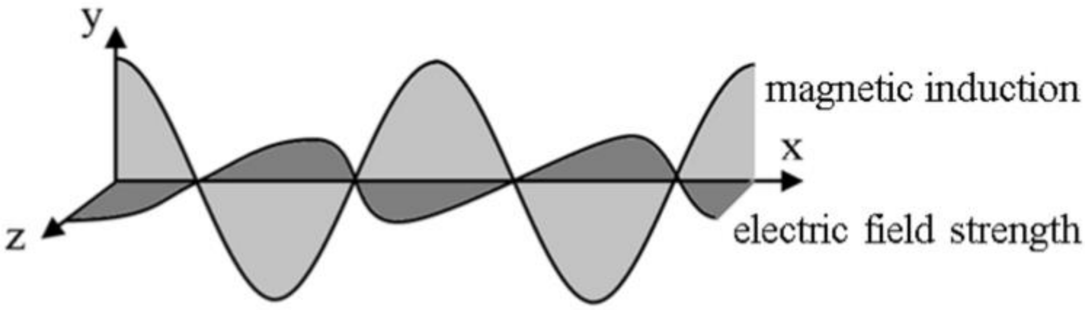
At high frequency the inductor has a big reactance so V_L will be high.
At low frequency the capacitor has a big reactance so V_C will be high.

Systems like this can be used to control voltages to other components through changing frequencies.

You can now complete tutorials 8.0, 8.1, 8.2

Electricity and magnetism

Electromagnetic waves oscillate in E and B fields at 90^0 to each other.



The speed of light, permittivity of free space and permeability of free space can all be combined.

This shows that all electromagnetic waves regardless of frequency or wavelength travel at the speed of light.

Example

1. Calculate the speed of light using the permeability of free space and permittivity of free space.

You can now complete tutorial 9.0

Electromagnetism

Describe what an electric field is.
A place where a charge experiences a force.

Describe what an electric field usually does to charged particles.
An electric field is usually used to accelerate charged particles.

State the meaning of the term 'electric field strength'.
The force per unit positive charge.

Describe the direction the arrows point in electric field diagrams.
The direction a positive charge would follow.

Describe the electric field strength around a hollow sphere.
Zero inside the sphere and decreasing at $1/r^2$.

State the meaning of the term 'electrostatic potential'.
The work done to bring a positive test charge from infinity to a point in an electric field.

Describe the electrostatic potential around a hollow sphere.
Maximum inside the sphere and decreasing at 1/r.

State the two forces which balance each other in Millikan's oil drop experiment.
Electrostatic force upwards balanced by weight downwards.

Describe what a magnetic field is.
A place where a **moving** charge experiences a force.

Describe what a magnetic field usually does to charged particles.
A magnetic field is usually used to deflect charged particles.

Describe what a ferromagnetic material is.
Ferromagnetic materials can be made into magnets. A magnet is held near them and the dipoles in the materials line up in the same direction.

State the names of three ferromagnetic materials.
Cobalt, Nickel and Iron

Describe the direction of the force between two current carrying wires.
If the current is in the same direction the force is attractive. If the current is in opposite direction the force is repulsive.

Describe the motion of a charged particle travelling parallel to a magnetic field.
The charged particle will travel at a constant velocity.

Describe the motion of a charged particle travelling perpendicular to a magnetic field.
The charged particle will travel in a circle with the magnetic field providing the central force.

Describe the motion of a charged particle travelling at an angle to a magnetic field.
The charged particle will travel in a helical path as the constant velocity parallel to the magnetic field combines with the circular motion perpendicular with the magnetic field.

Describe what the time constant is.
The time taken for the current in a capacitive or inductive circuit to reach 63% of its maximum value during an increase in current or down to 37% of its original value during a decrease in current.

State what is meant by the term ‘capacitive reactance’.
The opposition to current in a high frequency ac circuit.

State what is meant by the term ‘inductive reactance’.
The opposition to current in a low frequency ac circuit or dc circuit.

Describe how a change in frequency affects the current in a circuit with a capacitor.
An increase in frequency causes an increase in current. A decrease in frequency causes a decrease in current.

Describe how a change in frequency affects the current in a circuit with an inductor.
An increase in frequency causes a decrease in current. A decrease in frequency causes an increase in current.

Explain why the current in a circuit does not reach its maximum value immediately when a switch is closed in a circuit with an inductor.
The inductor causes a back emf which opposes the emf of the circuit.

Explain how inductors can be used to generate very large emf’s.
Rapid changes in current can cause large back emf’s to be produced.

Describe a light wave.
Light consists of an electric field and a magnetic field oscillating at right angles to each other.