Lockerbie Academy Physics Department

2022

AH Physics Compendium

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Data Sheet

DATA SHEET

COMMON PHYSICAL QUANTITIES

Quantity	Symbol	Value	Quantity	Symbol	Value
Gravitational acceleration on Earth	g	$9{\cdot}8\ \mathrm{m\,s^{-2}}$	Mass of electron	m_e	$9{\cdot}11 \times 10^{-31}\ \mathrm{kg}$
Radius of Earth	R_E	$6{\cdot}4 \times 10^{6}\ \mathrm{m}$	Charge on electron	e	$-1{\cdot}60 \times 10^{-19}\ \mathrm{C}$
Mass of Earth	M_E	$6{\cdot}0 \times 10^{24}\ \mathrm{kg}$	Mass of neutron	m_n	$1{\cdot}675 \times 10^{-27}\ \mathrm{kg}$
Mass of Moon	M_M	$7{\cdot}3 \times 10^{22}\ \mathrm{kg}$	Mass of proton	m_p	$1{\cdot}673 \times 10^{-27}\ \mathrm{kg}$
Radius of Moon	R_M	$1{\cdot}7 \times 10^{6}\ \mathrm{m}$	Mass of alpha particle	m_a	$6{\cdot}645 \times 10^{-27}\ \mathrm{kg}$
Mean Radius of Moon Orbit		$3{\cdot}84 \times 10^{8}\ \mathrm{m}$	Charge on alpha particle		$3{\cdot}20 \times 10^{-19}\ \mathrm{C}$
Solar radius		$6{\cdot}955 \times 10^{8}\ \mathrm{m}$	Planck's constant	h	$6{\cdot}63 \times 10^{-34}\ \mathrm{J\,s}$
Mass of Sun		$2{\cdot}0 \times 10^{30}\ \mathrm{kg}$	Permittivity of free space	ε_0	$8{\cdot}85 \times 10^{-12}\ \mathrm{F\,m^{-1}}$
1 AU		$1{\cdot}5 \times 10^{11}\ \mathrm{m}$	Permeability of free space	μ_0	$4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}$
Stefan-Boltzmann constant	σ	$5{\cdot}67 \times 10^{-8}\ \mathrm{W\,m^{-2}K^{-4}}$	Speed of light in vacuum	c	$3{\cdot}0 \times 10^{8}\ \mathrm{m\,s^{-1}}$
Universal constant of gravitation	G	$6{\cdot}67 \times 10^{-11}\ \mathrm{m^3\,kg^{-1}\,s^{-2}}$	Speed of sound in air	v	$3{\cdot}4 \times 10^{2}\ \mathrm{m\,s^{-1}}$

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	$2{\cdot}70 \times 10^{3}$	933	2623	$9{\cdot}02 \times 10^{2}$	$3{\cdot}95 \times 10^{5}$	. . . .
Copper	$8{\cdot}96 \times 10^{3}$	1357	2853	$3{\cdot}86 \times 10^{2}$	$2{\cdot}05 \times 10^{5}$	. . . .
Glass	$2{\cdot}60 \times 10^{3}$	1400	. . . .	$6{\cdot}70 \times 10^{2}$	. . . .	. . . .
Ice	$9{\cdot}20 \times 10^{2}$	273	. . . .	$2{\cdot}10 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	. . . .
Glycerol	$1{\cdot}26 \times 10^{3}$	291	563	$2{\cdot}43 \times 10^{3}$	$1{\cdot}81 \times 10^{5}$	$8{\cdot}30 \times 10^{5}$
Methanol	$7{\cdot}91 \times 10^{2}$	175	338	$2{\cdot}52 \times 10^{3}$	$9{\cdot}9 \times 10^{4}$	$1{\cdot}12 \times 10^{6}$
Sea Water	$1{\cdot}02 \times 10^{3}$	264	377	$3{\cdot}93 \times 10^{3}$	. . . .	. . . .
Water	$1{\cdot}00 \times 10^{3}$	273	373	$4{\cdot}19 \times 10^{3}$	$3{\cdot}34 \times 10^{5}$	$2{\cdot}26 \times 10^{6}$
Air	1·29	. . . .	. . . .	. . . .	. . . .	. . . .
Hydrogen	$9{\cdot}0 \times 10^{-2}$	14	20	$1{\cdot}43 \times 10^{4}$	. . . .	$4{\cdot}50 \times 10^{5}$
Nitrogen	1·25	63	77	$1{\cdot}04 \times 10^{3}$	. . . .	$2{\cdot}00 \times 10^{5}$
Oxygen	1·43	55	90	$9{\cdot}18 \times 10^{2}$	. . . .	$2{\cdot}40 \times 10^{4}$

The gas densities refer to a temperature of 273 K and a pressure of $1{\cdot}01 \times 10^{5}$ Pa.

Relationships Required For Higher Physics

$d = \bar{v}t$

$s = \bar{v}t$

$v = u + at$

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

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

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

$W = mg$

$F = ma$

$E_w = Fd$

$E_p = mgh$

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

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

$p = mv$

$Ft = mv - mu$

$F = G\frac{m_1 m_2}{r^2}$

$t' = \frac{t}{\sqrt{1 - \frac{v^2}{c^2}}}$

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

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

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

$v = H_0 d$

$W = QV$

$E = mc^2$

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

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

$I_1 d_1^2 = I_2 d_2^2$

$E = hf$

$E_k = hf - hf_0$

$v = f\lambda$

$E_2 - E_1 = hf$

$d\sin\theta = m\lambda$

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

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

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

Path difference= $m\lambda$ or $(m+ ½)\lambda$ where m = 0,1,2 …..

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

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

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

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

$V = IR$

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

$R_T = R_1 + R_2 + ...$

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

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

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

$E = V + Ir$

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

Q=It

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

Relationships Required for Advanced Higher Physics

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

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

$$v = u + at$$

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

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

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

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

$$\omega = \omega_0 + \alpha t$$

$$\theta = \omega_0 t + \frac{1}{2}\alpha t^2$$

$$\omega^2 = \omega_0^2 + 2\alpha\theta$$

$$s = r\theta$$

$$v = r\omega$$

$$a_t = r\alpha$$

$$\omega = 2\pi f$$

$$\omega = \frac{2\pi}{T}$$

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

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

$$I = \sum mr^2$$

$$\tau = Fr$$

$$\tau = I\alpha$$

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

$$L = I\omega$$

$$E_{k(rotational)} = \frac{1}{2}I\omega^2$$

$$E_P = E_{k(translational)} + E_{k(rotational)}$$

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

$$F = \frac{GMm}{r^2} = \frac{mv^2}{r} = mr\omega^2 = mr\left(\frac{2\pi}{T}\right)^2$$

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

$$E_p = Vm = -\frac{GMm}{r}$$

$$v_{esc} = \sqrt{\frac{2GM}{r}}$$

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

$$b = \frac{L}{4\pi d^2}$$

$$\frac{P}{A} = \sigma T^4$$

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

$$E = hf$$

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

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

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

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

$$F = qvB$$

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

$$F = -ky$$

$$\omega = 2\pi f = \frac{2\pi}{T}$$

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

$$y = A\sin\omega t \text{ or } y = A\cos\omega t$$

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

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

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

$$E = kA^2$$

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

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

$$opd = n \times gpd$$

$$opd = m\lambda \text{ or } \left(m + \tfrac{1}{2}\right)\lambda \text{ where } m = 0,1,2 \ldots$$

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

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

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

$$n = \tan i_P$$

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

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

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

$$F = QE$$

$$V = Ed$$

$$W = QV$$

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

$$B = \frac{\mu_0 I}{2\pi r}$$

$$F = IlB\sin\theta$$

$$F = qvB$$

$$\tau = RC$$

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

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

$$\varepsilon = -L\frac{dI}{dt}$$

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

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

$$X_L = 2\pi fL$$

$$c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}$$

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

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

$$\left(\frac{\Delta W^n}{W^n}\right) = n\left(\frac{\Delta W}{W}\right)$$

Additional relationships

Circle

circumference = $2\pi r$

area = πr^2

Sphere

area = $4\pi r^2$

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

Trigonometry

$$sin\,\theta = \frac{opposite}{hypotenuse}$$

$$cos\,\theta = \frac{adjacent}{hypotenuse}$$

$$tan\,\theta = \frac{opposite}{adjacent}$$

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

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

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

Table of standard integrals

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

Greek Alphabet

Upper Case Α Alpha Lower Case α	Upper Case Β Beta Lower Case β	Upper Case Γ Gamma Lower Case γ	Upper Case Δ Delta Lower Case δ
Upper Case Ε Epsilon Lower Case ε	Upper Case Ζ Zeta Lower Case ζ	Upper Case Η Eta Lower Case η	Upper Case Θ Theta Lower Case θ
Upper Case Ι Iota Lower Case ι	Upper Case Κ Kappa Lower Case κ	Upper Case Λ Lambda Lower Case λ	Upper Case Μ Mu Lower Case μ
Upper Case Ν Nu Lower Case ν	Upper Case Ξ Xi Lower Case ξ	Upper Case Ο Omicron Lower Case ο	Upper Case Π Pi Lower Case π
Upper Case Ρ Rho Lower Case ρ	Upper Case Σ Sigma Lower Case σ	Upper Case Τ Tau Lower Case τ	Upper Case Υ Upsilon Lower Case υ
Upper Case Φ Phi Lower Case φ	Upper Case Χ Chi Lower Case χ	Upper Case Ψ Psi Lower Case ψ	Upper Case Ω Omega Lower Case ω

Periodic Table

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

First derivative of displacement = velocity

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

$$velocity\ (ms^{-1})\ =\ rate\ (s^{-1}) of\ change\ of\ displacement\ (m)$$

Second derivative of displacement = acceleration
First derivative of velocity = acceleration

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

$$acceleration\ (ms^{-2})\ =\ rate\ (s^{-1}) of\ change\ of\ velocity\ (ms^{-1})$$

$$v = u + at$$

$$final\ velocity\ (ms^{-1}) = initial\ velocity\ (ms^{-1}) + acceleration\ (ms^{-2}) \times time\ (s)$$

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

$$displacement = initial\ velocity\ \times time + \frac{1}{2} \times acceleration\ (ms^{-2}) \times time^2\ (s^2)$$

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

$$final\ velocity^{\,2}\ (ms^{-1})^2\ =\ initial\ velocity^{\,2} (ms^{-1})^2 + 2 \times acceleration\ (ms^{-2}) \times dispacement\ (m)$$

First derivative of angular displacement = angular velocity

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

$$angular\ velocity\ (ms^{-1})\ =\ rate\ (s^{-1}) of\ change\ of\ angular\ displacement\ (rad)$$

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

$$angular\ acceleration\ (rad\ s^{-2})\ =\ rate\ (s^{-1}) of\ change\ of\ angular\ velocity\ (rad\ s^{-1})$$

Equation for motion for uniform angular acceleration

$$\omega = \omega_o + at$$

$$\begin{matrix} final\ angular\ velocity \\ (rad\ s^{-1}) \end{matrix} = \begin{matrix} initial\ angular\ velocity \\ (rad\ s^{-1}) \end{matrix} + \begin{matrix} angular\ acceleration \\ (rad\ s^{-2}) \end{matrix} \times \begin{matrix} time \\ (s) \end{matrix}$$

Equation for motion for uniform angular acceleration $$\omega^2 = \omega_o{}^2 + 2a\theta$$ $$\frac{final\ angular\ velocity^2}{(rad\ s^{-1})^2} = \frac{initial\ angular\ velocity^2}{(rad\ s^{-1})^2} + 2 \times \frac{angular\ acceleration}{(rad\ s^{-2})} \times \frac{angular\ dispacement}{(rad)}$$
Equation for motion for uniform angular acceleration $$\theta = \omega_o t + \frac{1}{2}at^2$$ $$\frac{angular\ displacement}{(rad)} = \frac{initial\ velocity}{(rad\ s^{-1})} \times \frac{time}{(s)} + \frac{1}{2} \times \frac{angular\ acceleration}{(rad\ s^{-2})} \times \frac{time^2}{(s)^2}$$
To convert from angular quantity to linear equivalent. Angles must be in radians $$s = r\theta$$ $$\frac{linear\ distance}{(m)} = \frac{radius}{(m)} \times \frac{angular\ displacement}{(rad)}$$
To convert from angular quantity to linear equivalent. $$v = r\omega$$ $$\frac{tangential\ velocity}{(m\ s^{-1})} = \frac{radius}{(m)} \times \frac{angular\ velocity}{(rad\ s^{-1})}$$
To convert from angular quantity to linear equivalent $$a_t = ra$$ $$\frac{tangential\ acceleration}{(m\ s^{-2})} = \frac{radius}{(m)} \times \frac{angular\ acceleration}{(rad\ s^{-2})}$$
Converts between angular velocity, frequency and period NB 2π rad = 1 revolution $$\omega = \frac{2\pi}{T}$$ $$angular\ velocity\ (rad\ s^{-1}) = \frac{2\pi}{Period\ (s)}$$

Converts between angular velocity, frequency and period $$\omega = 2\pi f$$ $$angular\ velocity\ (rad\ s^{-1}) = 2\pi \times frequency\ (Hz)$$
Radial or centripetal acceleration for uniform speed in a circle or radius r $$a_r = \frac{v^2}{r} = r\omega^2$$ $$\underset{(m\ s^{-2})}{radial\ acceleration} = \frac{tangential\ speed^2 (m\ s^{-1})^2}{radius\ of\ the\ circular\ motion\ (m)} = \underset{(m)}{radius\ of\ the\ circular\ motion} \times \underset{(rad\ s^{-1})^2}{angular\ velocity^2}$$
Centripetal (central) force is the unbalanced force acting towards the centre of a circle $$F = \frac{mv^2}{r} = mr\omega^2$$ $$\underset{(N)}{Centripetal\ Force} = \frac{mass\ (kg) \times tangential\ speed^2 (m\ s^{-1})^2}{radius\ of\ the\ circular\ motion\ (m)} = \underset{(kg)}{mass} \times \underset{(m)}{radius\ of\ the\ circular\ motion} \times \underset{(rad\ s^{-1})^2}{angular\ velocity^2}$$
Moment of inertia $$I = \Sigma mr^2$$ $$Moment\ of\ inertia\ (kg\ m^2) = Sum\ of\ (the\ mass\ of\ each\ particle\ (kg)\ \times (distance\ from\ the\ axis\ of\ rotation)^2\ (m)^2)$$ ***NB the equation for individual shapes of rigid bodies around a point of rotation is given in the relationships sheet.***
Torque is also known as the moment of force (or the turning effect of a force) $$\tau = Fr$$ $$torque\ (Nm) = Force (N) \times distance\ between\ the\ line\ of\ action\ of\ force\ and\ the\ point\ of\ rotation\ (m)$$
$$\tau = I\alpha$$ $$Torque\ (Nm) = Moment\ of\ inertia\ (kg\ m^2) \times angular\ acceleration\ (rad\ s^{-2})$$

Angular momentum of a particle

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

$$\frac{\textit{angular momentum of a particle}}{(kg\ m^2 s^{-1})} = \frac{\textit{mass}}{(kg)} \times \frac{\textit{linear velocity}}{(m\ s^{-1})} \times \frac{\textit{distance to the turning point}}{(m)}$$

$$\frac{\textit{angular momentum}}{(kg\ m^2 s^{-1})} = \frac{\textit{mass}}{(kg)} \times \frac{\textit{distance to turning point}^2}{(m)^2} \times \frac{\textit{angular velocity}}{(rad\ s^{-1})}$$

Angular momentum of a rigid body

$$L = I\omega$$

$$\frac{\textit{angular momentum}}{(kg\ m^2 s^{-1})} = \frac{\textit{Moment of inertia}}{(kg\ m^2)} \times \frac{\textit{angular velocity}}{(rad\ s^{-1})}$$

Rotational Kinetic Energy of a rigid body

$$E_{k(rotational)} = \frac{1}{2} I\omega^2$$

$$\frac{\textit{Rotational kinetic energy}}{(J)} = \frac{1}{2} \times \frac{\textit{Moment of inertia}}{(kg\ m^2)} \times \frac{(\textit{angular velocity})^2}{(rad\ s^{-1})^2}$$

For objects rolling down a slope

$$E_p = E_{k(transitional)} + E_{k(rotational)}$$

$$\textit{Loss in gravitational potential energy } (J) = \textit{gain in translational kinetic energy } (J) + \textit{gain in rotational kinetic energy } (J)$$

NB this assumes no slipping and no energy losses due to friction

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

$$\textit{Force } (N) = \frac{\textit{Universal gravitational Constant } (m^3 kg^{-1} s^{-2}) \times \textit{Mass}_1 (kg) \times \textit{Mass}_2 (kg)}{\textit{separation distance}^2\ (m^2)}$$

$$\textit{NB The Universal Gravitational Constant} = 6.67 \times 10^{-11}\ m^3 kg^{-1} s^{-2}$$

For equating the gravitational force providing the central force to keep objects in orbit

$$F = \frac{GMm}{r^2} = \frac{mv^2}{r} = mr\omega^2 = mr\left(\frac{2\pi}{T}\right)^2$$

$$\text{gravitational Force }(N) = \frac{\text{Universal gravitational Constant }(m^3kg^{-1}s^{-2}) \times Mass_1(kg) \times Mass_2(kg)}{\text{separation distance}^2\ (m^2)} =$$

$$= \underset{(N)}{\text{Centripetal Force}} = \frac{\text{mass }(kg) \times \text{tangential speed}^2 (m\,s^{-1})^2}{\text{radius of the circular motion }(m)}$$

$$= \text{centripetal force} = \underset{(kg)}{\text{mass}} \times \underset{(m)}{\text{radius of the circular motion}} \times \underset{(rad\ s^{-1})^2}{\text{angular velocity}^2}$$

$$= \underset{(N)}{\text{Centripetal Force}} = \underset{(kg)}{\text{mass}} \times \underset{(m)}{\text{radius of the circular motion}} \times \left(\frac{2\pi}{\text{orbital period }(s)}\right)^2$$

Gravitational potential is the work done (energy transferred) per unit mass needed to move an object from infinity to that location. As 0 J is at infinity all gravitational potentials are negative

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

$$\text{gravitational potential }(J\,kg^{-1}) = -\frac{\text{Universal Gravitational Constant }(m^3kg^{-1}s^{-2}) \times \text{mass }(kg)}{\text{separation distance}(m)}$$

Gravitational potential energy is the work done (energy transferred) needed to move an object from infinity to that location. As 0 J is at infinity all gravitational potential energies are negative

$$E_p = Vm = -\frac{GMm}{r}$$

$$\text{gravitational potential energy }(J) = \text{gravitational potential }(J\,kg^{-1}) \times \text{mass }(kg)$$

As the gravitational potential is negative the equation is Vm and not -Vm!

$$\text{gravitational potential energy }(J) = -\frac{\text{Universal gravitational Constant }(m^3kg^{-1}s^{-2}) \times Mass_1(kg) \times Mass_2(kg)}{\text{separation distance}(m)}$$

Escape velocity from the surface of an object. i.e. the minimum velocity required for unpowered flight to escape the gravitational field. As this has the number 2 in the equation it is derived from energy and not from forces.

$$v_{esc} = \sqrt{\frac{2GM}{r}}$$

$$escape\ velocity\ (ms^{-1}) = \sqrt{\frac{2\ \times\ Universal\ gravitational\ Constant\ (m^3 kg^{-1} s^{-2})\ \times\ Mass\ being\ escaped\ from\ (kg)}{radius\ of\ the\ object\ being\ escaped\ from\ (m)}}$$

The Schwarzchild radius- the radius of the event horizon of a black hole

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

$$Schwarzschild\ radius\ (m) = \frac{2 \times Universal\ Gravitational\ Constant(m^3 kg^{-1} s^{-2}) \times Mass\ of\ the\ black\ hole(kg)}{speed\ of\ light^2\ (ms^{-1})^2}$$

Apparent brightness how bright the star appears to a detector here on Earth

$$b = \frac{L}{4\pi d^2}$$

$$apparent\ brightness\ (Wm^{-2}) = \frac{Luminosity\ (W)}{4\pi \times distance^2 (m)^2}$$

Power radiated from a black body

$$\frac{P}{A} = \sigma T^4$$

$$\frac{Power\ per\ unit\ area}{(Wm^{-2})} = \frac{Stefan\ Boltzmann\ Constant}{(5.67\ \times 10^{-8}\ Wm^{-2}\ K^4)} \times \frac{(temperature)^4}{(K)^4}$$

NB The Stefan Boltzmann Constant can be found on page 2 of the exam paper on the Data Sheet and is equal to $5.67\ \times 10^{-8}\ Wm^{-2}\ K^4$

Equation for the luminosity of a star $$L = 4\pi r^2 \sigma T^4$$ $$\frac{Luminosity}{(Wm^{-2})} = 4\pi \times \frac{radius\ of\ the\ star^{\,2}}{(m)^2} \times \frac{Stefan\ Boltzmann\ Constant}{(5.67 \times 10^{-8}\ Wm^{-2}\ K^4)} \times \frac{Temperature^4}{(K)^4}$$ *NB The Stefan Boltzmann Constant can be found on page 2 of the exam paper on the Data Sheet and is equal to* $5.67 \times 10^{-8}\ Wm^{-2}\ K^4$
$$E = hf$$ $$energy\ (J) = Planck's\ Constant\ (Js) \times frequency\ (Hz)$$ *NB Planck's constant = 6.63 x* 10^{-34} *J s*
Bohr's Quantisation of Angular Momentum $$mvr = \frac{nh}{2\pi}$$ $$\frac{mass}{(kg)} \times \frac{velocity}{(ms^{-1})} \times \frac{radius}{(m)} = \frac{no.of\ shell \times Planck's\ Constant\ (J\ s)}{2\pi}$$ *The* 2π *is an indication of the circular nature equalling 1 full circle. NB Planck's constant = 6.63 x* 10^{-34} *J s*
The de Broglie wavelength, when a particle behaves like a wave and this is the wavelength associated with that. $$\lambda = \frac{h}{p}$$ $$de\ Broglie\ wavelength\ (m) = \frac{Planck's constant\ (J\ s)}{momentum (kg\ ms^{-1})}$$

Uncertainty principle as it refers to position and momentum $$\Delta x \Delta p_x \geq \frac{h}{4\pi}$$ $$\frac{\text{the uncertainty in position in x direction}}{(m)} \times \frac{\text{uncertainty in the x component of momentum}}{(kg\ ms^{-1})} \geq \frac{\text{Planck's Constant}}{4\pi}$$ *NB In some old resources this was incorrectly marked as divided by 2π as h was given as* $\hbar$ $$\text{For the minimum uncertainty the uncertainty in the two quantities will} = \frac{h}{4\pi}$$
Uncertainty principle as it refers to energy and time $$\Delta E \Delta t \geq \frac{h}{4\pi}$$ $$\frac{\text{the uncertainty in energy}}{(J)} \times \frac{\text{uncertainty in the time}}{(s)} \geq \frac{\text{Planck's Constant}}{4\pi}$$ *NB In some old resources this was incorrectly marked as divided by 2π as h was given as* $\hbar$ $$\text{For the minimum uncertainty the uncertainty in the two quantities will} = \frac{h}{4\pi}$$
Magnetic Force $$F = qvB$$ $$\text{Magnetic Force } (N) = \text{Charge}(C) \times \text{velocity } (ms^{-1}) \times \text{magnetic induction } (T)$$
$$F = \frac{mv^2}{r}$$ $$\frac{\text{Centripetal Force}}{(N)} = \frac{\text{mass } (kg) \times \text{tangential speed}^2 (m\ s^{-1})^2}{\text{radius of the circular motion } (m)}$$
Proof for an object moving in SHM $$F = -ky$$ $$\text{Force } (N) = \text{constant } (Nm^{-1}) \times \text{distance } (m)$$

Converts between angular velocity, frequency and period $$\omega = 2\pi f = \frac{2\pi}{T}$$ $$angular\ velocity\ (rad\ s^{-1}) = 2\pi \times frequency\ (Hz) = \frac{2\pi}{Period\ (s)}$$ NB 2π rad = 1 revolution
Definition of S.H.M $$a = \frac{d^2y}{dt^2} = -\omega^2 y$$ $$\underset{(ms^{-2})}{acceleration} = second\ derivative\ of\ displacement = \underset{(rad\ s^{-1})^2}{-angular\ frequency^2} \times \underset{(m)}{displacement from\ rest\ position}$$
Solution to SHM equation   *Sine function occurs when y=0 and t=0, cosine function occurs when y=A at t=0* $$y = A\cos\omega t\ \ or\ y = A\sin\omega t$$ $$displacement\ (m) = Amplitude(m) \times cosine\ \ angular\ frequency\ (rad\ s^{-1})\ \times time\ (s)$$ *or* $$displacement\ (m) = Amplitude(m) \times sine\ \ angular\ frequency\ (rad\ s^{-1})\ \times time\ (s)$$
Velocity of a particle undergoing SHM $$v = \pm\omega\sqrt{(A^2 - y^2)}$$ $$velocity\ (ms^{-1}) = \pm angular frequency(rad\ s^{-1}) \times \sqrt{(Amplitude^2(m)^2 - displacment^2(m)^2)}$$ $$NB\ v_{max}\ occurs\ when\ y = 0\ \therefore\ v_{max} = \pm\omega A$$
Kinetic energy of a particle undergoing SHM $$E_k = \frac{1}{2}m\omega^2(A^2 - y^2)$$ $$kinetic\ energy\ (J) = \frac{1}{2} \times mass(kg) \times angular\ frequency^2\ (rad\ s^{-1})^2 \times (Amplitude^2(m)^2 - displacment^2(m)^2))$$ *NB Ek is at a maximum when y = 0 and zero when y = A* $E_{k\ (max)} = \frac{1}{2}m\omega^2 A^2$

Potential energy of a particle undergoing SHM

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

$$potential\ energy\ (J) = \frac{1}{2} \times mass(kg) \times angular\ frequency^2\ (rad\ s^{-1})^2 \times displacment^2 (m)^2$$

NB The sum of Ep and Ek remains constant

Ep is maximum when y = A and zero when y = 0

Energy of a wave

$$E = kA^2$$

$$Energy\ of\ a\ wave\ (J) = constant(\ Jm^{-2}) \times\ amplitude^2 (m)^2$$

Travelling Wave Equation

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

$$displacement = Amplitude\ (m) \times sine \times 2 \times \pi \left(frequency\ (Hz) \times time\ (s) - \frac{distance\ (m)}{wavelength\ (m)}\right)$$

A wave travelling in the positive direction (left to right) has a negative sign in the equation, a wave travelling in the negative direction (right to left) has a positive in the equation.

Check out the various combinations of this equation where 2π could be multiplied out, a number can appear on the top which would equal $1/\lambda$, and $2\pi f$ can be replaced with ω.

It must be a travelling wave as the value of y changes with time.

$y\ =\ A \sin 2\pi f \left(t\ - \frac{x}{f\lambda}\right)$ $y = A sin 2\pi f (t - \frac{x}{v})$	$y\ =\ A \sin \omega \left(t\ - \frac{x}{v}\right)$ $y = A cos \omega (t - \frac{x}{v})$

Phase difference or phase angle between two positions on a travelling wave.

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

$$phase\ angle\ (rad) = \frac{2 \times \pi \times distance\ between\ the\ two\ positions\ (m)}{wavelength\ (m)}$$

$$opd = n \times gpd$$ $$optical\ path\ difference\ (m) = refractive\ index\ \times geometric\ path\ difference\ (m)$$
Conditions for constructive and destructive interference $$opd = m\lambda\ or \left(m + \frac{1}{2}\right)\lambda\ where\ m = 0, 1, 2, \ldots$$ $$\frac{optical\ path\ difference}{(m)} = \frac{a\ whole\ number\ of wavelength}{(m)}\ or\ \frac{a\ whole\ number\ of wavelength + \frac{1}{2} wavelength}{(m)}$$ $$\left(m + \frac{1}{2}\right)\lambda = destructive\ interference$$ $$m\lambda = constructive\ interference$$
Fringe separation for a thin wedge $$\Delta x = \frac{\lambda l}{2d}$$ $$fringe\ separation\ (m) = \frac{wavelength\ (m) \times wedge\ length\ (m)}{2\ \times wedge\ thickness\ (m)}$$ *Beware, sometimes the distance between a certain number of fringes is given and this is n-1 for the fringe separation*
Non- reflection lens coating thickness $$d = \frac{\lambda}{4n}$$ $$coating\ thickness\ (m) = \frac{wavelength\ of\ light\ to\ be\ reduced\ (m)}{4\ \times refraction\ index\ of\ the\ lens\ coating}$$
Fringe spacing for Young's Double Slit which only applies when D>>Δx $$\Delta x = \frac{\lambda D}{d}$$ $$fringe\ separation\ (m) = \frac{wavelength\ (m) \times distance\ from\ the\ slits\ to\ screen\ (m)}{slit\ spacing\ (m)}$$ *Beware, sometimes the distance between a certain number of fringes is given and this is n-1 for the fringe separation*
Brewster Angle or polarising angle formula $$n = tan\ i_p$$ $$refractive\ index = tan\ of\ the\ polarising\ angle\ (°or\ rad)$$

Coulomb's Inverse Square Law

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

$$Electrostatic\ Force\ (N) = \frac{Charge\ on\ point\ charge\ 1\ (C)\ \times charge\ on\ point\ charge\ 2\ (C)}{4\ \times\ \pi\ \times permitivity\ of\ free\ space\ (Fm^{-1}) \times separation\ of\ the\ two\ charges^2\ (m)^2}$$

Like charges will repel, opposite charges will attract

ε_o *is the permitivity of free space and is* $8.85\ \times 10^{-12}\ Fm^{-1}$ $\qquad \frac{1}{4\pi\varepsilon_o} \approx 9 \times 10^9$

Electric Potential

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

$$Electric\ potential\ (V) = \frac{Magnitude\ of\ the\ charge\ \ (C)}{4\ \times\ \pi\ \times permitivity\ of\ free\ space\ (Fm^{-1}) \times distance\ from\ the\ charge\ (m)}$$

ε_o *is the permitivity of free space and is* $8.85\ \times 10^{-12}\ Fm^{-1}$ $\qquad \frac{1}{4\pi\varepsilon_o} \approx 9 \times 10^9$

Electric field strength

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

$$Electric\ field\ strength\ (NC^{-1}) = \frac{Magnitude\ of\ the\ charge\ \ (C)}{4\ \times\ \pi\ \times permitivity\ of\ free\ space\ (Fm^{-1}) \times separation\ of\ the\ two\ charges^2\ (m)^2}$$

ε_o *is the permitivity of free space and is* $8.85\ \times 10^{-12}\ Fm^{-1}$ $\qquad \frac{1}{4\pi\varepsilon_o} \approx 9 \times 10^9$

Use for the definition of Electric field strength

$$F = QE$$

$$Electric\ Force\ (N) = magnitudeof\ the\ charge\ (C)\ \times Electric\ field\ strength\ (NC^{-1})$$

Relationship for a uniform electric field

$$V = Ed$$

$$Electric\ potential\ (V) = Electric\ field\ strength\ (NC^{-1}) \times distance\ (m)$$

Work done moving a charge through a potential difference.

$$W = QV$$

$$work\ done\ (J) = magnitudeof\ the\ charge\ (C)\ \times potential\ difference\ (V)$$

$$E_k = \frac{1}{2}mv^2$$ $$kinetic\ energy\ (J) = \frac{1}{2} \times mass\ (kg) \times speed^2\ \ (m\ s^{-1})^2$$
Magnetic induction at a perpendicular distance from an "infinite" straight current carrying conductor. $$B = \frac{\mu_o I}{2\pi r}$$ $$Magnetic\ Induction\ (T) = \frac{Permeability\ of\ free\ space\ (Hm^{-1}) \times current\ (A)}{2 \times \pi \times distance\ (m)}$$ $\mu_0 = \ 4\pi \times 10^{-7}\ Hm^{-1}$
Force on a current carrying conductor in a magnetic field $$F = IlB \sin\theta$$ $$\frac{Magnetic\ Force}{(N)} = \frac{Current}{(A)} \times \frac{length}{(m)} \times \frac{magnetic\ induction}{(T)} \times \sin\left(\frac{angle\ between\ I\ and\ B}{(^\circ\ or\ rad)}\right)$$
Derive from $F = IlB\sin\theta$ $$F = qvB$$ $$\frac{Electric\ Force}{(N)} = \frac{magnitude of\ the\ charge}{(C)} \times \frac{velocity\ of\ the\ charge}{(m\ s^{-1})} \times \frac{magnetic\ induction}{(T)}$$
The time constant is the time required to charge the capacitor, through the resistor, from an initial charge voltage of zero to approximately 63.2% of the value of an applied DC voltage, or to discharge the capacitor through the resistor to approximately 36.8% of its initial charge voltage. $$\tau = RC$$ $$time\ constant\ (s) = Resistance of\ series\ resistor\ (\ \Omega)\ \times Capacitance\ (F)$$
Reactance (opposition to a.c.) of a capacitor. V and I may either <u>both</u> be peak or r.m.s $$X_c = \frac{V}{I}$$ $$Capacitive\ reactance\ (\Omega)\ = \frac{voltage\ (V)}{current\ (A)}$$
Reactance (opposition to a.c.) of a capacitor. $$X_c = \frac{1}{2\pi f C}$$ $$Capacitive\ reactance\ (\Omega)\ = \frac{1}{2 \times \pi \times frequency\ (Hz) \times Capacitance\ (F)}$$

$$\varepsilon = -L\frac{dI}{dt}$$ $$induced\ e.m.f\ (V) = -inductance(H) \times rate\ of\ change\ of\ current\ (As^{-1})$$ The negative sign indicates the induced e.m.f opposes the change causing it. ε is also a negative and the two negatives cancel.
Energy stored in the magnetic field of an inductor $$E = \frac{1}{2}LI^2$$ $$\underset{(J)}{energy\ stored\ in\ the\ magnetic\ field\ of\ an\ inductor} = \frac{1}{2} \times \underset{(H)}{inductance} \times \underset{(A)^2}{current}$$
Reactance (opposition to a.c.) of an inductor. V and I may either <u>both</u> be peak or r.m.s $$X_L = \frac{V}{I}$$ $$inductive\ reactance\ (\Omega) = \frac{voltage\ (V)}{current\ (A)}$$
Reactance (opposition to a.c.) of an inductor. $$X_L = 2\pi fL$$ $$inductive\ reactance\ (\Omega) = 2 \times \pi \times frequency\ (Hz) \times inductance\ (H)$$
Equation to calculate the speed of light and all electromagnetic radiations in a vacuum. $$c = \frac{1}{\sqrt{\varepsilon_o \mu_o}}$$ $$speed\ of\ light\ in\ a\ vacuum\ (ms^{-1}) = \frac{1}{\sqrt{permittivity\ of\ free\ space\ (Fm^{-1}) \times permeability\ of\ free\ space\ (Hm^{-1})}}$$ $\mu_0 = 4\pi \times 10^{-7}\ Hm^{-1}$, ε_o is the permitivity of free space and is $8.85 \times 10^{-12}\ Fm^{-1}$
A method for combining uncertainties in a single measurement $$\Delta W = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$$ $$Total\ uncertainty\ in\ W\ is\ equal\ to\ the\ square\ root\ of\ the\ square\ of\ the\ uncertainties\ in\ X, Y\ and\ Z$$ NB the units of X,Y and Z are the units of the measurement

A method of combining fractional (or percentage) uncertainties in different variables. $$\frac{\Delta W}{W}=\sqrt{\left(\frac{\Delta X}{X}\right)^2+\left(\frac{\Delta Y}{Y}\right)^2+\left(\frac{\Delta Z}{Z}\right)^2}$$ $\textit{Fractional uncertainty in W is equal to the square root of the square of the fractional uncertainties in X, Y and Z}$
A method of calculating an uncertainty raised to a power $$\left(\frac{\Delta W^n}{W^n}\right)=n\left(\frac{\Delta W}{W}\right)$$ $\textit{The fractional uncertainty in W raised to power n is n times the fractional uncertainty in W}$
$$d=\bar{v}t$$ $$distance\ (m)=average\ speed\ (ms^{-1})\times time\ (s)$$
$$s=\bar{v}t$$ $$displacement\ (m)=average\ velocity\ (ms^{-1})\times time\ (s)$$
$$v=u+at$$ $$final\ velocity\ (ms^{-1})=initial\ velocity\ (ms^{-1})+acceleration\ (ms^{-2})\times time\ (s)$$
$$s=ut+\frac{1}{2}at^2$$ $$displacement=initial\ velocity\ \times time+\frac{1}{2}\times acceleration\ (ms^{-2})\times time^2\ (s^2)$$
$$v^2=u^2+2as$$ $$final\ velocity^{\,2}\ (ms^{-1})^2=\ initial\ velocity^{\,2}(ms^{-1})^2+2\times acceleration\ (ms^{-2})\times dispacement\ (m)$$
$$s=\frac{1}{2}(v+u)t$$ $$displacement\ (m)=\frac{1}{2}\times(final\ velocity\ (ms^{-1})+initial\ velocity\ (ms^{-1}))\times time\ (s)$$
$$F=ma$$ $$force\ (N)=mass\ (kg)\times acceleration\ (ms^{-2})$$
$$W=mg$$ $$weight\ (N)=mass\ (kg)\times gravitational\ field\ strength\ (N\ kg^{-1})$$

$$E_w = Fd$$ $$work\ done\ (J) = force\ (N) \times distance\ (m)$$
$$E_p = mgh$$ $$gravitational\ potential\ energy\ (J) = mass\ (kg) \times gravitational\ field\ strength\ (N\ kg^{-1}) \times vertical\ height\ (m)$$
$$E_k = \frac{1}{2}mv^2$$ $$kinetic\ energy\ (J) = \frac{1}{2} \times mass\ (kg) \times speed^2 (ms^{-1})^2$$
$$P = \frac{E}{t}$$ $$power\ (W) = \frac{energy\ (J)}{time\ (s)}$$
$$p = mv$$ $$momentum\ (kgms^{-1}) = mass(kg) \times velocity\ (ms^{-1})$$
$$Ft = mv - mu$$ $$Impulse\ (Ns) = mass\ (kg) \times final\ velocity\ (ms^{-1}) - mass\ (kg) \times initial\ velocity\ (ms^{-1})$$ $$Impulse\ (Ns) = change\ in\ momentum\ (kg\ ms^{-1})$$
$$F = G\frac{m_1 m_2}{r^2}$$ $$Force\ (N) = Universal\ gravitational\ Constant\ (m^3 kg^{-1} s^{-2}) \frac{Mass_1(kg) \times Mass_2(kg)}{separation\ distance^2\ (m^2)}$$ $$NB\ The\ Universal\ Gravitational\ Constant = 6.67 \times 10^{-11}\ m^3 kg^{-1} s^{-2}$$
$$t' = \frac{t}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$ $$relativistic\ time\ (s) = \frac{time\ (s)}{\sqrt{1 - \left(\frac{speed\ (ms^{-1})}{speed\ of\ light\ in\ vacuum\ (ms^{-1})}\right)^2}}$$ *NB time can be in other units as this is a ratio, but both times must be in the same unit.* *$c = 3.0 \times 10^8\ ms^{-1}$*

$$l' = l\sqrt{1-\left(\frac{v}{c}\right)^2}$$ $$relativistic\ length\ (m) = length\ (m) \times \sqrt{1-\left(\frac{speed\ (ms^{-1})}{speed\ of\ light\ in\ vacuum\ (ms^{-1})}\right)^2}$$ $c = 3.0 \times 10^8\ ms^{-1}$
$$f_o = f_s\left(\frac{v}{v \pm v_s}\right)$$ $$\frac{frequency\ observed}{(Hz)} = \frac{frequency\ of\ source}{(Hz)} \times \left(\frac{speed\ \ of\ sound\ (ms^{-1})}{\underset{(ms^{-1})}{speed\ of\ sound} \pm \underset{(ms^{-1})}{velocity\ of\ source}}\right)$$ ADD when the object moves AWAY from the observer and *TAKE AWAY (subtract) when the object comes TOWARDS the observer*
$$z = \frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}}$$ $$Redshift\ (no\ unit) = \frac{observed\ wavelength\ (m) - rest\ wavelength\ (m)}{rest\ wavelength\ (m)}$$
$$z = \frac{v}{c}$$ $$Redshift\ (no\ unit) = \frac{recessional\ velocity\ (ms^{-1})}{speed\ of\ light\ in\ vacuum\ (ms^{-1})}$$
$$v = H_o d$$ $$\underset{(ms^{-1})}{recessional\ velocity} = \underset{(s^{-1})}{Hubble's\ Constant} \times \underset{(m)}{distance\ from\ galaxy\ to\ observer}$$ *NB for this course the Hubble Constant Ho is given as 2·3 x 10^{-18} s^{-1}*
$$W = QV$$ $$Work\ done\ moving\ a\ charge\ across\ a\ p.d.\ (J) = electrical\ charge\ (C) \times voltage\ (V)$$

$$E = mc^2$$ $$Energy\ (J) = mass\ (kg) \times speed\ of\ light\ squared\ (ms^{-1})^2$$ NB the speed of light squared is equal to $9.0 \times 10^{16}\ m^2s^{-2}$
$$E = hf$$ $$energy\ (J) = Planck's\ Constant\ (Js) \times frequency\ (Hz)$$ NB Planck's constant = 6.63×10^{-34} Js
$$E_k = hf - hf_o$$ $$\begin{matrix} Kinetic\ Energy \\ (J) \end{matrix} = \left(\begin{matrix} Planck's\ Constant \\ (Js) \end{matrix} \times \begin{matrix} incident\ frequency \\ (Hz) \end{matrix} \right) - \left(\begin{matrix} Planck's\ Constant \\ (Js) \end{matrix} \times \begin{matrix} threshold\ frequency \\ (Hz) \end{matrix} \right)$$ NB Planck's constant = 6.63×10^{-34} Js hf_o is also known as the work function (J), hf is the energy of the incident photon (J)
$$E_2 - E_1 = hf$$ $$most\ excited\ energy (J) - least\ excited\ energy\ (J) = Planck's\ Constant\ (Js) \times frequency\ (Hz)$$
$$T = \frac{1}{f}$$ $$Period\ (s) = \frac{1}{Frequency\ (Hz)}$$
$$v = f\lambda$$ $$speed\ (ms^{-1}) = frequency\ (Hz) \times wavelength\ (m)$$
$$d \sin \theta = m\lambda$$ $$Slit\ separation\ (m) \times sin\ of\ angle\ from\ centre\ to\ the\ spot\ =\ m\ \ a\ whole\ number\ of\ wavelengths\ (m)$$ NB This equation is for constructive interference
$$n = \frac{\sin \theta_1}{\sin \theta_2}$$ $$Refractive\ index\ = \frac{sine\ of\ the\ angle\ in\ vacuum/air}{sine\ of\ the\ angle\ in\ the\ material}$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$$ $$Refractive\ index = \frac{sin\ of\ the\ angle\ in\ vacuum/air}{sin\ of\ the\ angle\ in\ the\ material} = \frac{wavelength\ (air)(m)}{wavelength\ (material)(m)} = \frac{speed\ \ (air)\ (ms^{-1})}{speed\ (material)(ms^{-1})}$$ $$refractive\ index = ratio\ of\ wavelengths\ in\ vacuum/air\ and\ material$$ $$refractive\ index = ratio\ of\ the\ speeds\ in\ \frac{vacuum}{air}\ and\ the\ material$$ *This formula really applies to material 1 being a vacuum, but there is not much difference between the refractive indexes of air and a vacuum ∴ we assume for Higher they have the same value.*
$$\sin\theta_c = \frac{1}{n}$$ $$Sine\ of\ the\ critical\ angle\ = \frac{1}{refractive\ index}$$ *The critical angle is the angle in the material when the angle in air is 90°*
$$I = \frac{k}{d^2}$$ $$irradiance\ (Wm^{-2}) = \frac{constant\ (W)}{distance^2 (m^2)}$$ *This is more easily understood as* $$irradiance (Wm^{-2}) \times distance^2 (m^2) = constant\ value\ (W)$$
$$I = \frac{P}{A}$$ $$irradiance\ (Wm^{-2}) = \frac{power\ (W)}{area\ (m^2)}$$
$$V_{rms} = \frac{V_{peak}}{\sqrt{2}}$$ $$root\ mean\ square\ A.C. voltage\ (V)\ = \frac{peak\ voltage\ (V)}{1.414}$$

$$I_{rms} = \frac{I_{peak}}{\sqrt{2}}$$ $$root\ mean\ square\ A.C.current\ (A) = \frac{peak\ current\ (A)}{1.414}$$
$$Q = It$$ $$Charge\ (C) = current\ (A) \times time\ (s)$$ $$This\ is\ better\ explained\ as\ current\ is\ the\ rate\ of\ flow\ of\ charge\ \left(I = \frac{Q}{t}\right)$$
$$V = IR$$ $$Voltage(V) = Current\ (A) \times Resistance(\Omega)$$
$$P = IV = I^2R = \frac{V^2}{R}$$ $$Power\ (W) = current\ (A) \times voltage(V) = current\ ^2(A^2) \times Resistance\ (\Omega) = \frac{Voltage^2\ (V^2)}{Resistance\ (\Omega)}$$
For resistors in series $$R_T = R_1 + R_2 + \cdots$$ $$total\ resistance\ (\Omega) = resistance\ _1(\Omega) + resistance\ _2(\Omega) + \cdots$$
For resistors in parallel $$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$$ $$\frac{1}{total\ resistance\ (\Omega)} = \frac{1}{resistance\ _1(\Omega)} + \frac{1}{resistance\ _2(\Omega)} + \cdots$$
$$E = V + Ir$$ $$e.m.f\ (V) = terminial\ potential\ difference\ (V) + current\ (A) \times internal\ resistance\ (\Omega)$$ This can also be written as $$E = I(R + r) \quad or \quad E = IR + Ir$$ *I is the total current in the circuit, r is in series with the combined circuit resistance*

$$V_1 = \left(\frac{R_1}{R_1 + R_2}\right) V_s$$ $$voltage\ across\ component\ 1\ in\ potential\ divider (V) = \left(\frac{resistance_1\ (\Omega)}{total\ resistance (\Omega)}\right) \times supply\ voltage\ (V)$$
For resistances in series (potential divider circuits) $$\frac{V_1}{V_2} = \frac{R_1}{R_2}$$ Ratio of the voltages in series = ratio of the resistance in series $$\frac{Voltage\ across\ resistor 1\ (V)}{voltageacross\ resistor\ 2\ (V)} = \frac{resistance\ of\ resistor 1\ (\Omega)}{resistance\ of\ resistor\ 2\ (\Omega)}$$
$$C = \frac{Q}{V}$$ $$Capacitance\ (F) = \frac{Charge\ (C)}{Voltage\ (V)}$$
$$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$$ $$\underset{(J)}{Energy\ stored\ in\ capacitor} = \frac{1}{2} \times \underset{(C)}{charge\ stored\ in\ capacitor} \times \underset{(V)}{voltage\ across\ capacitor}$$ $$\underset{(J)}{Energy\ stored\ in\ capacitor} = \frac{1}{2} \times \underset{(F)}{capacitance} \times \underset{(V)^2}{voltage\ across\ capacitor^2}$$ $$\underset{(J)}{Energy\ stored\ in\ capacitor} = \frac{1}{2} \times \frac{(charge\ stored\ in\ capacitor)^2\ (C^2)}{voltage\ across\ capacitor (V)}$$

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

$$\begin{matrix} Path\ difference \\ (m) \end{matrix} = \begin{matrix} whole\ number\ of\ wavelengths \\ (constructive\ interference) \end{matrix}$$

$$\begin{matrix} path\ difference \\ (m) \end{matrix} = \begin{matrix} whole\ number\ of\ wavelengths + \frac{1}{2}\ a\ wavelength \\ (destructive\ interference) \end{matrix}$$

$$Random\ Uncertainty = \frac{Max\ value - min\ value}{number\ of\ values} \qquad or\ \Delta R = \frac{R_{max} - R_{min}}{n}$$

NB for the random uncertainty in a value the units of the random uncertainty are the same as for the quantity you are finding the uncertainty for.

$$Random\ Uncertainty(units\ of\ the\ quantity) = \frac{Max\ value - min\ value}{number\ of\ values}$$

SI Units

There is an international standard for units called the Systeme International D'Unites, SI units for short.

These consist of seven basic units, two of which we do not use in this course (the unit of luminous intensity, the candela, and the amount of substance containing a certain number of elementary particles, the mole).

The 5 basic units we use are units of mass, length, time, temperature and current. Every other unit can be expressed using a combination of these seven basic units.

Quantity	Symbol	Units
Mass	m	kilogram, kg
Length	l	metre, m
Time	t	second, s
Temperature	T	degrees Celsius, Kelvin, K
Current	I	ampere, A

Prefixes

Prefix	Symbol	Multiple	Multiple in full
Peta	P	$x10^{15}$	x 1 000 000 000 000 000
Tera	T	$x10^{12}$	x1 000 000 000 000
Giga	G	$x10^{9}$	x1 000 000 000
Mega	M	$x10^{6}$	x1 000 000
Kilo	K	$x10^{3}$	x1 000
Centi	C	$x10^{-2}$	÷100
Milli	m	$x10^{-3}$	÷1 000
Micro	μ	$x10^{-6}$	÷1 000 000
Nano	n	$x10^{-9}$	÷1 000 000 000
Pico	p	$x10^{-12}$	÷1 000 000 000 000
femto	f	$x10^{-15}$	÷1 000 000 000 000 000

Above is a table of prefixes, which you will commonly find in AH Physics.

The Physics Course

Course content

The course content includes the following areas of physics:

Rotational motion and astrophysics

The topics covered are:

- *kinematic relationships*
- *angular motion*
- *rotational dynamics*
- *gravitation*
- *general relativity*
- *stellar physics*

Quanta and waves

The topics covered are:

- *introduction to quantum theory*
- *particles from space*
- *simple harmonic motion*
- *waves*
- *interference*
- *polarisation*

Electromagnetism

The topics covered are:

- *fields*
- *circuits*
- *electromagnetic radiation*

Units, prefixes and uncertainties

The topics covered are:

- *units, prefixes and scientific notation*
- *uncertainties*
- *data analysis*
- *evaluation and significance of experimental uncertainties*

Course overview

This course consists of 32 SCQF credit points, which includes time for preparation for course assessment. The notional length of time for candidates to complete the course is 160 hours.

The course assessment has two components.

Component	Marks	Scaled mark	Duration
Component 1: question paper	155	120	3 hours
Component 2: project	30	40	see ‘Course assessment’ section

No		✓✗	Traffic Light		
ROTATIONAL MOTION AND ASTROPHYSICS					
Kinematic relationships			☺	😐	☹
1.1	*I know that differential calculus notation is used to represent rate of change.*		☺	😐	☹
1.2	*I know that velocity is the rate of change of displacement with time, acceleration is the rate of change of velocity with time and acceleration is the second differential of displacement with time.*		☺	😐	☹
1.3	*I can derive the equations of motion* $v=u+at$ *and* $s=ut+\frac{1}{2}at^2$ *using calculus methods.*		☺	😐	☹
1.4	*I can use calculus methods to calculate instantaneous displacement, velocity and acceleration for straight line motion with a constant or varying acceleration.*		☺	😐	☹
1.5	*I can use appropriate relationships to carry out calculations involving displacement, velocity, acceleration, and time for straight line motion with constant or varying acceleration.*		☺	😐	☹
1.6	$v=\frac{ds}{dt}$ $a=\frac{dv}{dt}=\frac{d^2s}{dt^2}$ $\left.\begin{array}{l} v=u+at \\ s=ut+\frac{1}{2}at^2 \\ v^2=u^2+2as \end{array}\right\}$ for constant acceleration only		☺	😐	☹

No		✓x	Traffic Light		
1.7	I know that the gradient of a curve (or a straight line) on a motion-time graph represents instantaneous rate of change, and can be found by differentiation.		☺	😐	☹
1.8	I know that the gradient of a curve (or a straight line) on a displacement-time graph is the instantaneous velocity, and that the gradient of a curve (or a straight line) on a velocity-time graph is the instantaneous acceleration.		☺	😐	☹
1.9	I know that the area under a line on a graph can be found by integration.		☺	😐	☹
1.10	I know that the area under an acceleration-time graph between limits is the change in velocity, and that the area under a velocity-time graph between limits is the displacement.		☺	😐	☹
	I can determine displacement, velocity or acceleration by the calculation of the gradient of the line on a graph or the calculation of the area under the line between limits on a graph.		☺	😐	☹
Angular motion			☺	😐	☹
2.1	I can use the radian as a measure of angular displacement.		☺	😐	☹
2.2	I can convert between degrees and radians.		☺	😐	☹
2.3	I can use appropriate relationships to carry out calculations involving angular displacement, angular velocity, angular acceleration, and time.		☺	😐	☹
2.4	$\omega = \frac{d\theta}{dt}$ $\alpha = \frac{d\omega}{dt} = \frac{d^2\theta}{dt^2}$ $\left.\begin{array}{l}\omega = \omega_o + \alpha t \\ \omega^2 = \omega_o^2 + 2\alpha\theta \\ \theta = \omega_o t + \frac{1}{2}\alpha t^2\end{array}\right\}$ for constant angular acceleration only		☺	😐	☹

No		✓✗	Traffic Light		
2.5	*I can use appropriate relationships to carry out calculations involving angular and tangential motion.*		☺	😐	☹
2.6	$s = r\theta$ $v = r\omega$ $a_t = r\alpha$		☺	😐	☹
2.7	*I can use appropriate relationships to carry out calculations involving constant angular velocity, period and frequency.*		☺	😐	☹
2.8	$\omega = \frac{2\pi}{T}$ $\omega = 2\pi f$		☺	😐	☹
2.9	*I know that a centripetal (radial or central) force acting on an object is necessary to maintain circular motion, and results in centripetal (radial or central) acceleration of the object.*		☺	😐	☹
2.10	*I can use appropriate relationships to carry out calculations involving centripetal acceleration and centripetal force.*		☺	😐	☹
2.11	$a_r = \frac{v^2}{r} = r\omega^2$ $F = \frac{mv^2}{r} = mr\omega^2$		☺	😐	☹
Rotational dynamics			☺	☺	😐
3.1	*I know that an unbalanced torque causes a change in the angular (rotational) motion of an object.*		☺	😐	☹
3.2	*I can define the moment of inertia of an object as a measure of its resistance to angular acceleration about a given axis.*		☺	😐	☹
3.3	*I know that moment of inertia depends on mass and the distribution of mass about a given axis of rotation.*		☺	😐	☹
3.4	*I can use an appropriate relationship to calculate the moment of inertia for discrete masses.*		☺	😐	☹
3.5	$I = mr^2$		☺	😐	☹

No		✓✗	Traffic Light		
3.6	*I can use an appropriate relationship to calculate the moment of inertia for discrete masses.*		☺	😐	☹
3.7	$I = \sum mr^2$		☺	😐	☹
3.8	*I can use appropriate relationships to calculate the moment of inertia for rods, discs and spheres about given axes.*		☺	😐	☹
3.9	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 $I = \frac{2}{5}mr^2$		☺	😐	☹
3.10	*I can use appropriate relationships to carry out calculations involving torque, perpendicular force, distance from the axis, angular acceleration, and moment of inertia.*		☺	😐	☹
3.11	$\tau = Fr$ $\tau = I\alpha$		☺	😐	☹
3.12	*I can use appropriate relationships to carry out calculations involving angular momentum, angular velocity , moment of inertia, tangential velocity, mass and its distance from the axis.*		☺	😐	☹
3.13	$L = mvr = mr^2\omega$ $L = I\omega$		☺	😐	☹
3.14	*I can make a statement of the principle of conservation of angular momentum.* "In the absence of external torques the total angular momentum before a collision is the same as the total angular momentum after a collision"		☺	😐	☹
3.15	*I can use the principle of conservation of angular momentum to solve problems.*		☺	😐	☹

No		✓✗	Traffic Light		
3.16	I can use appropriate relationships to carry out calculations involving potential energy, rotational kinetic energy, translational kinetic energy, angular velocity, linear velocity, moment of inertia, and mass.		☺	😐	☹
3.17	$E_k = \frac{1}{2}I\omega^2$ or $E_{k(rotational)} = \frac{1}{2}I\omega^2$		☺	😐	☹
3.18	$E_P = E_{k\ \text{(translational)}} + E_{k\ \text{(rotational)}}$		☺	😐	☹
Gravitation			☺	☺	😐
4.1	I can convert between astronomical unit (AU) and metres and between light years (ly) and metres		☺	😐	☹
4.2	I can define gravitational field strength as the gravitational force acting on a unit mass.		☺	😐	☹
4.3	I can sketch of gravitational field lines and field line patterns around astronomical objects and astronomical systems involving two objects.		☺	😐	☹
4.4	I can use an appropriate relationship to carry out calculations involving gravitational force, masses and their separation.		☺	😐	☹
4.5	$F = \frac{GMm}{r^2}$		☺	😐	☹
4.6	I can use appropriate relationships to carry out calculations involving period of satellites in circular orbit, masses, orbit radius, and satellite speed.		☺	😐	☹
4.7	$F = \frac{GMm}{r^2} = \frac{mv^2}{r} = mr\omega^2 = mr\left(\frac{2\pi}{T}\right)^2$		☺	😐	☹
4.8	I can define gravitational potential of a point in space as the work done in moving unit mass from infinity to that point		☺	😐	☹
4.9	I know that the energy required to move mass between two points in a gravitational field is independent of the path taken.		☺	😐	☹

No		✓✗	Traffic Light		
4.10	*I can use appropriate relationships to carry out calculations involving gravitational potential, gravitational potential energy, masses and their separation.*		☺	😐	☹
4.11	$V = -\frac{GM}{r}$ $E_P = Vm = -\frac{GMm}{r}$		☺	😐	☹
4.12	*I can define escape velocity as the minimum velocity required to allow a mass to escape a gravitational field to infinity, where the mass achieves zero kinetic energy and maximum (zero) potential energy.*		☺	😐	☹
4.13	*I can derive the relationship* $v = \sqrt{\frac{2GM}{r}}$.		☺	😐	☹
4.14	*I can use of an appropriate relationship to carry out calculations involving escape velocity, mass and distance.*		☺	😐	☹
4.15	$v = \sqrt{\frac{2GM}{r}}$		☺	😐	☹
General relativity			☺	☺	😐
5.1	*I know that special relativity deals with motion in inertial (non-accelerating) frames of reference and that general relativity deals with motion in non-inertial (accelerating) frames of reference*		☺	😐	☹
5.2	*I can state the equivalence principle (that it is not possible to distinguish between the effects on an observer of a uniform gravitational field and of a constant acceleration) and I know of its consequences*		☺	😐	☹
5.3	*I consider spacetime as a representation of three dimensions of space and one dimension of time.*		☺	😐	☹
5.4	*I know that general relativity leads to the interpretation that mass curves spacetime, and that gravity arises from the curvature of spacetime.*		☺	😐	☹

No		✓✗	Traffic Light		
5.5	*I know that light or a freely moving object follows a geodesic (the shortest distance between two points) in spacetime.*		☺	😐	☹
5.6	*I can represent world lines for objects which are stationary, moving with constant velocity and accelerating*		☺	😐	☹
5.7	*I know that the escape velocity from the event horizon of a black hole is equal to the speed of light.*		☺	😐	☹
5.8	*I know that, from the perspective of a distant observer, time appears to be frozen at the event horizon of a black hole.*		☺	😐	☹
5.9	*I know that the Schwarzschild radius of a black hole is the distance from its centre (singularity) to its event horizon.*		☺	😐	☹
5.10	*I can use an appropriate relationship to solve problems relating to the Schwarzschild radius of a black hole.*		☺	😐	☹
5.11	$r_{Schwarzschild} = \frac{2GM}{c^2}$		☺	😐	☹
Stellar physics			☺	☺	😐
6.1	*I can use appropriate relationships to solve problems relating to luminosity, apparent brightness, b, distance between the observer and the star, power per unit area, stellar radius, and stellar surface temperature. (Using the assumption that stars behave as black bodies.)*		☺	😐	☹
6.2	apparent brightness $b = \frac{L}{4\pi d^2}$ $\frac{P}{A} = \sigma T^4$ $L = 4\pi r^2 \sigma T^4$		☺	😐	☹
6.3	*I know that stars are formed in interstellar clouds when gravitational forces overcome thermal pressure and cause a molecular cloud to contract until the core becomes hot enough to sustain nuclear fusion, which them provides a thermal poressure that balances the gravitational force.*		☺	😐	☹

No		✓✗	Traffic Light		
6.4	*I know of the stages in the proton-proton chain (p-p chain) in stellar fusion reactions which convert hydrogen to helium. One example of a p-p chain is:*		☺	😐	☹
6.5	${}^{1}_{1}H + {}^{1}_{1}H \rightarrow {}^{2}_{1}H + {}^{0}_{+1}e + \nu_e$ ${}^{2}_{1}H + {}^{1}_{1}H \rightarrow {}^{3}_{2}He + \gamma$ ${}^{3}_{2}He + {}^{3}_{2}He \rightarrow {}^{4}_{2}He + 2{}^{1}_{1}H$		☺	😐	☹
6.6	*I know that the Hertzsprung-Russell (H-R) diagram is a representation of the classification of stars.*		☺	😐	☹
6.7	*I can classify stars and position in Hertzsprung-Russell (H-R) diagram, including main sequence, giant, supergiant and white dwarf.*		☺	😐	☹
6.8	*I can use Hertzsprung-Russell (H-R) diagram to determine stellar properties, including prediction of colour of stars from their position in the H-R diagram.*		☺	😐	☹
6.9	*I know that the fusion of hydrogen occurs in the core of stars in the main sequence of a Hertzsprung-Russell (H-R) diagram.*		☺	😐	☹
6.10	*I know that when hydrogen fusion in the core of a star supplies the energy that maintains the star's outward thermal pressure to balance inward gravitational forces. When the hydrogen in the core becomes depleted, nuclear fusion in the core ceases. The gas surrounding the core, however, will still contain hydrogen. Gravitational forces cause both the core, and the surrounding shell of hydrogen to shrink. In a star like the Sun, the hydrogen shell becomes hot enough for hydrogen fusion in the shell of the star. This leads to an increase in pressure which pushes the surface of the star outwards, causing it to cool. At this stage, the star will be in the giant or supergiant regions of a Hertzspung-Russell (H-R) diagram.*		☺	😐	☹
6.11	*I know that in a star like the Sun, the core shrinks and will become hot enough for the helium in the core to begin fusion*		☺	😐	☹
6.12	*I know that the mass of a star will determine its lifetime*		☺	😐	☹

No		✓x	Traffic Light		
6.13	*I know that every star will ultimately become a white dwarf, a neutron star or a black hole. The mass of the star will determine its eventual fate*		☺	😐	☹
QUANTA AND WAVES					
Introduction to quantum theory			☺	☺	😐
7.1	*I know of experimental observations that cannot be explained by classical physics, but can be explained using quantum theory:*		☺	😐	☹
7.1a	*Black-body radiation curves (ultraviolet catastrophe);*		☺	😐	☹
7.1b	*The formation of emission and absorption spectra. ;*		☺	😐	☹
7.1c	*The photoelectric effect.*		☺	😐	☹
7.2	*I can use an appropriate relationship to solve problems involving photon energy and frequency.*		☺	😐	☹
7.3	$E = hf$		☺	😐	☹
7.4	*I know that the Bohr model of the atom in terms of the quantisation of angular momentum, the principal quantum number n and electron energy states, and how this explains the characteristics of atomic spectra.*		☺	😐	☹
7.5	*I can use an appropriate relationship to solve problems involving the angular momentum of an electron and its principal quantum number.*		☺	😐	☹
7.6	$mvr = \frac{nh}{2\pi}$		☺	😐	☹
7.7	*I can provide a description of experimental evidence for the particle-like behaviour of 'waves' and for the wave-like behaviour of 'particles'.*		☺	😐	☹
7.8	*I can use an appropriate relationship to solve problems involving the de Broglie wavelength of a particle and its momentum.*		☺	😐	☹

No		✓x	Traffic Light		
7.9	$\lambda = \frac{h}{p}$		☺	😐	☹
7.10	*I know that it is not possible to know the position and the momentum of a quantum particle simultaneously*		☺	😐	☹
7.11	*I know that it is not possible to know the lifetime of a quantum particle and the associated energy change simultaneously.*		☺	😐	☹
7.12	*I can use appropriate relationships to solve problems involving the uncertainties in position, momentum, energy and time. The lifetime of a quantum particle can be taken as the uncertainty in time.*		☺	😐	☹
7.13	$\Delta x \Delta p_x \geq \frac{h}{4\pi}$ $\Delta E \Delta t \geq \frac{h}{4\pi}$		☺	😐	☹
7.14	*I know of implications of the Heisenberg uncertainty principle, including the concept of quantum tunnelling, in which a quantum particle can exist in a position that, according to classical physics, it has insufficient energy to occupy.*		☺	😐	☹
Particles from space			☺	☺	😐
8.1	*I know of the origin and composition of cosmic rays and the interaction of cosmic rays with Earth's atmosphere*		☺	😐	☹
8.2	*I know of the composition of the solar wind as charged particles in the form of plasma.*		☺	😐	☹
8.3	*I can explain the helical motion of charged particles in the Earth's magnetic field.*		☺	😐	☹
8.4	*I can use appropriate relationships to solve problems involving the force on a charged particle, its charge, its mass, its velocity, the radius of its path, and the magnetic induction of a magnetic field.*		☺	😐	☹

No		✓✗	Traffic Light		
8.5	$F = qvB$ $F = \frac{mv^2}{r}$		☺	😐	☹
Simple harmonic motion (SHM)			☺	☺	😐
9.1	*I can define SHM in terms of the restoring force and acceleration proportional to, and in the opposite direction to, the displacement from the rest position.*		☺	😐	☹
9.2	*I can use of calculus methods to show that the expressions* $y = A\sin\omega t$ *and* $y = A\cos\omega t$ *are consistent with the definition of* SHM ($a = -\omega^2 y$)		☺	😐	☹
9.3	*I can derive the relationships* $v = \pm\omega\sqrt{\left(A^2 - y^2\right)}$ *and* $E_k = \frac{1}{2}m\omega^2(A^2 - y^2)$.		☺	😐	☹
9.4	*I can use appropriate relationships to solve problems involving the displacement, velocity, acceleration, angular frequency, period, and energy of an object executing SHM.*		☺	😐	☹
9.5	$F = -ky$ $\omega = 2\pi f = \frac{2\pi}{T}$ $a = \frac{d^2y}{dt^2} = -\omega^2 y$ $y = A\cos\omega t$ or $y = A\sin\omega t$ $v = \pm\omega\sqrt{\left(A^2 - y^2\right)}$ $E_k = \frac{1}{2}m\omega^2\left(A^2 - y^2\right)$ $E_P = \frac{1}{2}m\omega^2 y^2$		☺	😐	☹
9.6	*I know of the effects of damping in SHM (to include underdamping, critical damping and overdamping).*		☺	😐	☹

No		✓✗	Traffic Light		
Waves			☺	☺	😐
10.1	*I can use an appropriate relationship to solve problems involving the energy transferred by a wave and its amplitude.*		☺	😐	☹
10.2	$E = kA^2$		☺	😐	☹
10.3	*I know of the mathematical representation of travelling waves.*		☺	😐	☹
10.4	*I can use appropriate relationships to solve problems involving wave motion, phase difference and phase angle.*		☺	😐	☹
10.5	$y = A\sin 2\pi\left(ft - \frac{x}{\lambda}\right)$ $\phi = \frac{2\pi x}{\lambda}$		☺	😐	☹
10.6	*I know that stationary waves are formed by the interference of two waves, of the same frequency and amplitude, travelling in opposite directions. A stationary wave can be described in terms of nodes and antinodes.*		☺	😐	☹
Interference			☺	☺	😐
11.1	*I know that two waves are coherent if they have a constant phase relationship*		☺	😐	☹
11.2	*I know of the conditions for constructive and destructive interference in terms of coherence and phase*		☺	😐	☹
11.3	*I can use an appropriate relationship to solve problems involving optical path difference, geometrical path difference and refractive index.*		☺	😐	☹
11.4	*optical path difference* $= n \times$ *geometrical path difference*		☺	😐	☹
11.5	*I know that a wave experiences a phase change of* π *when it is travelling in a less dense medium and reflects from an interface with a more dense medium.*		☺	😐	☹

No		✓✗	Traffic Light		
11.6	I know that a wave does not experience a phase change when it is travelling in a more dense medium and reflects from an interface with a less dense medium		☺	😐	☹
11.7	I can explain interference by division of amplitude, including optical path length, geometrical path length, phase difference, optical path difference,		☺	😐	☹
11.8	I know of thin film interference and wedge fringes.		☺	😐	☹
11.9	For light interfering by division of amplitude, I can use an appropriate relationship to solve problems involving the optical path difference between waves, wavelength and order number.		☺	😐	☹
11.10	optical path difference $= m\lambda$ or $\left(m+\frac{1}{2}\right)\lambda$ where $m = 0,1,2...$		☺	😐	☹
11.11	I know that a coated (bloomed) lens can be made non-reflective for a specific wavelength of light.		☺	😐	☹
11.12	I can derive the relationship $d = \frac{\lambda}{4n}$ for glass lenses with a coating such as magnesium fluoride.		☺	😐	☹
11.13	I can use appropriate relationships to solve problems involving interference of waves by division of amplitude		☺	😐	☹
11.14	$\Delta x = \frac{\lambda l}{2d}$		☺	😐	☹
11.15	$d = \frac{\lambda}{4n}$		☺	😐	☹
11.16	I can explain interference by division of wavefront.		☺	😐	☹
11.17	I have a knowledge of Young's slits interference.		☺	😐	☹
11.18	I can use an appropriate relationship to solve problems involving interference of waves by division of wavefront.		☺	😐	☹
11.19	$\Delta x = \frac{\lambda D}{d}$		☺	😐	☹

No		✓x	Traffic Light		
Polarisation			☺	☺	😐
12.1	*I know of what is meant by a plane-polarised wave.*		☺	😐	☹
12.2	*I know of the effect on light of polarisers and analysers.*		☺	😐	☹
12.3	*I know that when a ray of unpolarised light is incident on the surface of an insulator at Brewster's angle the reflected ray becomes plane-polarised.*		☺	😐	☹
12.4	*I can derive the relationship* $n = \tan i_p$.		☺	😐	☹
12.5	*I can use an appropriate relationship to solve problems involving Brewster's angle and refractive index.*		☺	😐	☹
12.6	$n = \tan i_p$		☺	😐	☹
ELECTROMAGNETISM					
Fields			☺	☺	😐
13.1	*I know that an electric field is the region that surrounds electrically charged particles in which a force is exerted on other electrically charged particles.*		☺	😐	☹
13.2	*I can define electric field strength as the electrical force acting on unit positive charge.*		☺	😐	☹
13.3	*I can sketch electric field patterns around single point charges, a system of charges and a uniform electric field.*		☺	😐	☹
13.4	*I can define electrical potential at a point as the work done in moving unit positive charge from infinity to that point.*		☺	😐	☹
13.5	*I know that the energy required to move charge between two points in an electric field is independent of the path taken.*		☺	😐	☹
13.6	*I can use appropriate relationships to solve problems involving electric force, electric potential and electric field strength, around a point charge and a system of charges.*		☺	😐	☹

No		✓x	Traffic Light		
13.7	$F = \frac{Q_1 Q_2}{4\pi\varepsilon_o r^2}$ $E = \frac{Q}{4\pi\varepsilon_o r^2}$ $V = \frac{Q}{4\pi\varepsilon_o r}$		☺	😐	☹
13.8	*I can use appropriate relationships to solve problems involving charge, energy, potential difference, and electric field strength, in situations involving a uniform electric field.*		☺	😐	☹
13.9	$F = QE$ $V = Ed$ $W = QV$		☺	😐	☹
13.10	*I know Millikan's experimental method for determining the charge on an electron.*		☺	😐	☹
13.11	*I can use appropriate relationships to solve problems involving the motion of charged particles in uniform electric fields.*		☺	😐	☹
13.12	$F = QE$ $V = Ed$ $W = QV$ $E_k = \frac{1}{2}mv^2$		☺	😐	☹
13.13	*I know that the electronvolt (eV) is the energy acquired when one electron accelerates through a potential difference of one volt.*		☺	😐	☹
13.14	*I can convert between electronvolts and joules*		☺	😐	☹
13.15	*I know that electrons are in motion around atomic nuclei and individually produce a magnetic effect.*		☺	😐	☹

No		✓✗	Traffic Light		
13.16	*I know that, for example, iron, nickel, cobalt, and some rare earths exhibit a magnetic effect called ferromagnetism, in which magnetic dipoles can be made to align, resulting in the material becoming magnetised.*		☺	😐	☹
13.17	*I can sketch magnetic field patterns between magnetic poles, and around solenoids, including the magnetic field pattern around the Earth.*		☺	😐	☹
13.18	*I can compare gravitational, electrostatic, magnetic and nuclear forces in terms of their relative strength and range.*		☺	😐	☹
13.19	*I can use an appropriate relationship to solve problems involving magnetic induction around a current carrying wire, the current in the wire and the distance from the wire.*		☺	😐	☹
13.20	$B = \frac{\mu_o I}{2\pi r}$		☺	😐	☹
13.21	*I can explain the helical path followed by a moving charged particle in a magnetic field.*		☺	😐	☹
13.22	*I can use appropriate relationships to solve problems involving the forces acting on a current-carrying wire in a magnetic field and a charged particle in a magnetic field.*		☺	😐	☹
13.23	$F = IlB\sin\theta$ $F = qvB$ $F = \frac{mv^2}{r}$		☺	😐	☹
Circuits			☺	☺	😐
14.1	*I know of the variation of current and potential difference with time in an RC circuit during charging and discharging.*		☺	😐	☹
14.2	*I can define the time constant for an RC circuit as the time to increase the charge stored by 63% of the difference between initial charge and full charge, or the time taken to discharge the capacitor to 37% of initial charge*		☺	😐	☹

No		✓x	Traffic Light		
14.3	I can use an appropriate relationship to determine the time constant for an RC circuit.		☺	😐	☹
14.4	$\tau = RC$		☺	😐	☹
14.5	I know that, in an RC circuit, an uncharged capacitor can be considered to be fully charged after a time approximately equal to 5τ		☺	😐	☹
14.6	I know that, in an RC circuit, a fully charged capacitor can be considered to be fully discharged after a time approximately equal to 5τ .		☺	😐	☹
14.7	I can determine graphically the time constant for an RC circuit.		☺	😐	☹
14.8	I know that capacitive reactance is the opposition of a capacitor to changing current		☺	😐	☹
14.9	I can use appropriate relationships to solve problems involving capacitive reactance, voltage, current, frequency, and capacitance.		☺	😐	☹
14.10	$X_C = \frac{V}{I}$ $X_C = \frac{1}{2\pi fC}$		☺	😐	☹
14.11	I know of the growth and decay of current in a DC circuit containing an inductor		☺	😐	☹
14.12	I can explain the self-inductance (inductance) of a coil.		☺	😐	☹
14.3	I have knowledge of Lenz's law and its implications		☺	😐	☹
14.4	I can define inductance and back EMF.		☺	😐	☹
14.5	I know that energy is stored in the magnetic field around a current-carrying inductor.		☺	😐	☹
14.6	I know of the variation of current with frequency in an AC circuit containing an inductor.		☺	😐	☹

No		✓x	Traffic Light		
14.7	I know that inductive reactance is the opposition of an inductor to changing current.		☺	😐	☹
14.8	I can use appropriate relationships to solve problems relating to inductive reactance, voltage, current, frequency, energy, and self-inductance (inductance).		☺	😐	☹
14.9	$\mathcal{E} = -L\frac{dI}{dt}$ $E = \frac{1}{2}LI^2$ $X_L = \frac{V}{I}$ $X_L = 2\pi fL$		☺	😐	☹
Electromagnetic radiation			☺	😐	☹
15.1	I have a knowledge of the unification of electricity and magnetism.		☺	😐	☹
15.2	I know that electromagnetic radiation exhibits wave properties as it transfers energy through space. It has both electric and magnetic field components which oscillate in phase, perpendicular to each other and to the direction of energy propagation.		☺	😐	☹
15.3	I can use an appropriate relationship to solve problems involving the speed of light, the permittivity of free space and the permeability of free space.		☺	😐	☹
15.4	$c = \frac{1}{\sqrt{\varepsilon_o \mu_o}}$		☺	😐	☹
UNITS, PREFIXES AND UNCERTAINTIES					
Units, prefixes and scientific notation			☺	😐	☹
16.1	I can make appropriate use of units, including electronvolt (eV), light year (ly) and astronomical unit (AU).		☺	😐	☹

No		✓x	Traffic Light		
16.2	I can use SI units with all physical quantities where appropriate.		☺	😐	☹
16.3	I can use prefixes where appropriate. These include femto (f), pico (p), nano (n), micro (μ), milli (m), kilo (k), mega (M), giga (G), tera (T), and peta (P)		☺	😐	☹
16.4	I can use the appropriate number of significant figures in final answers. This means that the final answer can have no more significant figures than the data with fewest number of significant figures used in the calculation.		☺	😐	☹
16.5	I can make appropriate use of scientific notation		☺	😐	☹
Uncertainties			☺	😐	☹
17.1	I know and can use uncertainties, including systematic uncertainties, scale reading uncertainties, random uncertainties, and calibration uncertainties.		☺	😐	☹
17.2	I know systematic uncertainty occurs when readings taken are either all too small or all too large. This can arise due to measurement techniques or experimental design		☺	😐	☹
17.3	I know a scale reading uncertainty is an indication of how precisely an instrument scale can be read		☺	😐	☹
17.4	I know random uncertainty arises when measurements are repeated and slight variations occur. Random uncertainty may be reduced by increasing the number of repeated measurements.		☺	😐	☹
17.5	I know calibration uncertainty arises when there is a difference between a manufacturer's claim for the accuracy of an instrument compared with an approved standard.		☺	😐	☹
17.6	I can solve problems involving absolute uncertainties and fractional/percentage uncertainties		☺	😐	☹
17.7	I can make appropriate use of significant figures in absolute uncertainties.		☺	😐	☹

No		✓x	Traffic Light		
17.8	*Absolute uncertainty should be rounded to one significant figure. In some instances a second significant figures may be retained (if the absolute uncertainty is small).*		☺	😐	☹
Data analysis			☺	😐	☹
18.1	*I can combine various types of uncertainties to obtain the total uncertainty in a measurement.*		☺	😐	☹
18.2	*I know that, when uncertainties in a single measurement are combined, an uncertainty can be ignored if it is less than one third of one of the other uncertainties in the measurement.*		☺	😐	☹
18.3	*I can use an appropriate relationship to determine the total uncertainty in a measured value.*		☺	😐	☹
18.4	$\Delta W = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$		☺	😐	☹
18.5	*I can combine uncertainties in measured values to obtain the total uncertainty in a calculated value*		☺	😐	☹
18.6	*I know that, when uncertainties in measured values are combined, a fractional/percentage uncertainty in a measured value can be ignored if it is less than one third of the fractional/percentage uncertainty in another measured value.*		☺	😐	☹
18.7	*I can use an appropriate relationship to determine the total uncertainty in a value calculated from the product or quotient of measured values.*		☺	😐	☹
18.8	$\frac{\Delta W}{W} = \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\Delta Z}{Z}\right)^2}$		☺	😐	☹
18.9	*I can use an appropriate relationship to determine the uncertainty in a value raised to a power.*		☺	😐	☹
18.10	$\left(\frac{\Delta W^n}{W^n}\right) = n\left(\frac{\Delta W}{W}\right)$		☺	😐	☹
18.11	*I can use error bars to represent absolute uncertainties on graphs.*		☺	😐	☹

No		✓✗	Traffic Light		
18.12	*I can estimate uncertainty in the gradient and intercept of the line of best fit on a graph.*		☺	😐	☹
18.13	*I can correctly use the terms accuracy and precision in the context of an evaluation of experimental results.* *The accuracy of a measurement compares how close the measurement is to the 'true' or accepted value. The precision of a measurement gives an indication of the uncertainty in the measurement.*		☺	😐	☹
Data analysis			☺	😐	☹
19.1	*I can identify the dominant uncertainty/uncertainties in an experiment or in experimental data.*				
19.2	*I can suggest potential improvements to an experiment, which may reduce the dominant uncertainty/uncertainties.*				

Course assessment structure: project

Project 30 marks

The project has 30 marks. This is scaled by SQA to represent 25% of the overall marks.

The purpose of the project is to allow you to carry out an in-depth investigation of a physics topic and produce a project report. You are required to plan and carry out a physics investigation.

You should keep a record of their work (daybook) as this will form the basis of your project report. This record should include details of your research, experiments and recorded data.

It gives you an opportunity to demonstrate the following skills, knowledge and understanding:

- *extending and applying knowledge of physics to new situations, interpreting and analysing information to solve more complex problems*
- *planning and designing physics experiments/investigations, using reference material, to test a hypothesis or to illustrate particular effects*
- *recording systematic detailed observations and collecting data*
- *selecting information from a variety of sources*
- *presenting detailed information appropriately in a variety of forms*
- *processing and analysing physics data (using calculations, significant figures and units, where appropriate)*
- *making reasoned predictions from a range of evidence/information*
- *drawing valid conclusions and giving explanations supported by evidence/justification*
- *critically evaluating experimental procedures by identifying sources of uncertainty, and suggesting and implementing improvements*
- *drawing on knowledge and understanding of physics to make accurate statements, describe complex information, provide detailed explanations, and integrate knowledge*
- *communicating physics findings/information fully and effectively*
- *analysing and evaluating scientific publications and media reports*

Project overview

Candidates carry out an in-depth investigation of a physics topic. Candidates choose their topic and individually investigate/research its underlying physics. Candidates must discuss potential topics with their teacher and/or lecturer to ensure that they do not waste time researching unsuitable topics. This is an open-ended task that may involve candidates carrying out a significant part of the work without supervision.

Section	Expected response	Mark allocation
Abstract	A brief abstract (summary) stating the overall aim and findings/conclusion(s) of the project.	1
Underlying physics	A description of the underlying physics that: • is relevant to the project • demonstrates an understanding of the physics theory underpinning the project • is of an appropriate level and commensurate with the demands of Advanced Higher Physics	4
Procedures	Labelled diagrams and/or descriptions of apparatus, as appropriate	2
	Clear descriptions of how the apparatus was used to obtain experimental readings.	2
	Procedures are at an appropriate level of complexity and demand. Factors to be considered include: • range of procedures • control of variables • accuracy and precision • originality of approach and/or experimental techniques • degree of sophistication of experimental design and/or equipment	3
Results (including uncertainties)	Data is sufficient and relevant to the aim of the project.	1
	Appropriate analysis of data, for example, quality of graphs, lines of best fit, calculations.	4
	Uncertainties in individual readings and final results.	3
Discussion (conclusion(s) and evaluation)	Valid conclusion(s) that relate to the aim of the project	1
	Evaluations of experimental procedures to include, as appropriate, comment on: • accuracy and precision of experimental measurements • adequacy of repeated readings • adequacy of range over which variables are altered • adequacy of control of variables • limitations of equipment • reliability of methods • sources of uncertainties	3
	Coherent discussion of overall conclusion(s) and critical evaluation of the project as a whole, to include, as appropriate, comment on: • selection of procedures • problems encountered during planning • modifications to planned procedures • interpretation and significance of findings • suggestions for further improvements to procedures • suggestions for further work	3

Section	Expected response	Mark allocation
	A report which indicates a quality project.	1
Presentation	Appropriate structure, including informative title, contents page and page numbers.	1
	References cited in the text and listed at an appropriate point in the report. Citing and listing using either Vancouver or Harvard referencing system.	1
Total		**30**