Wallace Hall Academy

CfE Advanced Higher Physics

Homework

DATA SHEET

COMMON PHYSICAL QUANTITIES

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

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

Hydrogen	656	Red	Cadmium	644	Red
	486	Blue-green		509	Green
	434	Blue-violet		480	Blue
	410	Violet	*Lasers*		
	397	Ultraviolet	*Element*	*Wavelength/nm*	*Colour*
	389	Ultraviolet	Carbon dioxide	9550 } 10590 }	Infrared
Sodium	589	Yellow	Helium-neon	633	Red

PROPERTIES OF SELECTED MATERIALS

Substance	*Density/* kg m^{-3}	*Melting Point/* K	*Boiling Point/K*	*Specific Heat Capacity/* $\text{J kg}^{-1}\ \text{K}^{-1}$	*Specific Latent Heat of Fusion/* J kg^{-1}	*Specific Latent Heat of Vaporisation/* 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.

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

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

$$v = u + at$$

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

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

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

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

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

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

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

$$s = r\theta$$

$$v = r\omega$$

$$a_t = r\alpha$$

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

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

$$T = Fr$$

$$T = I\alpha$$

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

$$L = I\omega$$

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

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

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

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

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

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

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

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

$$E = hf$$

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

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

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

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

$$F = qvB$$

$$\omega = 2\pi f$$

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

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

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

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

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

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

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

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

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

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

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

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

$$n = \tan i_P$$

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

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

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

$$F = QE$$

$$V = Ed$$

$$F = IlB\sin\theta$$

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

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

$$t = RC$$

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

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

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

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

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

$$X_L = 2\pi fL$$

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

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

$$d = \bar{v}t$$

$$s = \bar{v}t$$

$$v = u + at$$

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

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

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

$$W = mg$$

$$F = ma$$

$$E_W = Fd$$

$$E_P = mgh$$

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

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

$$p = mv$$

$$Ft = mv - mu$$

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

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

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

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

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

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

$$v = H_0 d$$

$$E_W = QV$$

$$E = mc^2$$

$$E = hf$$

$$E_K = hf - hf_0$$

$$E_2 - E_1 = hf$$

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

$$v = f\lambda$$

$$d\sin\theta = m\lambda$$

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

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

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

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

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

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

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

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

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

$$Q = It$$

$$V = IR$$

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

$$R_T = R_1 + R_2 + \ldots.$$

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

$$E = V + Ir$$

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

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

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

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

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

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

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

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

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

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

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

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

1. (*a*) The acceleration of a particle moving in a straight line is given by

$$a = \frac{dv}{dt}$$

where the symbols have their usual meaning.

(i) Show, by integration, that when a is constant

$$v = u + at.$$ **2**

(ii) Show that when a is constant

$$v^2 = u^2 + 2as.$$ **1**

(*b*) The path taken by a short track speed skater is shown in Figure 2A. The path consists of two straights each of length 29·8 m and two semicircles each of radius 8·20 m.

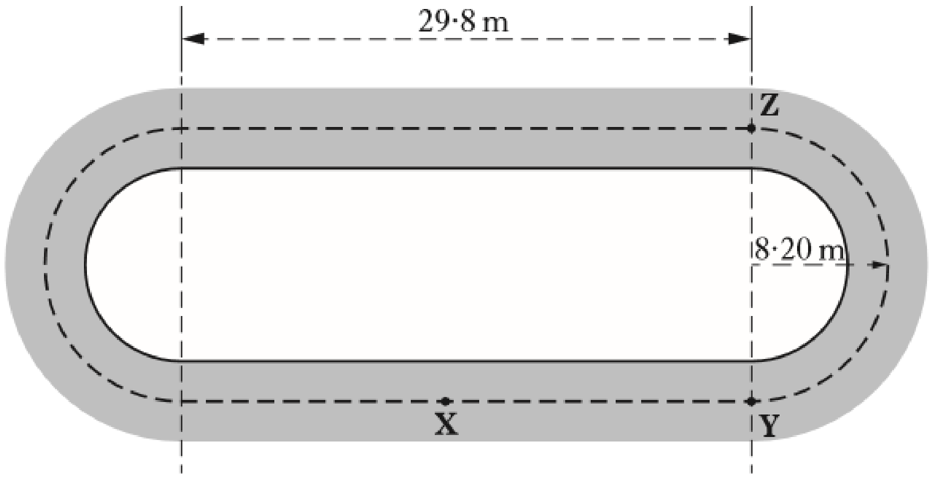


Figure 2A

Starting at point **X**, half way along the straight, the skater accelerates uniformly from rest. She reaches a speed of 9·64 m s^{-1} at point **Y**, the end of the straight.

(i) Calculate the acceleration of the skater. **2**

(ii) The skater exits the curve at point **Z** with a speed of 10·9 m s^{-1}.

Calculate the average **angular** acceleration of the skater between **Y** and **Z**. **3**

2. The acceleration of a particle moving in a straight line is described by the expression

$$a = 1{\cdot}2t.$$

At time, $t = 0$ s the displacement of the particle is 0 m and its velocity is $1{\cdot}4\ \text{m s}^{-1}$.

(*a*) Show that the velocity of the particle at time t is given by the expression

$$v = 0{\cdot}6t^2 + 1{\cdot}4.$$ **2**

(*b*) Calculate the displacement of the particle when its velocity is $3{\cdot}8\ \text{m s}^{-1}$. **3**

3. A motorised model plane is attached to a light string anchored to a ceiling.

The plane follows a circular path of radius 0·35 m as shown in Figure 2A.

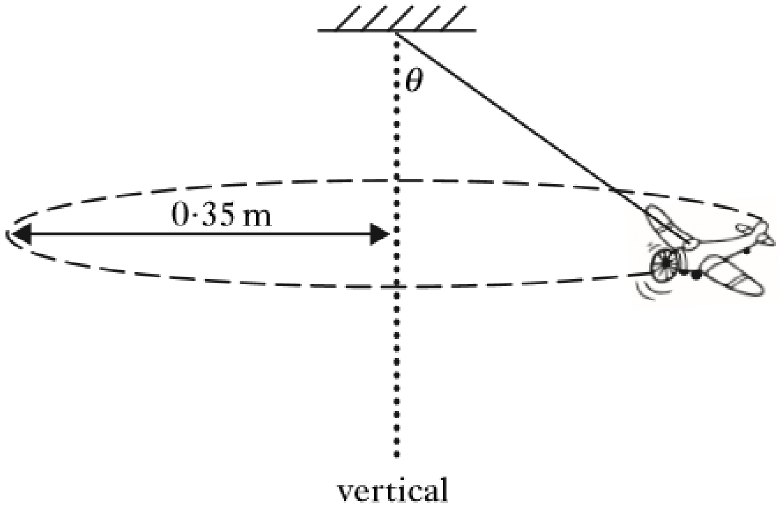


Figure 2A

The plane has a mass of 0·20 kg and moves with a constant angular velocity of 6·0 rad s^{-1}.

(*a*) Calculate the central force acting on the plane. **2**

(*b*) Calculate angle θ of the string to the vertical. **2**

(*c*) What effect would a decrease in the plane's speed have on angle θ?

Justify your answer. **2**

4. A flywheel consisting of a solid, uniform disc is free to rotate about a fixed axis as shown in Figure 1A. The disc has a mass of 16 kg and a radius of 0·30 m.

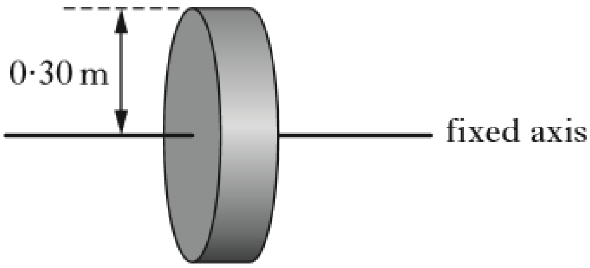


Figure 1A

(*a*) Calculate the moment of inertia of the flywheel. **2**

(*b*) A mass is attached to the flywheel by a light string as shown in Figure 1B.

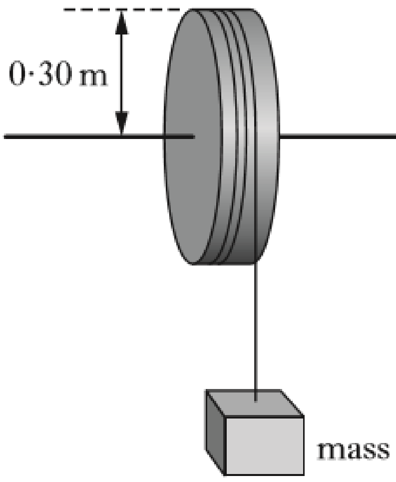


Figure 1B

The mass is allowed to fall and is found to be travelling at 3·0 m s^{-1} when the string leaves the flywheel. The flywheel makes 5 further revolutions before it comes to rest.

(i) Calculate the angular acceleration of the flywheel after the string leaves the flywheel. **3**

(ii) Calculate the frictional torque acting on the flywheel. **2**

(*c*) The experiment is repeated with a flywheel made from a more dense material with the same physical dimensions. The string, falling mass and all frictional forces are the same as in part (*b*).

As the string detaches from the flywheel, is the speed of the falling mass greater than, the same as or less than 3·0 m s^{-1}?

You must justify your answer. **2**

P.T.O.

4. Continued

(*d*) A Kinetic Energy Recovery System (KERS) is used in racing cars to store energy that is usually lost when braking.

One of these systems uses a flywheel, as shown in Figure 1C, to store the energy.

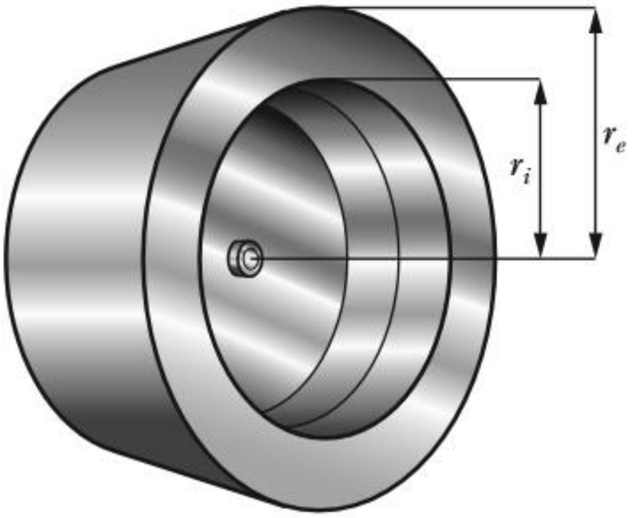


Figure 1C

Data for this KERS flywheel is given below.

Internal radius r_i = 0·15 m

External radius r_e = 0·20 m

Mass of flywheel M = 6·0 kg

Maximum rate of revolution = $6 \cdot 0 \times 10^4$ revolutions per minute

(i) Using the expression

$$I = \tfrac{1}{2} M(r_i^2 + r_e^2)$$

determine the moment of inertia of the flywheel. **1**

(ii) Calculate the maximum rotational kinetic energy that can be stored in the flywheel. **3**

5. A stunt driver is attempting to "loop the loop" in a car as shown in Figure 1. Before entering the loop the car accelerates along a horizontal track.

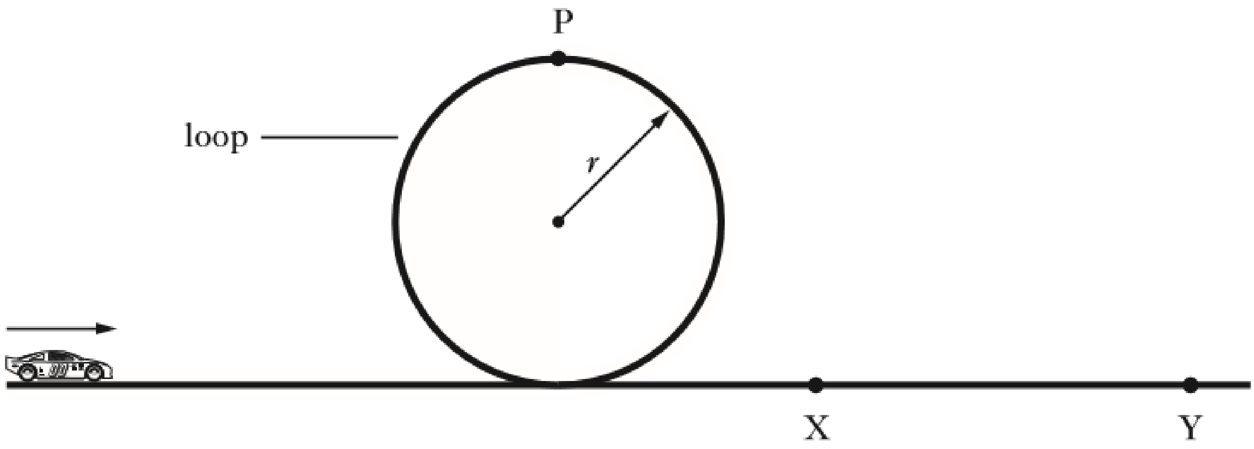


Figure 1

The radius r of the circular loop is 6·2 m.
The total mass of the car and driver is 870 kg.

(*a*) Show that the car must have a minimum speed of $7{\cdot}8\,\mathrm{m\,s^{-1}}$ at point P to avoid losing contact with the track. **2**

(*b*) During one attempt the car is moving at a speed of $9{\cdot}0\,\mathrm{m\,s^{-1}}$ at point P.

(i) Draw a labelled diagram showing the vertical forces acting on the car at point P. **1**

(ii) Calculate the size of each force. **3**

(*c*) When the car exits the loop the driver starts braking at point X. For one particular run the displacement of the car from point X **until the car comes to rest** at point Y is given by the equation

$$s = 9{\cdot}1t - 3{\cdot}2\,t^2$$

Sketch a graph to show how the displacement of the car varies with time between points X and Y.

Numerical values are required on both axes. **3**

6. The front wheel of a racing bike can be considered to consist of 5 spokes and a rim, as shown in Figure 2A.

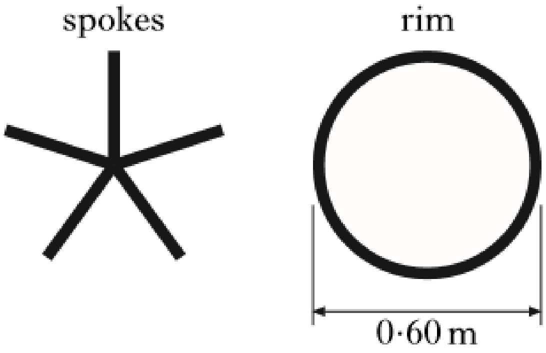


Figure 2A

The mass of each spoke is 0·040 kg and the mass of the rim is 0·24 kg. The wheel has a diameter of 0·60 m.

(*a*) (i) Each spoke can be considered as a uniform rod. Calculate the moment of inertia of a spoke as the wheel rotates. **2**

(ii) Show that the total moment of inertia of the wheel is $2{\cdot}8 \times 10^{-2}\,\text{kg}\,\text{m}^2$. **2**

(*b*) The wheel is placed in a test rig and rotated as shown in Figure 2B.

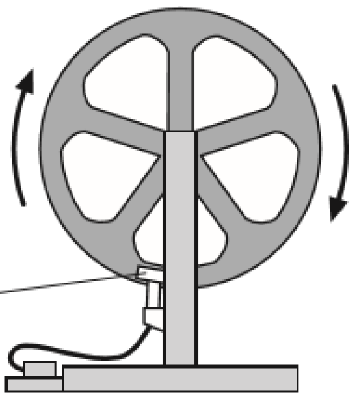


Figure 2B

(i) The tangential velocity of the rim is $19{\cdot}2\,\text{m}\,\text{s}^{-1}$. Calculate the angular velocity of the wheel. **2**

(ii) The brake is now applied to the rim of the wheel, bringing it uniformly to rest in 6·7 s.

(A) Calculate the angular acceleration of the wheel. **2**

(B) Calculate the torque acting on the wheel. **2**

7. (*a*) A turntable consists of a uniform disc of radius 0·15 m and mass 0·60 kg.

(i) Calculate the moment of inertia of the turntable about the axis of rotation shown in Figure 1. **2**

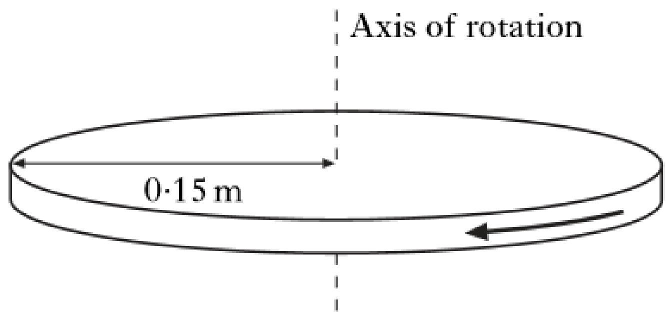


Figure 1

(ii) The turntable accelerates uniformly from rest until it rotates at 45 revolutions per minute. The time taken for the acceleration is 1·5 s.

(A) Show that the angular velocity after 1·5 s is 4·7 rad s^{-1}. **1**

(B) Calculate the angular acceleration of the turntable. **2**

(iii) When the turntable is rotating at 45 revolutions per minute, its motor is disengaged. The turntable continues to rotate freely with negligible friction.

A small mass of 0·20 kg is dropped onto the turntable at a distance of 0·10 m from the centre, as shown in Figure 2.

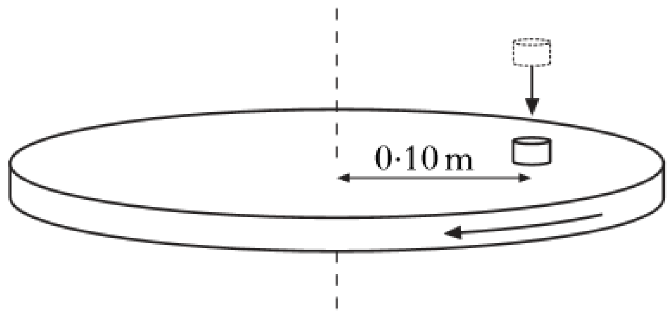


Figure 2

The mass remains in this position on the turntable due to friction, and the turntable and mass rotate together.

Calculate the new angular velocity of the turntable and mass. **3**

8. (*a*) In the first method the student measures the mass of the cylinder to be 0·115 kg and the diameter to be 0·030 m.

Calculate the moment of inertia of the cylinder. **2**

(*b*) In a second method the student allows the cylinder to roll down a slope and measures the final speed at the bottom of the slope to be $1{\cdot}6\,\text{m}\,\text{s}^{-1}$. The cylinder has a diameter of 0·030 m and the slope has a height of 0·25 m, as shown in Figure 2.

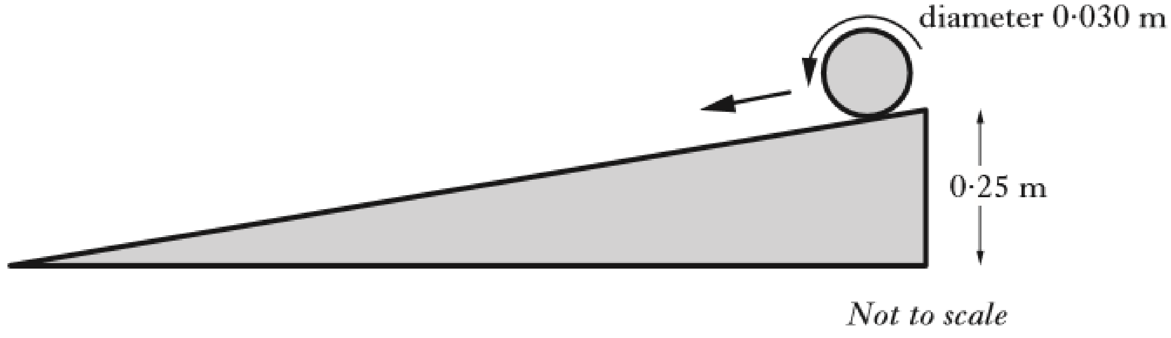


Figure 2

Using the conservation of energy, calculate the moment of inertia. **4**

(*c*) Explain why the moment of inertia found in part (*b*) is greater than in part (*a*). **1**

9. (*a*) The Moon orbits the Earth due to the gravitational force between them.

(i) Calculate the magnitude of the gravitational force between the Earth and the Moon. **2**

(ii) Hence calculate the tangential speed of the Moon in its orbit around the Earth. **2**

(iii) Define the term *gravitational potential* at a point in space. **1**

(iv) Calculate the potential energy of the Moon in its orbit. **2**

(v) Hence calculate the total energy of the Moon in its orbit. **2**

(*b*) (i) Derive an expression for the escape velocity from the surface of an astronomical body. **2**

(ii) Calculate the escape velocity from the surface of the Moon. **2**

10. (*a*) The gravitational field strength g on the surface of Mars is $3{\cdot}7\ \text{N kg}^{-1}$.
The mass of Mars is $6{\cdot}4 \times 10^{23}$ kg.
Show that the radius of Mars is $3{\cdot}4 \times 10^{6}$ m. **2**

(*b*) (i) A satellite of mass m has an orbit of radius R. Show that the angular velocity ω of the satellite is given by the expression

$$\omega = \sqrt{\frac{GM}{R^3}}$$

where the symbols have their usual meanings. **2**

(ii) A satellite remains above the same point on the equator of Mars as the planet spins on its axis.

Figure 4 shows this satellite orbiting at a height of $1{\cdot}7 \times 10^{7}$ m above the Martian surface.

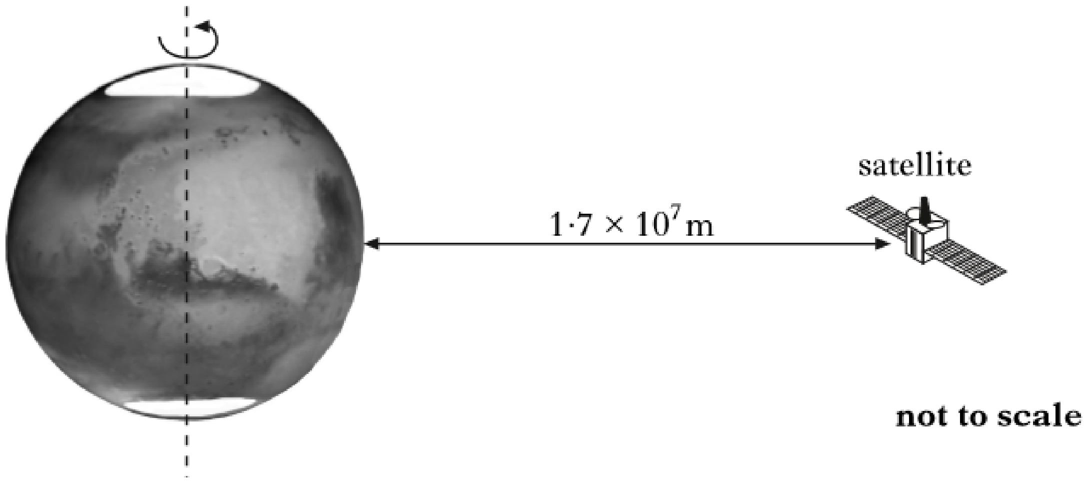


Figure 4

Calculate the angular velocity of the satellite. **2**

(iii) Calculate the length of one Martian day. **2**

(*c*) The following table gives data about three planets orbiting the Sun.

Planet	Radius R of orbit around the Sun/10^9 m	Orbit period T around the Sun/years
Venus	108	0·62
Mars	227	1·88
Jupiter	780	12·0

Use **all** the data to show that T^2 is directly proportional to R^3 for these three planets. **3**

11. An X-ray binary system consists of a star in a **circular** orbit around a black hole as shown in Figure 3A.

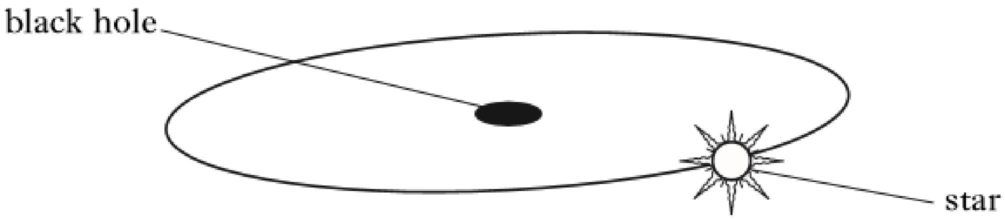


Figure 3A

The star has a mass of $2{\cdot}0 \times 10^{30}$ kg and takes 5·6 days to orbit the black hole. The orbital radius is $3{\cdot}6 \times 10^{10}$ m.

(*a*) Show that the angular velocity of the star is $1{\cdot}3 \times 10^{-5}\,\text{rad s}^{-1}$. **1**

(*b*) Calculate the mass of the black hole. **3**

(*c*) (i) Show that the potential energy of the star in its orbit is $-4{\cdot}4 \times 10^{41}$ J. **1**

(ii) Calculate the kinetic energy of the star. **2**

(iii) Calculate the total energy of the star due to its motion and position. **1**

(*d*) The binary system orbits in the same plane as an earth-based telescope, as shown in Figure 3B.

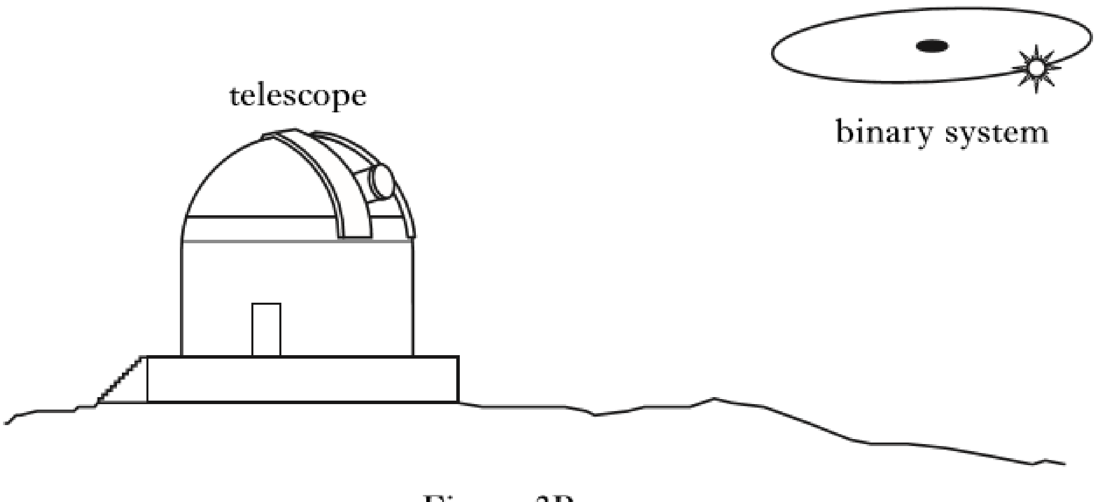


Figure 3B

Light from the star is analysed and found to contain the emission spectrum of hydrogen gas. The frequency of a particular line in the spectrum is monitored and a periodic variation in frequency is recorded.

Explain the periodic variation in the frequency. **2**

12. (*a*) The world lines for three objects A, B and C are shown in Figure 4A.

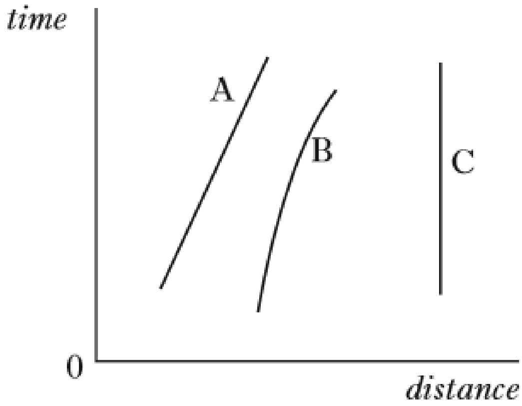


Figure 4A

To which of these objects does the General Theory of Relativity apply? Explain your choice. **2**

(*b*) A rocket ship is accelerating through space. Clocks P and Q are at opposite ends of the ship as shown in Figure 4B. An astronaut inside the rocket ship is beside clock P and can also observe clock Q.

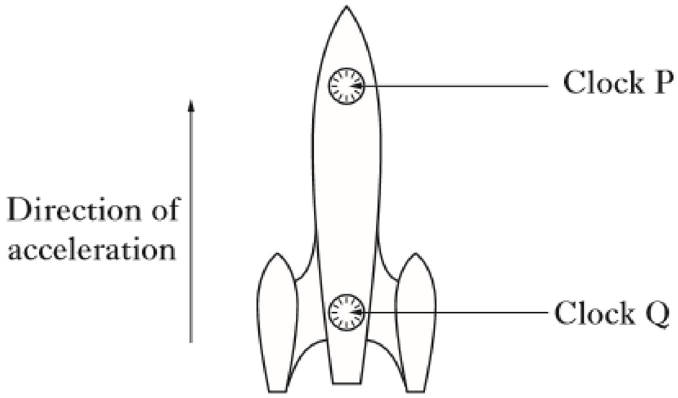


Figure 4B

What does the astronaut observe about the passage of time for these clocks? Justify you answer. **2**

(*c*) Part of an astronaut's training is to experience the effect of "weightlessness". This can be achieved inside an aircraft that follows a path as shown in Figure 4C.

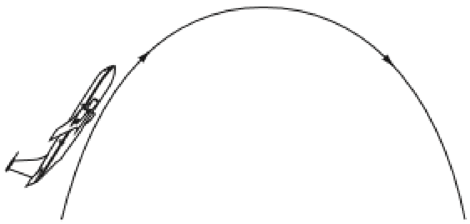


Figure 4C

Use the equivalence principle to explain how this "weightlessness" is achieved. **2**

13. (*a*) With reference to General Relativity, explain why the Moon orbits the Earth. **2**

(*b*) General Relativity also predicts gravitational lensing.

Figure 2 shows the relative positions of Earth, a massive object and a distant star.

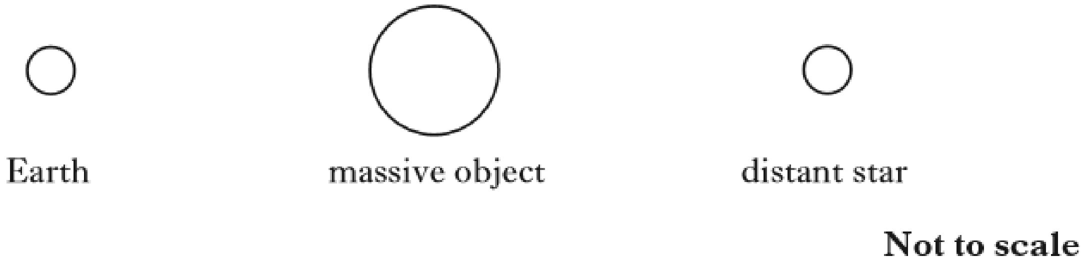


Figure 2

Copy the diagram. On your diagram show:

(i) the path of light from the star to Earth; **1**

(ii) the observed position of the star from Earth. **1**

(*c*) Two students visit the tallest building on Earth. Student A takes a lift to the top of the building while student B waits at the bottom. General Relativity predicts that time will not pass at the same rate for both students. For which student does time pass at a slower rate?

You must justify your answer. **2**

14. The luminosity of the Sun is $3 \cdot 9 \times 10^{26}$ W and the mean radius of the Earth's orbit around the Sun is 1 astronomical unit (AU).

(*a*) Calculate the Sun's apparent brightness at the surface of the Earth. **2**

(*b*) The distance *d* to a star can be calculated using the relationship:

$$10^{0 \cdot 2(m-M)} = \frac{d}{10}$$

This gives a distance in parsecs. 1 parsec is equivalent to 3·26 light years.

The apparent magnitude (m) of a celestial body is a measure of its brightness as viewed from Earth. The absolute magnitude (M) of a celestial body is a measure of its intrinsic brightness.

The following data was obtained for a star.

Apparent magnitude = 5·62
Absolute magnitude = –4·38

Calculate the distance in light years to this star from Earth. **3**

15. A typical Hertsprung-Russell (H-R) diagram is shown in Figure 5A.

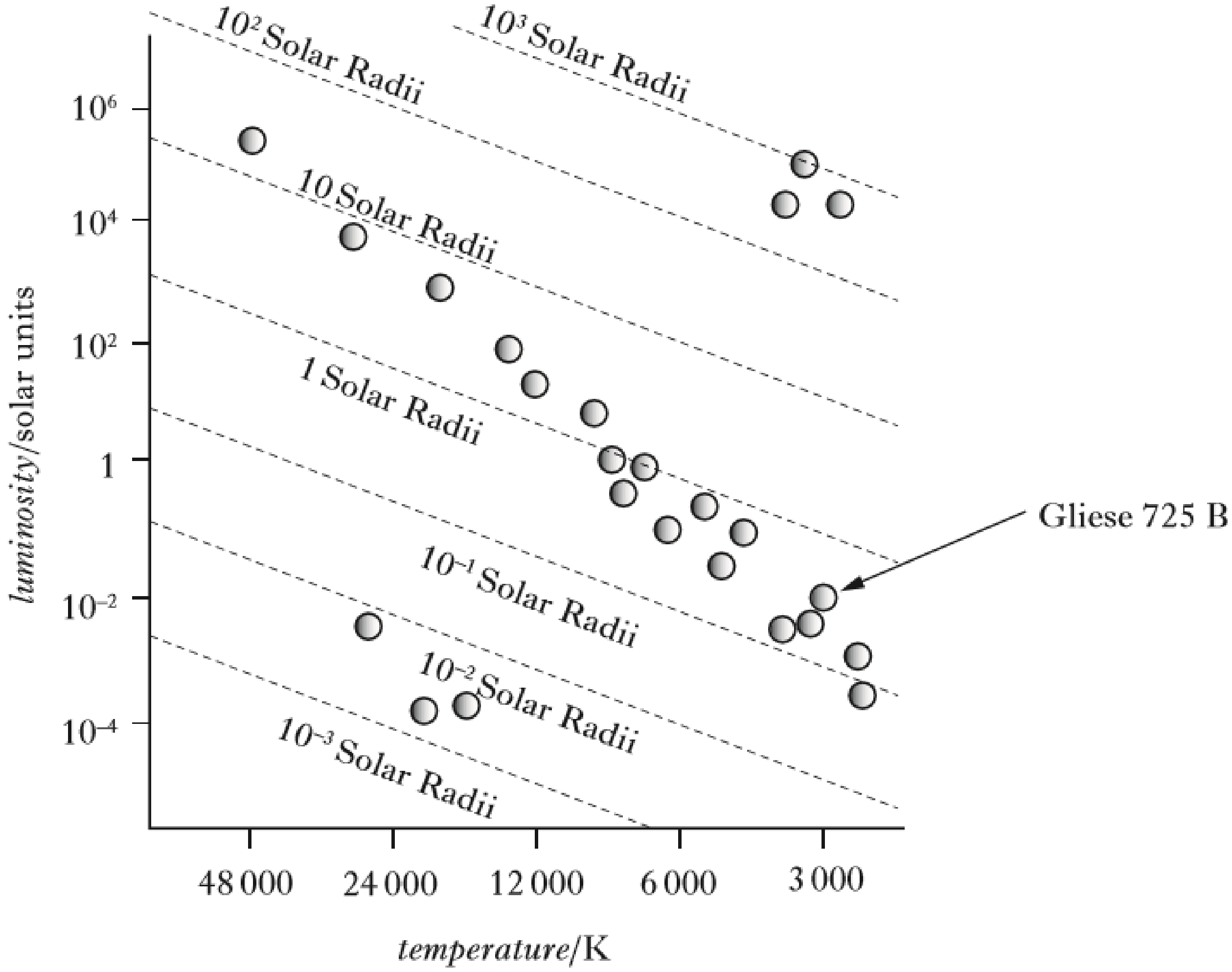


Figure 5A

(*a*) The luminosity of the Sun is $3{\cdot}9 \times 10^{26}$ W.

Using information from Figure 5A:

(i) determine the luminosity in watts of Gliese 725 B; **1**

(ii) show that the radius of Gliese 725 B is 3×10^{8} m; **2**

(iii) explain why it would be inappropriate to give the answer for part (ii) to more than one significant figure. **1**

P.T.O.

15. Continued

(*b*) Figure 5B shows how the radiation intensity varies with frequency for a black body radiator.

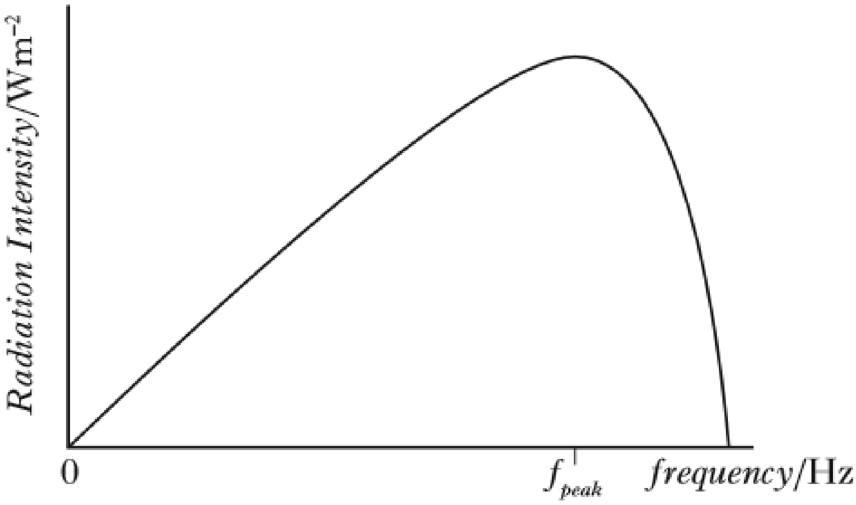


Figure 5B

This spectrum has a peak intensity at a frequency of f_{peak}.
f_{peak} can be estimated using the relationship

$$f_{peak} = \frac{2 \cdot 8 k_b T}{h}$$

where $k_b = 1{\cdot}38 \times 10^{-23}$ J K^{-1} (Boltzmann constant) and the other symbols have their usual meanings.

(i) Estimate f_{peak} for Gliese 725 B. **2**

(ii) The cosmic microwave background radiation (CMBR) has a spectrum which peaks at a wavelength of 1·9 mm. Calculate the temperature of the CMBR. **3**

(*c*) Some astronomers have suggested that primordial black holes of mass $1{\cdot}0 \times 10^{-10}$ solar masses could make up the dark matter in our galaxy.

Determine the Schwarzchild radius of such a black hole. **3**

16. In 1928 Davisson and Germer fired a beam of electrons through a very thin layer of nickel in a vacuum, which resulted in the production of a diffraction pattern.

(*a*) (i) What did they conclude from the results of their experiment? **1**

(ii) Give **one** example of experimental evidence that photons of light exhibit particle properties. **1**

(*b*) Calculate the de Broglie wavelength of an electron travelling at $4{\cdot}4 \times 10^6\,\mathrm{m\,s^{-1}}$. **2**

(*c*) A 20 g bullet travelling at $300\,\mathrm{m\,s^{-1}}$ passes through a 500 mm gap in a target.

Using the data given, explain why no diffraction pattern is observed. **2**

(*d*) (i) Describe the Bohr model of the hydrogen atom. **2**

(ii) Calculate the angular momentum of an electron in the third stable orbit of a hydrogen atom. **2**

17. One of the key ideas in Quantum Theory is the Heisenberg Uncertainty Principle.

(*a*) The uncertainty in the position of a particle can be estimated as its de Broglie wavelength. An electron has an average speed of $3{\cdot}2 \times 10^6\,\text{m s}^{-1}$.

(i) Calculate the minimum uncertainty in the momentum of this electron. **3**

(ii) It is not possible to measure accurately the position of an electron using visible light. Describe the effect of using a beam of X-rays rather than visible light on the measurement of the electron's position and momentum. Justify your answer. **2**

(*b*) Polonium 212 decays by alpha emission. The energy required for an alpha particle to escape from the Polonium nucleus is 26 MeV. Prior to emission, alpha particles in the nucleus have an energy of 8·78 MeV. With reference to the Uncertainty Principle, explain how this process can occur. **2**

18. (*a*) Electrons can exhibit wave-like behaviour. Give **one** example of evidence which supports this statement. **1**

(*b*) The Bohr model of the hydrogen atom suggests a nucleus with an electron occupying one of a series of stable orbits.

A nucleus and the first two stable orbits are shown in Figure 6.

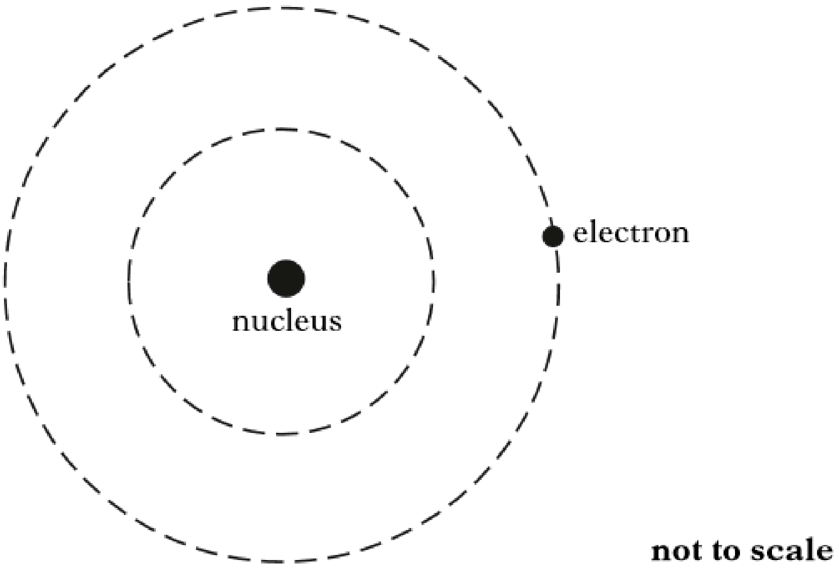


Figure 6

(i) Calculate the angular momentum of the electron in the second stable orbit. **2**

(ii) Starting with the relationship

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

show that the circumference of the second stable orbit is equal to two electron wavelengths. **2**

(iii) The circumference of the second stable orbit is $1{\cdot}3 \times 10^{-9}$ m.

Calculate the speed of the electron in this orbit. **2**

19. A simple pendulum consists of a lead ball on the end of a long string as shown in Figure 5.

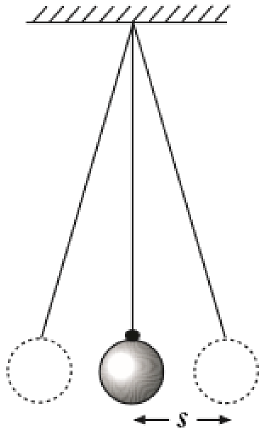


Figure 5

The ball moves with simple harmonic motion. At time t the displacement s of the ball is given by the expression

$$s = 2 \cdot 0 \times 10^{-2} \cos 4 \cdot 3t$$

where s is in metres and t in seconds.

(*a*) (i) State the definition of *simple harmonic motion*. **1**

(ii) Calculate the period of the pendulum. **2**

(*b*) Calculate the maximum speed of the ball. **2**

(*c*) The mass of the ball is $5 \cdot 0 \times 10^{-2}$ kg and the string has negligible mass.

Calculate the total energy of the pendulum. **2**

(*d*) The period T of a pendulum is given by the expression

$$T = 2\pi\sqrt{\frac{L}{g}}$$

where L is the length of the pendulum.

Calculate the length of this pendulum. **2**

(*e*) In the above case, the assumption has been made that the motion is not subject to *damping*.

State what is meant by *damping*. **1**

20. Car engines use the ignition of fuel to release energy which moves the pistons up and down, causing the crankshaft to rotate.

The vertical motion of the piston approximates to simple harmonic motion.

Figure 8 shows different positions of a piston in a car engine.

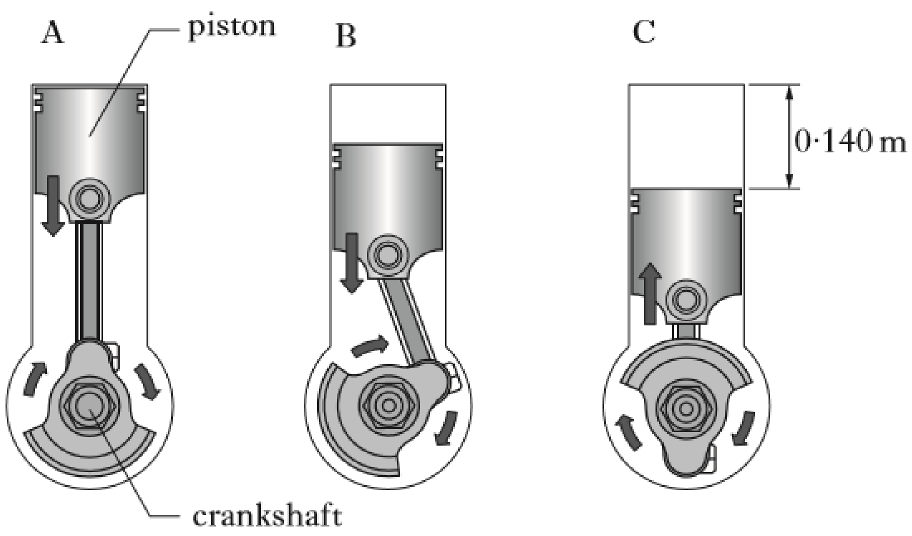


Figure 8

(*a*) Define *simple harmonic motion*. **1**

(*b*) Determine the amplitude of the motion. **1**

(*c*) In this engine the crankshaft rotates at 1500 revolutions per minute and the piston has a total mass of 1·40 kg.

(i) Calculate the maximum acceleration of the piston. **3**

(ii) Calculate the maximum kinetic energy of the piston. **2**

21. The Sun is constantly losing mass through nuclear fusion. Particles also escape from the corona as shown in Figure 7A. This stream of particles radiating from the Sun is known as the Solar wind and its main constituent, by mass, is protons.

Figure 7A

(*a*) Astronomers estimate that the Sun loses mass at a rate of $1{\cdot}0 \times 10^9\,\mathrm{kg\,s^{-1}}$. This rate has been approximately constant through the Sun's lifetime of $4{\cdot}6 \times 10^9$ years.

Estimate the mass lost by the Sun in its lifetime as a percentage of its current mass. **2**

(*b*) A proton in the solar wind has energy of 3·6 MeV.

(i) Calculate the velocity of this proton. **3**

(ii) The proton enters the magnetic field around the Earth at an angle of 50° as shown in Figure 7B. The magnetic field strength is $58\,\mu\mathrm{T}$.

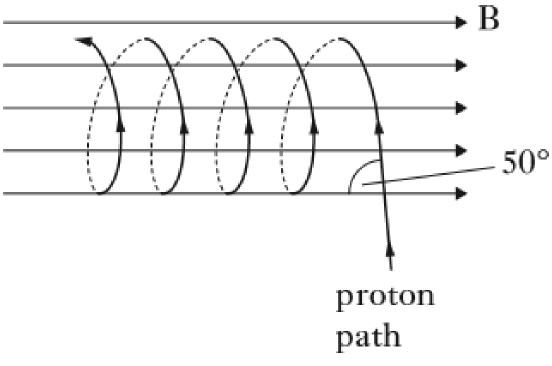


Figure 7B

(A) Explain the shape of the path followed by the proton in the magnetic field. **2**

(B) Calculate the radius of curvature of this path. **3**

(iii) An antiproton of energy 3·6 MeV enters the same region of the Earth's magnetic field at an angle of 30° to the field.

Describe **two** differences in the paths taken by the antiproton and the original proton. **2**

22. (*a*) When sunlight hits a thin film of oil floating on the surface of water, a complex pattern of coloured fringes is observed.

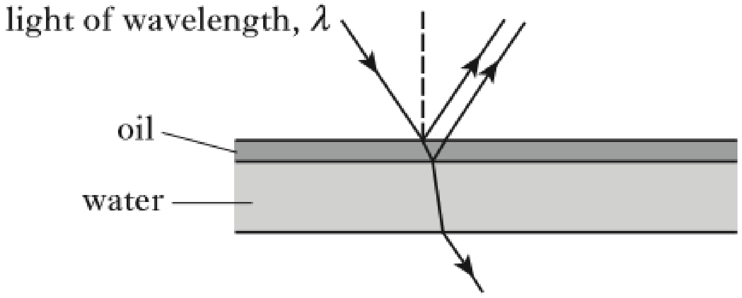


Figure 10

Explain how these fringes are formed. **2**

(*b*) The surface of a lens is coated with a thin film of magnesium fluoride.

Calculate the minimum thickness required to make the lens non-reflecting at a wavelength of 555 nm. **2**

(*c*) The lens of a digital camera appears to be purple in white light.

Explain this observation. **2**

23. High quality *optical flats* made from glass are often used to test components of optical instruments. A high quality optical flat has a very smooth and flat surface.

(*a*) During the manufacture of an optical flat, the quality of the surface is tested by placing it on top of a high quality flat. This results in a thin air wedge between the flats as shown in Figure 8A.

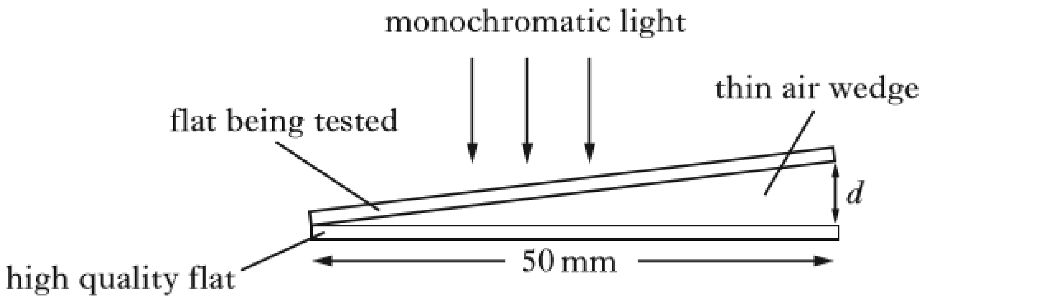


Figure 8A

The thickness *d* of the air wedge is $6{\cdot}2 \times 10^{-5}$ m.

Monochromatic light is used to illuminate the flats from above. When viewed from above using a travelling microscope, a series of interference fringes is observed as shown in Figure 8B.

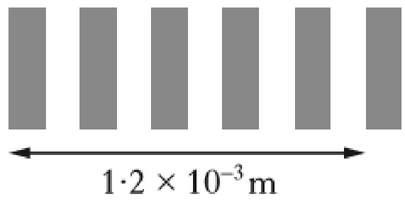


Figure 8B

Calculate the wavelength of the monochromatic light. **3**

(*b*) A second flat is tested using the same method as in part (*a*). This flat is slightly curved as shown in Figure 8C.

Figure 8C

Draw the fringe pattern observed. **1**

P.T.O.

23. Continued

(*c*) Good quality optical flats often have a non-reflecting coating of magnesium fluoride applied to the surface as shown in Figure 8D.

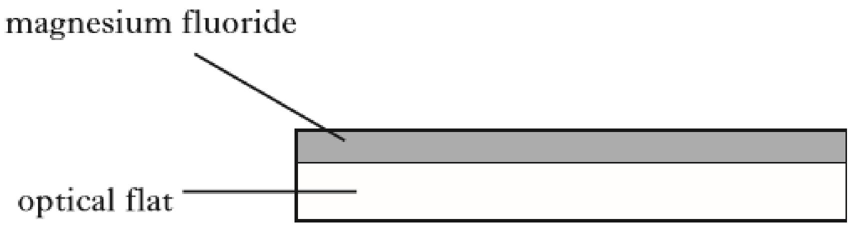


Figure 8D

(i) With the aid of a diagram explain fully how the coating reduces reflections from the flat for monochromatic light. **2**

(ii) Calculate the minimum thickness of magnesium fluoride required to make the flat non-reflecting for yellow light from a sodium lamp. **2**

24. Light from a helium-neon laser is incident on a double slit. A pattern of light and dark fringes is observed on a screen 3·50 m beyond the slits as shown in Figure 20.

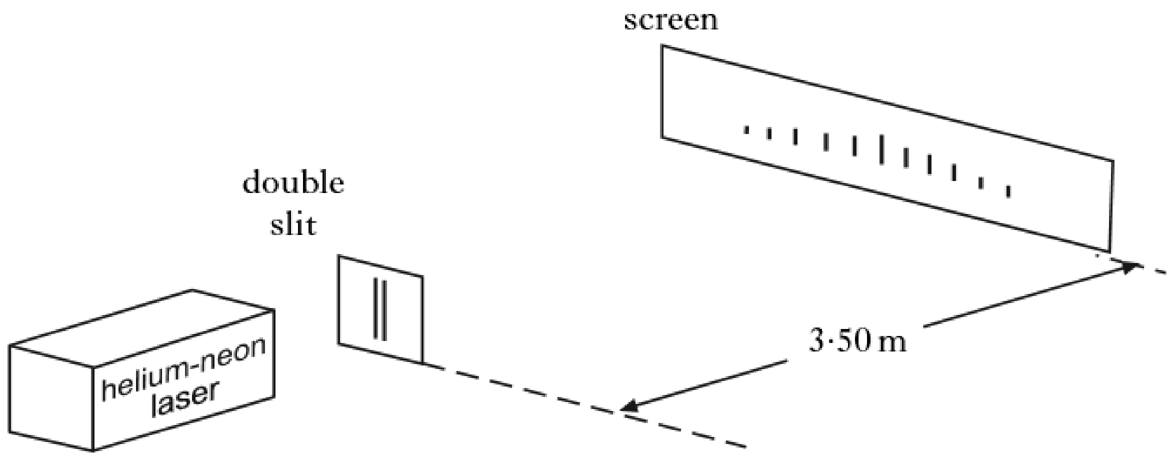


Figure 20

(*a*) State whether these fringes are caused by division of amplitude or division of wavefront. **1**

(*b*) The distance between two adjacent bright fringes on the screen is 7·20 mm. Calculate the separation of the two slits. **2**

(*c*) The distance between the double slit and screen is increased to 5·50 m. The distance between the fringes is remeasured and the calculation of the slit separation is repeated.

(i) Explain **one** advantage of moving the screen further away from the double slit. **2**

(ii) State **one** disadvantage of moving the screen further away from the double slit. **1**

25. A transverse wave travels along a string as shown in Figure 9A.

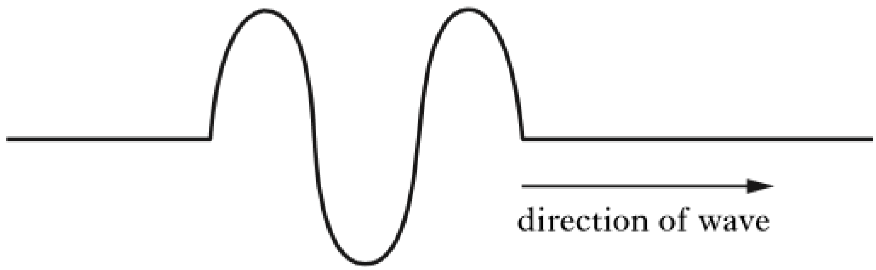


Figure 9A

The equation representing the travelling wave on the string is

$$y = 8{\cdot}6 \times 10^{-2} \sin 2\pi\,(2{\cdot}4t - 2{\cdot}0x)$$

where x and y are in metres and t is in seconds.

(*a*) State the frequency of the wave. **1**

(*b*) Calculate the velocity of the wave. **2**

(*c*) Attached to the end of the string is a very light ring. The ring is free to move up and down a fixed vertical rod.

Figure 9B shows the string after the wave reflects from the vertical rod.

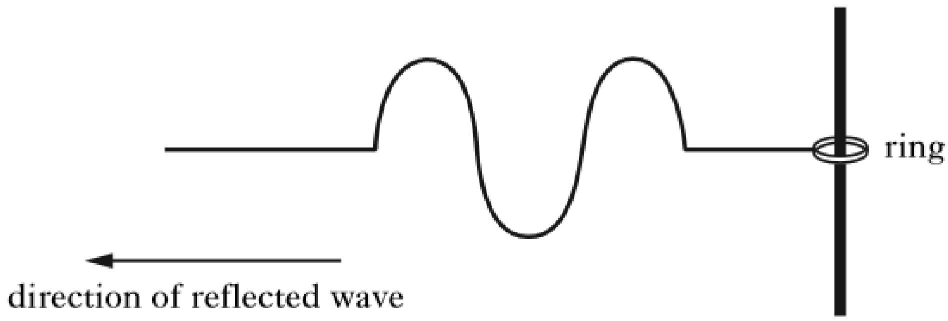


Figure 9B

When the wave reflects, its intensity falls to one quarter of its original value. The frequency and wavelength are constant.

Write the equation that represents this reflected wave. **2**

26.

A travelling wave moves from left to right at a speed of $1 \cdot 25\ \mathrm{m\,s^{-1}}$.

Figure 9A represents this wave at a time t. P and Q are partcles on the wave.

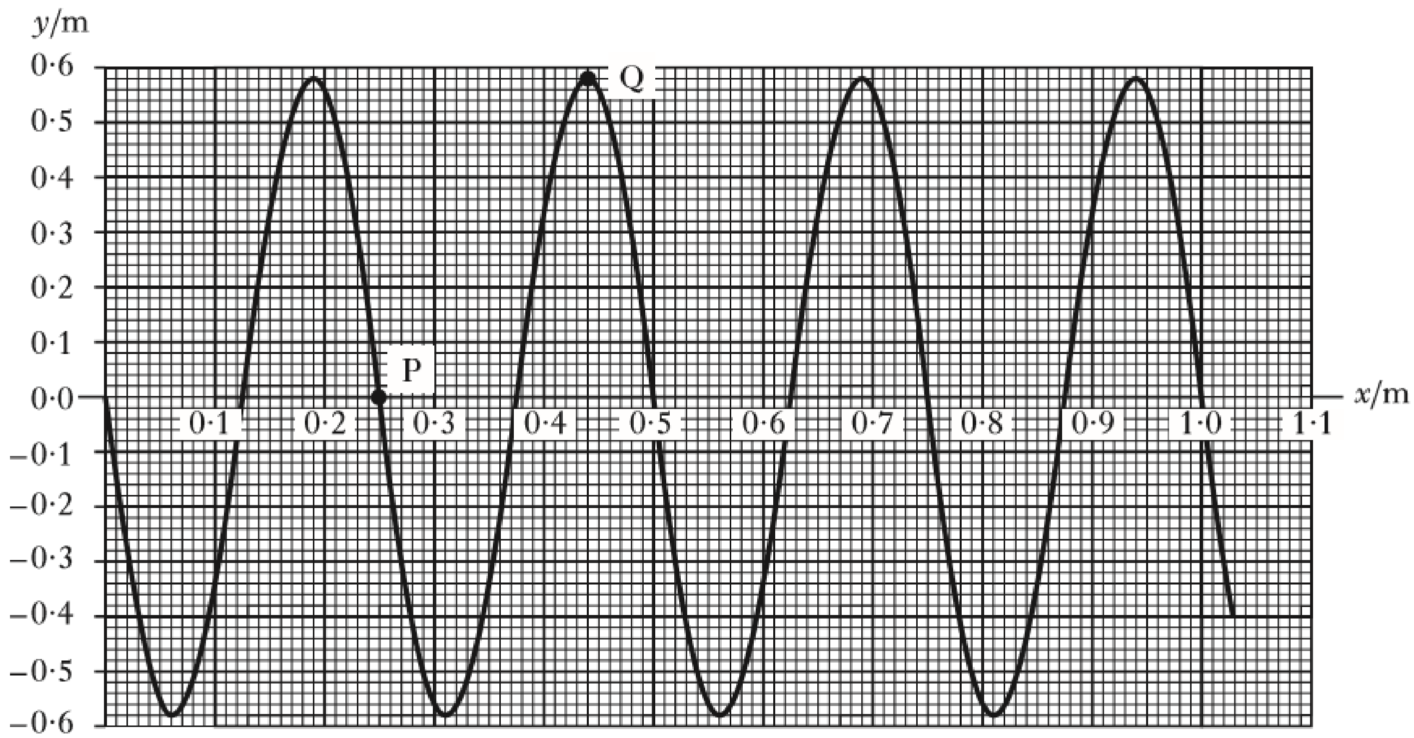


Figure 9A

(*a*) (i) Determine the wavelength of the wave. **1**

(ii) State the amplitude of the wave. **1**

(iii) Calculate the frequency of the wave. **1**

(iv) What is the phase difference, in radians, between particles P and Q? **2**

(*b*) Write an equation for this travelling wave in terms of y, x and t.

Numerical values are required. **2**

(*c*) State the equation for a wave of half the amplitude travelling in the opposite direction. **1**

27. A stretched wire, supported near its ends, is made to vibrate by touching a tuning fork of unknown frequency to the supporting surface. One of the supports is moved until a stationary wave pattern appears as shown in Figure 10A.

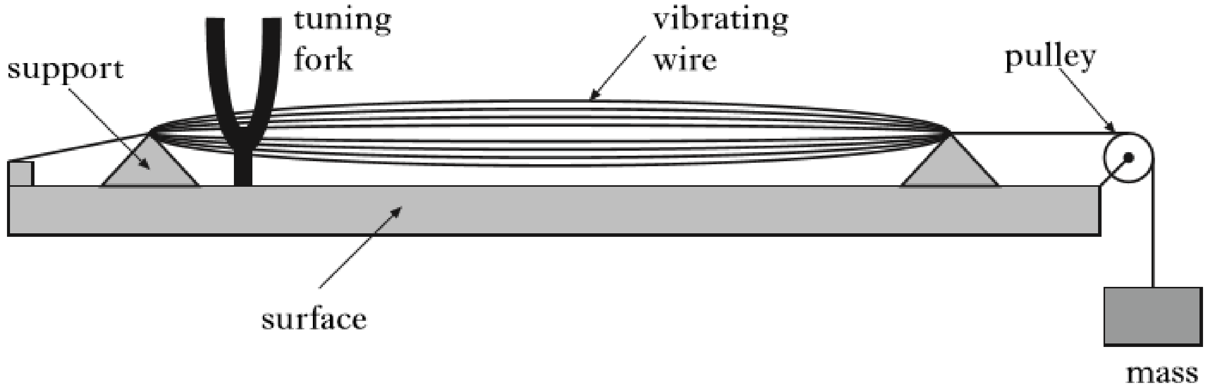


Figure 10A

(*a*) Explain how waves on this wire produce a stationary wave pattern. **2**

(*b*) The formula for the frequency of the note from a stretched wire is given by:

$$f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$$

where l is the distance between the supports,
T is the stretching force,
μ is the mass per unit length of the wire.

The results of the experiment are given below:

mass per unit length of wire $= 1{\cdot}92 \times 10^{-4}\,\text{kg m}^{-1}$
distance between the supports $= 0{\cdot}780\,\text{m}$
mass of load on wire $= 4{\cdot}02\,\text{kg}$

(i) The table below gives information about the note produced by tuning forks of different frequency. Identify the note most likely to correspond to the tuning fork used in the experiment. **2**

Note	A	B	C	D	E	F	G
Frequency (Hz)	220	245	262	294	330	349	392

(ii) A second tuning fork produces the pattern shown in Figure 10B. Suggest a frequency for this tuning fork. **1**

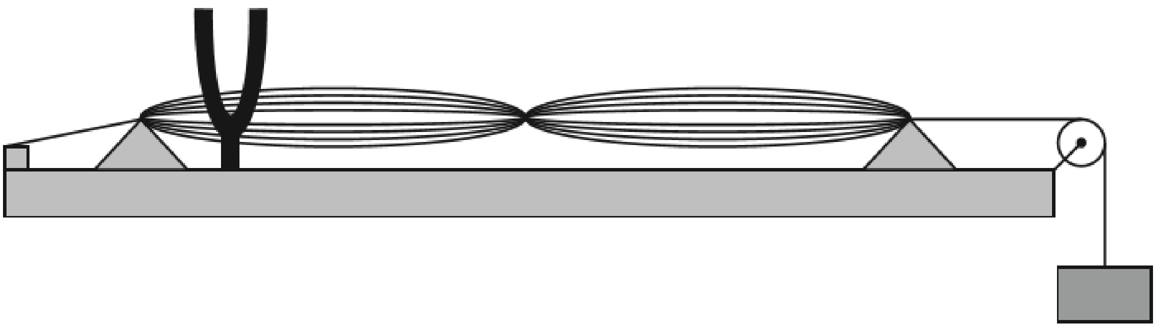


Figure 10B

28. A water wave of frequency 2·5 Hz travels from left to right.

Figure 9 represents the displacement y of the water at one instant in time.

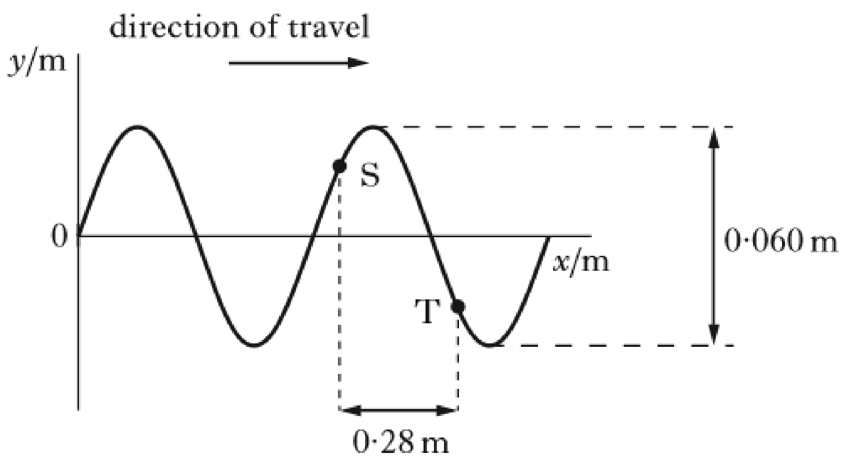


Figure 9

Points S and T are separated by a horizontal distance of 0·28 m.

The phase difference between these two points is 3·5 radians.

(*a*) Calculate the wavelength of this wave. **2**

(*b*) A second wave with double the frequency travels in the same direction through the water. This wave transfers five times the energy of the wave in part (*a*).

Calculate:

(i) the speed of this wave; **1**

(ii) the amplitude of this wave. **2**

29.

A light source produces a beam of unpolarised light. The beam of light passes through a polarising filter called a polariser. The transmission axis of the polariser is shown in Figure 11A.

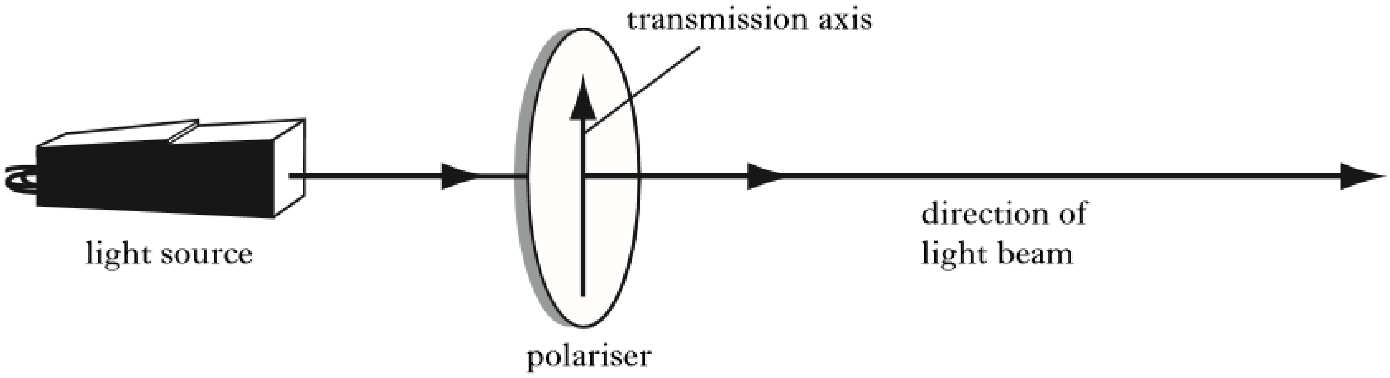


Figure 11A

(*a*) Explain the difference between the unpolarised light entering the polariser and the plane polarised light leaving the polariser. **1**

(*b*) The plane polarised light passes through a second polarising filter called an analyser.

The irradiance of the light passing through the analyser is measured by a light meter.

The transmission axis of the analyser can be rotated and its angle of rotation measured using a scale as shown in Figure 11B.

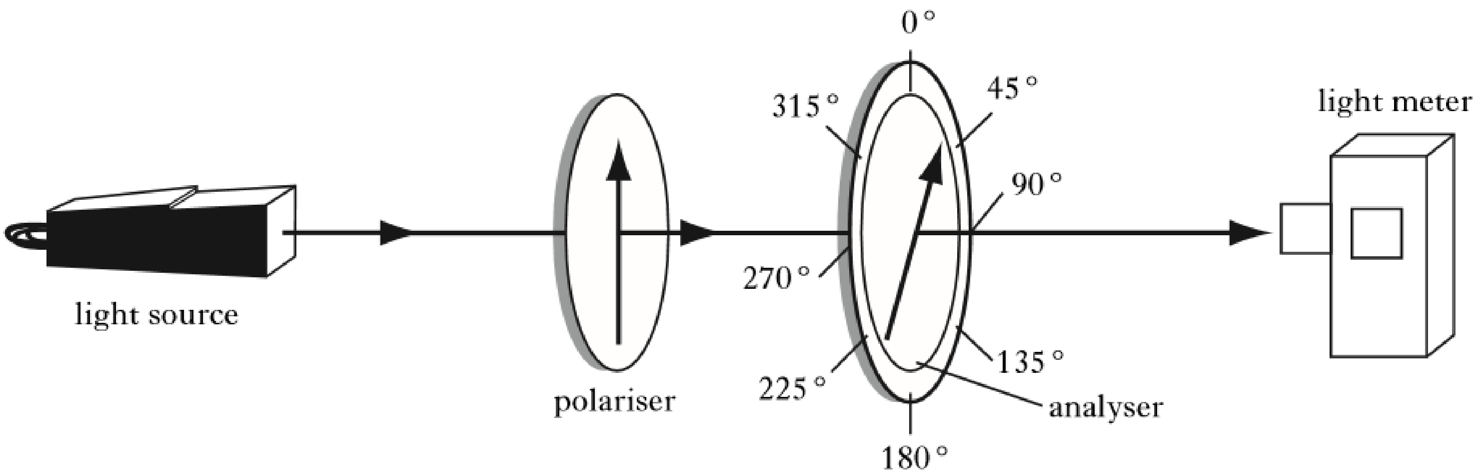


Figure 11B

(i) The analyser is rotated.

State the **two** positions on the analyser scale that will produce a maximum reading of irradiance, I_0, on the light meter. **2**

P.T.O.

29. Continued

(ii) The relationship between the irradiance I detected by the light meter and the angle of rotation θ is given by

$$I = I_0 \cos^2\theta.$$

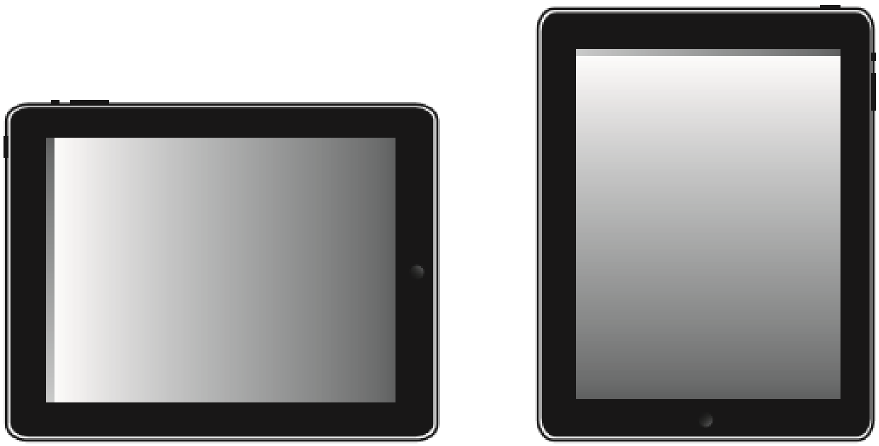
Explain how the equipment shown in Figure 11B could be used to establish this relationship.

Your answer should include:

- the measurements required;
- a description of how the relationship would be verified. **3**

30. A student, wearing polarising sunglasses, is using a tablet computer outdoors. The orientation of the tablet seems to affect the image observed by the student.

Two orientations are shown in Figure 11A.



Landscape mode　　　　Portrait mode

Figure 11A

(*a*) In landscape mode the image appears bright and in portrait mode it appears dark.

(i) What may be concluded about the light emitted from the tablet screen? **1**

(ii) The student slowly rotates the tablet. Describe the change in brightness observed by the student as it is rotated through 180°. **2**

(*b*) Unpolarised sunlight is incident on a water surface a shown in Figure 11B.

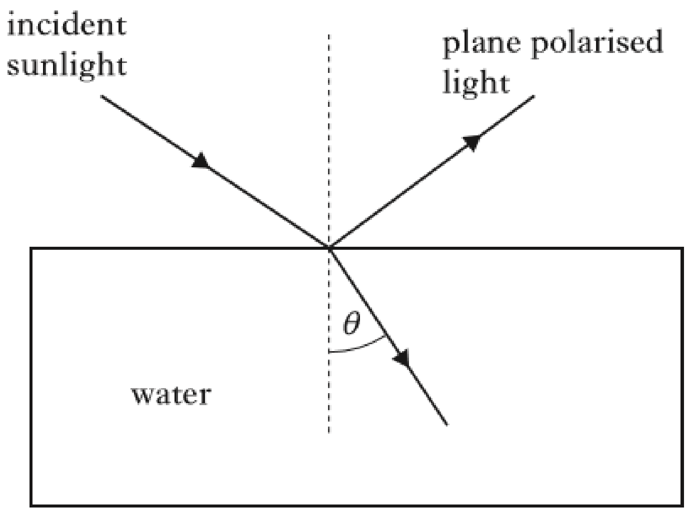


Figure 11B

The light is 100% plane polarised on reflection.

Calculate the angle of refraction θ. **2**

31. (*a*) Two point charges Q_1 and Q_2 each has a charge of $-4{\cdot}0\,\mu C$. The charges are $0{\cdot}60\,m$ apart as shown in Figure 7.

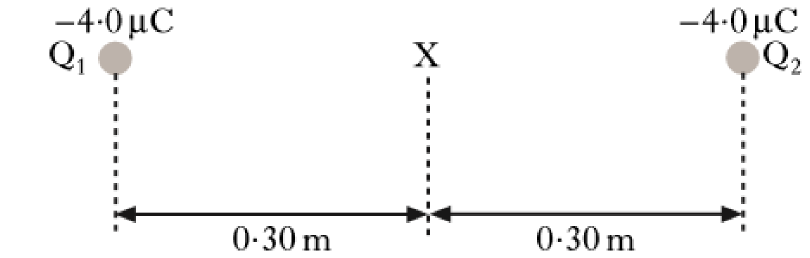


Figure 7

(i) Draw a diagram to show the electric field lines between charges Q_1 and Q_2. **1**

(ii) Calculate the electrostatic potential at point X, midway between the charges. **2**

(*b*) A third point charge Q_3 is placed near the two charges as shown in Figure 8.

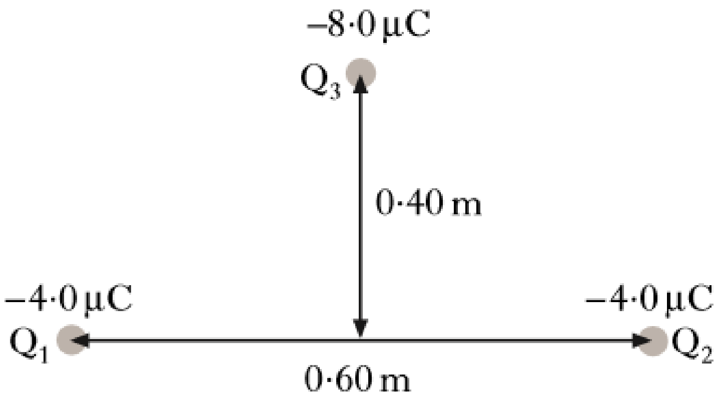


Figure 8

(i) Show that the force between charges Q_1 and Q_3 is $1{\cdot}2\,N$. **2**

(ii) Calculate the **magnitude** and **direction** of the resultant force on charge Q_3 due to charges Q_1 and Q_2. **2**

32.

A hollow metal sphere, radius 1·00 mm, carries a charge of $-1{\cdot}92 \times 10^{-12}$ C.

(*a*) Calculate the electric field strength, *E*, at the surface of the sphere. **2**

(*b*) Four students sketch graphs of the variation of electric field strength with distance from the centre of the sphere as shown in Figure 6A.

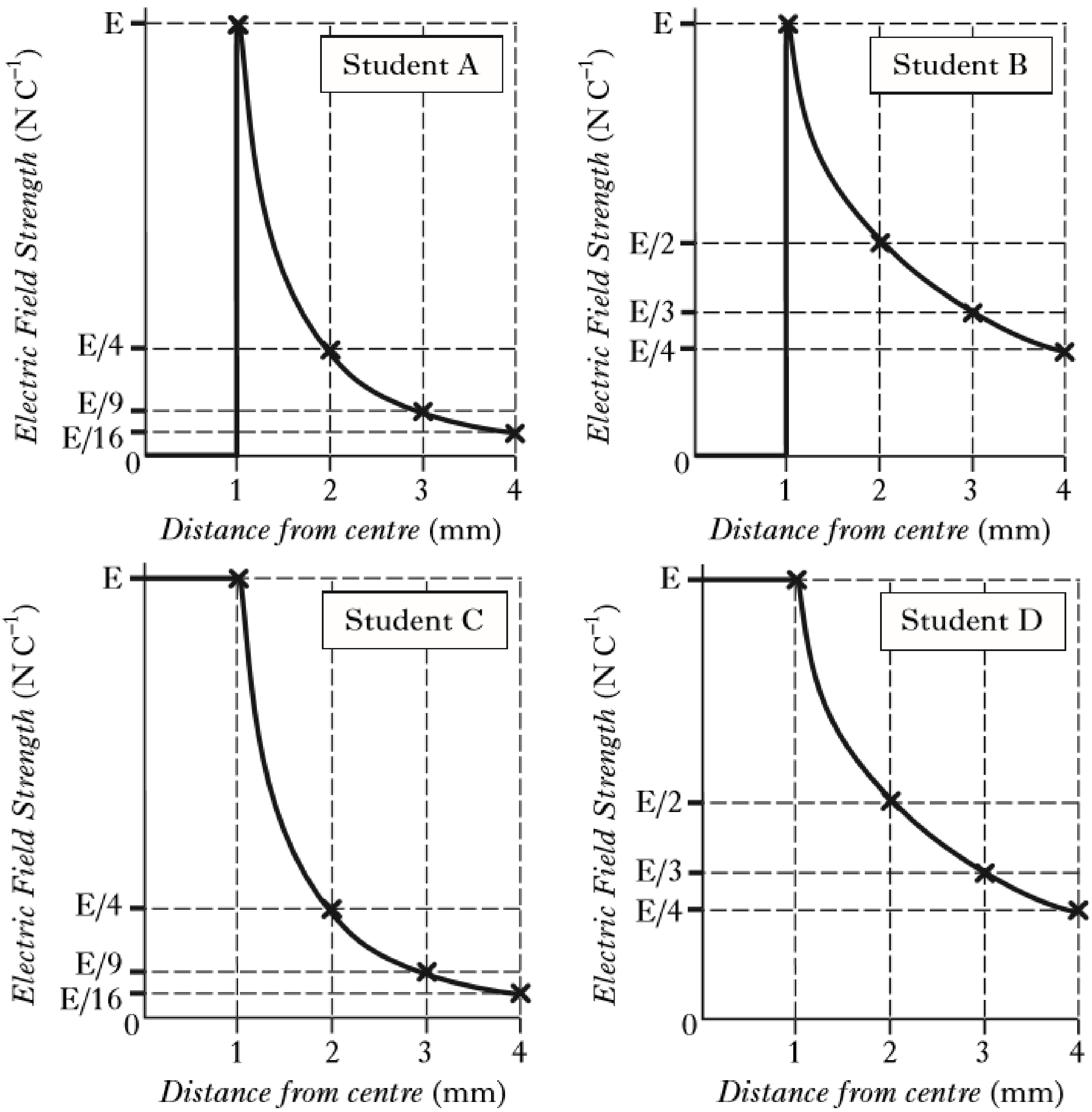


Figure 6A

(i) Which student has drawn the correct graph? **1**

(ii) Give **two** reasons to support your choice. **2**

P.T.O.

32. Continued

(*c*) Four point charges, Q_1, Q_2, Q_3 and Q_4, each of value $-2{\cdot}97 \times 10^{-8}$ C, are held in a square array. The hollow sphere with charge $-1{\cdot}92 \times 10^{-12}$ C is placed 30·0 mm above the centre of the array where it is held stationary by an electrostatic force.

The hollow sphere is 41·2 mm from each of the four charges as shown in Figure 6B.

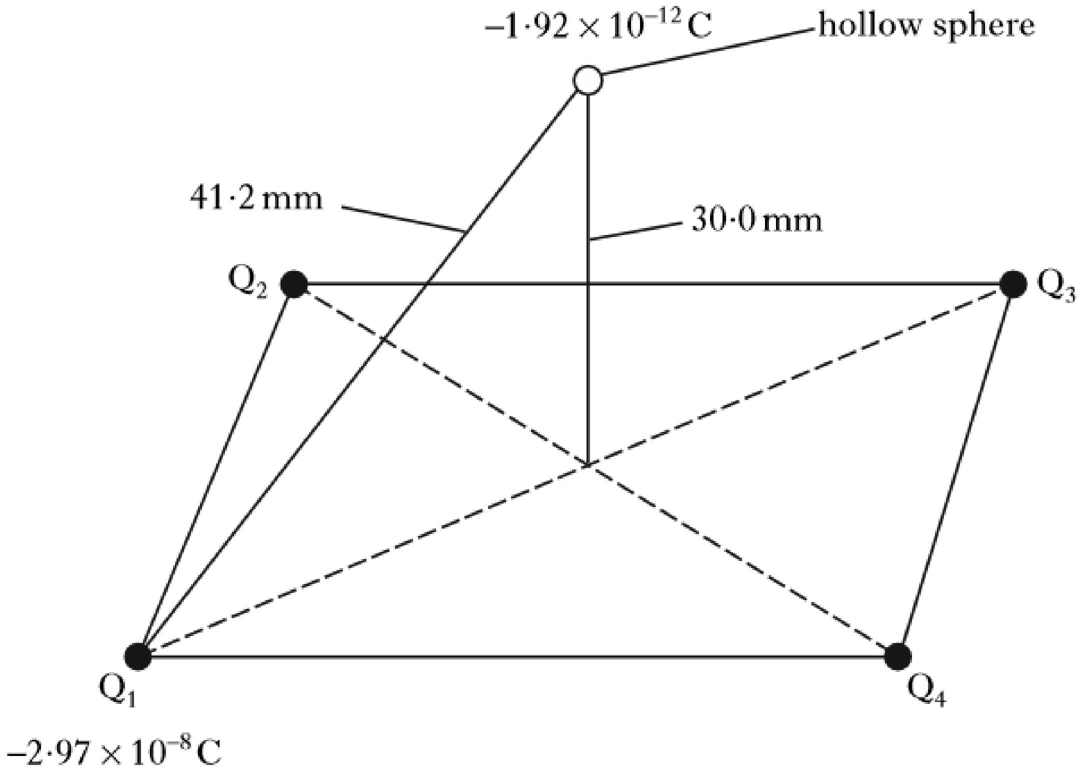


Figure 6B

(i) Calculate the magnitude of the force acting on the sphere due to charge Q_1. **2**

(ii) Calculate the vertical component of this force. **2**

(iii) Calculate the resultant electrostatic force on the sphere due to the whole array. **1**

(iv) Calculate the mass of the sphere. **2**

33. (*a*) A proton moving at constant speed v enters a uniform magnetic field of induction B as shown in Figure 9A.

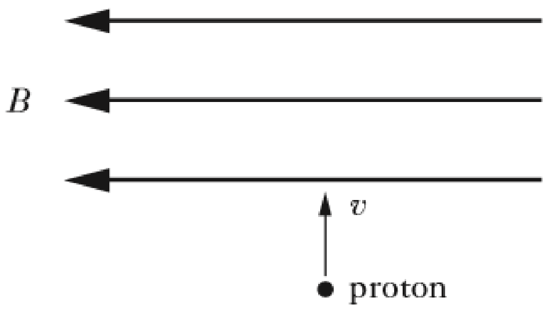


Figure 9A

Within the field the proton follows a circular path of radius r.

(i) Explain why the proton follows a circular path. **1**

(ii) Show that the radius of the path r is given by

$$r = \frac{1 \cdot 05 \times 10^{-8} v}{B}.$$ **2**

(*b*) Another proton moving at the same speed v enters the magnetic field at an angle θ to the magnetic field lines as shown in Figure 9B.

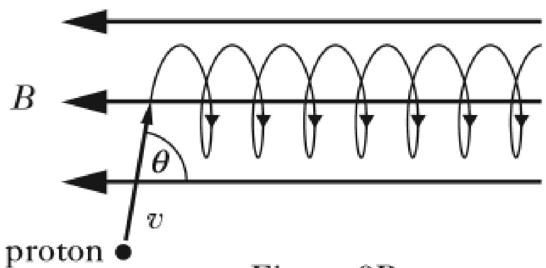


Figure 9B

Explain the shape of the path followed by this proton in the magnetic field. **2**

P.T.O.

33. Continued

(*c*) The solar wind is a stream of charged particles, mainly protons and electrons, released from the atmosphere of the Sun. Many of these particles become trapped by the magnetic field of the Earth.

Some of the trapped particles move back and forth in helical paths between two ***magnetic mirror points***. The path followed by one particular proton is shown in Figure 9C.

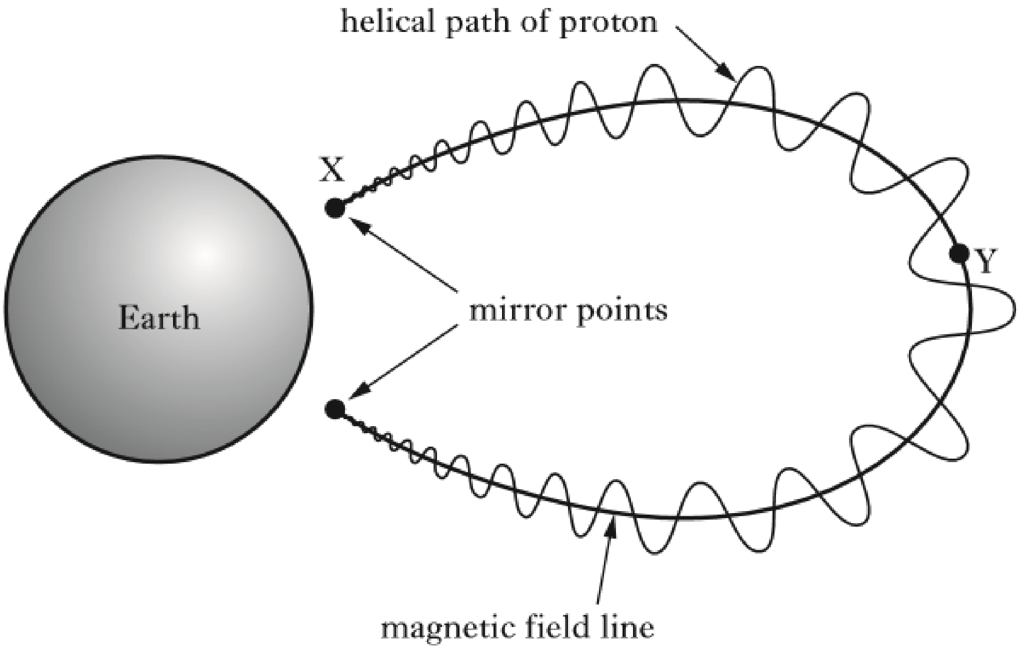


Figure 9C

The speed of the proton remains constant at $1{\cdot}2 \times 10^7\,\mathrm{m\,s^{-1}}$ as it travels along its helical path from one magnetic mirror point to the other.

(i) The proton oscillates between the two mirror points with a frequency of 4·0 Hz. Calculate the distance that the proton travels in moving from one mirror point to the other. **3**

(ii) Explain why the radius of the helical path followed by the proton increases as it moves from point X to point Y as shown in Figure 9C. **1**

(iii) At point X the radius of curvature of the helix for this proton is $1{\cdot}0 \times 10^4$ m. Calculate the strength of the Earth's magnetic field at this point. **2**

34. A beam of protons enters a region of uniform magnetic field, at right angles to the field.

The protons follow a circular path in the magnetic field until a potential difference is applied across the deflecting plates. The deflected protons hit a copper target. The protons travel through a vacuum. A simplified diagram is shown in Figure 7A.

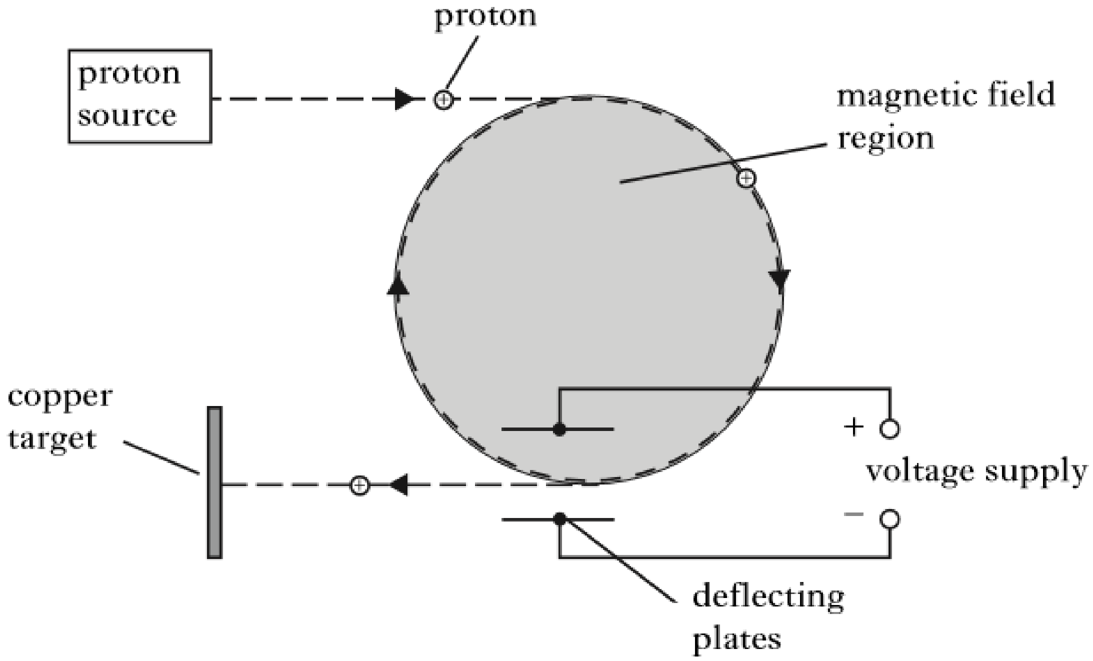


Figure 7A

(*a*) State the direction of the magnetic field, *B*. **1**

(*b*) The speed of the protons is $6{\cdot}0 \times 10^6\,\text{m s}^{-1}$ and the magnetic induction is $0{\cdot}75\,\text{T}$. Calculate the radius of the circular path followed by the protons. **3**

(*c*) Calculate the electric field strength required to make the protons move off at a tangent to the circle. **2**

P.T.O.

34. Continued

(*d*) A proton of charge q initially travels at speed v directly towards a copper nucleus as shown in Figure 7B. The copper nucleus has charge Q.

Figure 7B

(i) Show that the distance of closest approach, r, to the copper nucleus is given by

$$\frac{qQ}{2\pi\varepsilon_0 mv^2}.$$ **1**

(ii) Calculate the distance of closest approach for a proton initially travelling at $6{\cdot}0 \times 10^6\,\mathrm{m\,s^{-1}}$. **3**

(iii) Name the force that holds the protons together in the copper nucleus. **1**

(*e*) The beam of protons in Figure 7A is replaced by a beam of electrons. The speed of the electrons is the same as the speed of the protons.

State **two** changes that must be made to the magnetic field to allow the electrons to follow the same circular path as the protons. **2**

35. A long thin horizontal conductor AB carrying a current of 25 A is supported by two fine threads of negligible mass. The tension in each supporting thread is T as shown in Figure 8A.

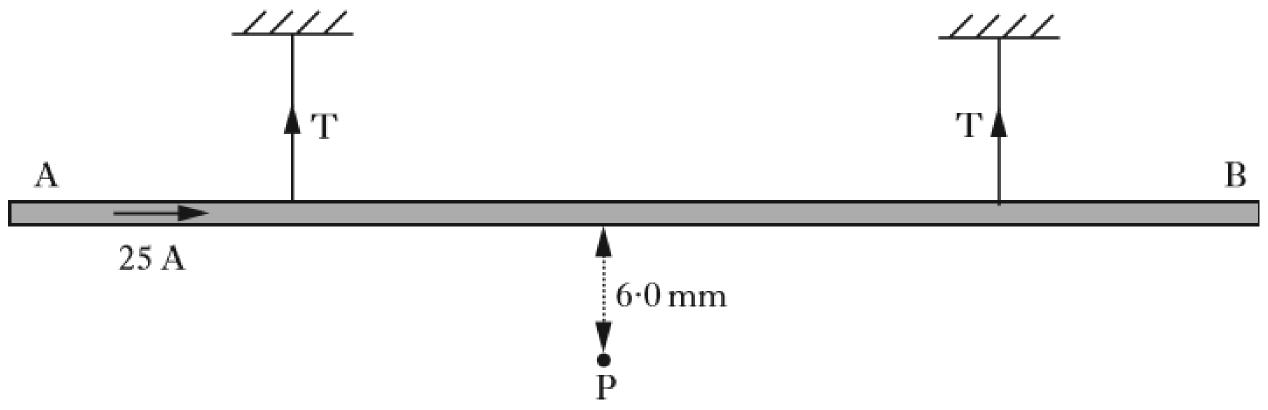


Figure 8A

(*a*) Calculate the magnetic induction at a point P, 6·0 mm directly below conductor AB. **2**

(*b*) A second conductor CD carrying current I is now fixed in a position a distance r directly below AB as shown in Figure 8B. CD is unable to move.

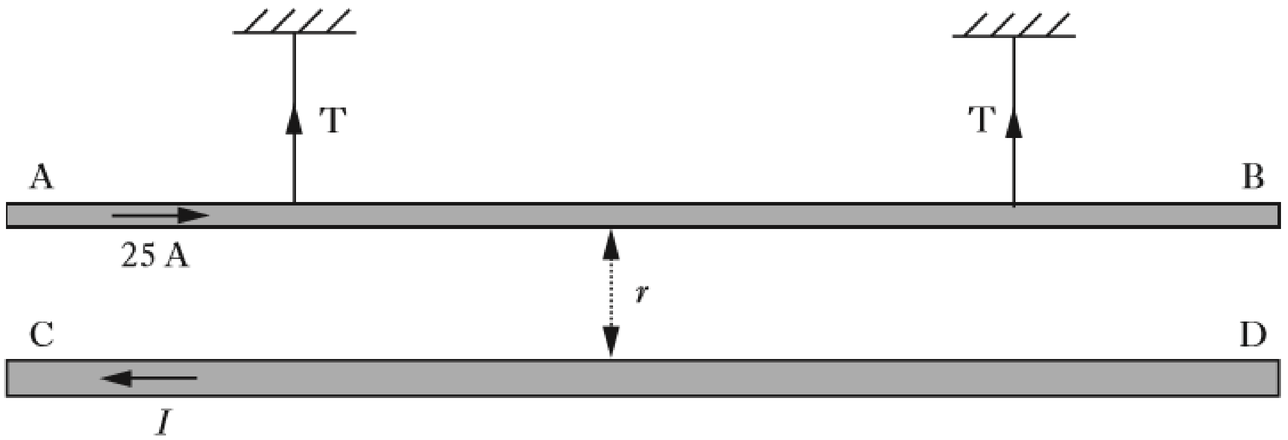


Figure 8B

(i) Explain why there is a force of repulsion between conductors AB and CD. **2**

(ii) Show that the force per unit length acting on each conductor can be written as

$$\frac{F}{l} = \frac{5 \cdot 0 \times 10^{-6} I}{r}.$$ **1**

(iii) The mass per unit length of the conductor AB is $5{\cdot}70 \times 10^{-3}$ kg m^{-1}. When the conductors are separated by 6·0 mm, the current I in conductor CD is gradually increased. Calculate the value of I which reduces the tension in the supporting threads to zero. **3**

36. The shape of the Earth's magnetic field is shown in Figure 8.

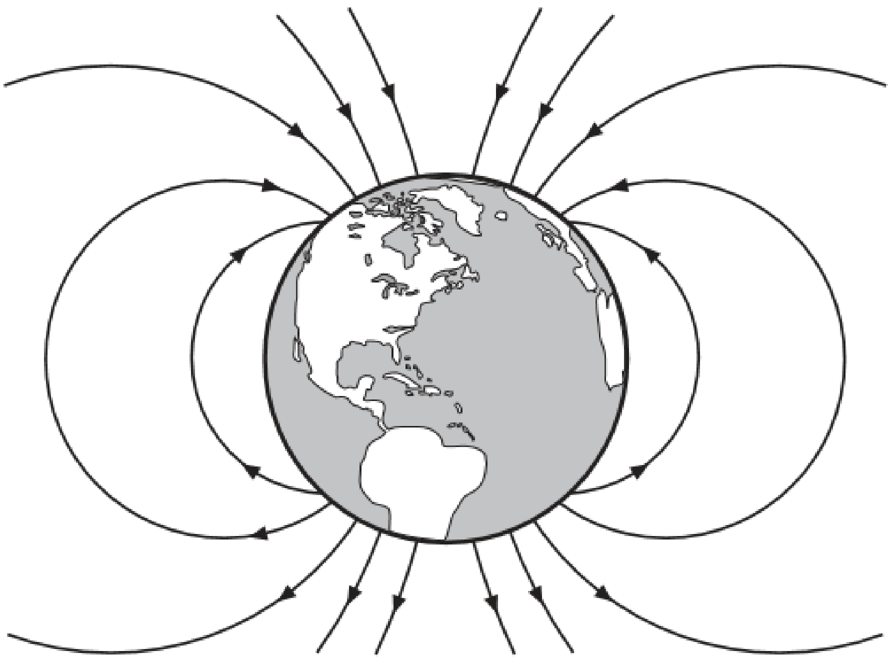


Figure 8

At a particular location in Scotland the field has a magnitude of $5{\cdot}0 \times 10^{-5}$ T directed into the Earth's surface at an angle of 69° as shown in Figure 9.

Figure 9

(*a*) Show that the component of the field perpendicular to the Earth's surface is $4{\cdot}7 \times 10^{-5}$ T. **1**

P.T.O.

36. Continued

(*b*) At this location a student sets up a circuit containing a straight length of copper wire lying horizontally in the North – South direction as shown in Figure 10.

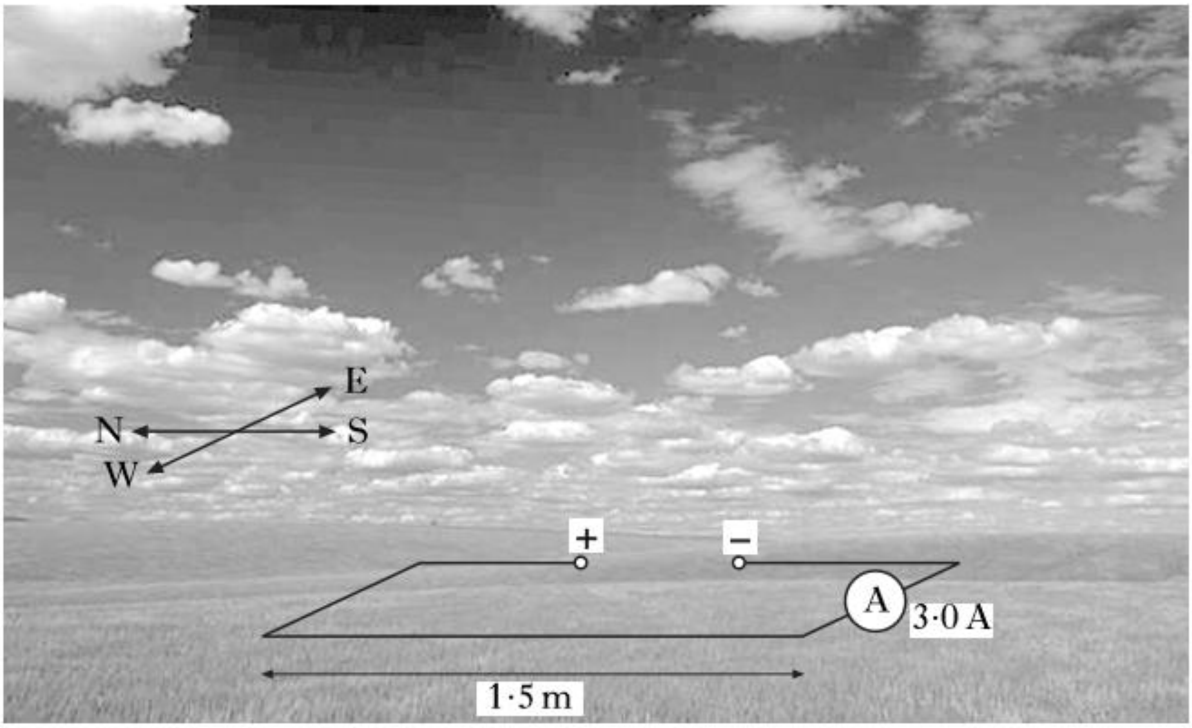


Figure 10

The length of the wire is 1·5 m and the current in the circuit is 3·0 A.

(i) Calculate the magnitude of the force acting on the wire due to the Earth's magnetic field. **2**

(ii) State the direction of this force. **1**

(*c*) The wire is now tilted through an angle of 69 ° so that it is parallel to the direction of the Earth's magnetic field.

Determine the force on the wire due to the Earth's magnetic field. **1**

(*d*) A long straight current carrying wire produces a magnetic field. The current in this wire is 3·0 A.

(i) Calculate the distance from the wire at which the magnitude of the magnetic field is $5{\cdot}0 \times 10^{-5}$ T. **2**

(ii) Describe the shape of this magnetic field. **1**

37.(*a*) Figure 11 shows a d.c. power supply in series with a switch, lamp and inductor.

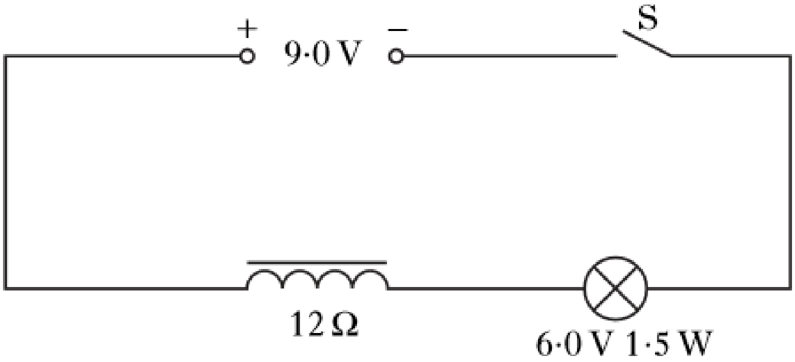


Figure 11

The inductor consists of a coil of wire with a resistance of 12 Ω.
The lamp is rated at 6·0 V 1·5 W.
The 9·0 V d.c. power supply has negligible internal resistance.

(i) Explain why the lamp does not reach its maximum brightness immediately after the switch is closed. **2**

(ii) When the lamp reaches its maximum brightness it is operating at its stated power rating.

Calculate the current in the circuit. **1**

(iii) The maximum energy stored in the inductor is 75 mJ.

Calculate the inductance of the inductor. **2**

(iv) The inductor in Figure 11 is replaced with another inductor which has the same type of core and wire, but with twice as many turns.

State the effect this has on:

(A) the maximum current;

(B) the time to reach maximum current. **2**

38. An inductor of negligible resistance is connected in the circuit shown in Figure 11.

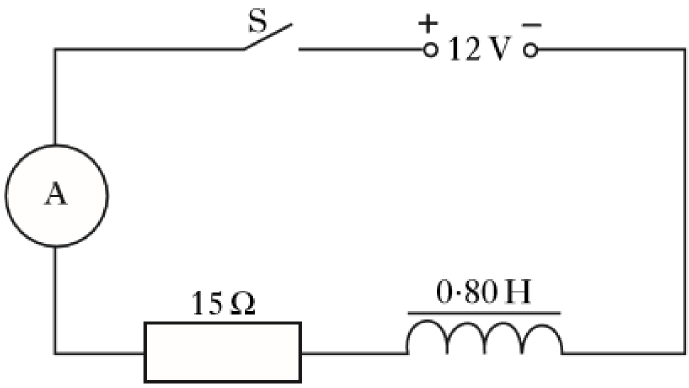


Figure 11

(*a*) The inductor has an inductance of 0·80 H.

Switch S is closed.

(i) Explain why there is a time delay before the current reaches its maximum value. **1**

(ii) Calculate the maximum current in the circuit. **2**

(iii) Calculate the maximum energy stored in the inductor. **2**

(iv) Calculate the rate of change of current when the current in the circuit is 0·12 A. **3**

(*b*) Switch S is opened and the iron core is removed from the inductor. Switch S is now closed.

(i) Will the maximum current be bigger, smaller or the same as the maximum current calculated in (*a*)(ii)? **1**

(ii) Explain any change in the time delay to reach the maximum current. **2**

(iii) Explain why the maximum energy stored in the inductor is less than in (*a*)(iii). **1**

(*c*) The iron core is replaced in the inductor. The d.c. supply is replaced with a variable frequency supply as shown in Figure 12.

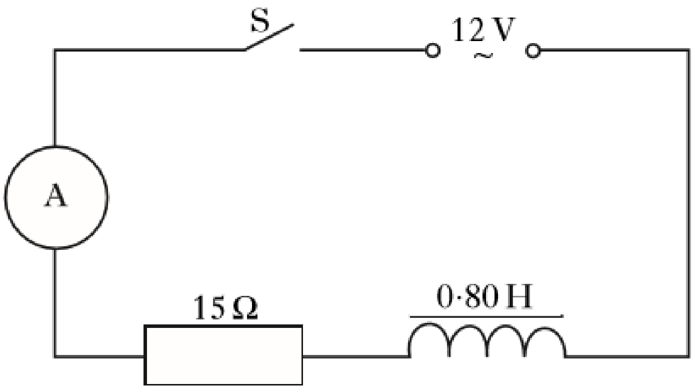


Figure 12

Sketch a graph to show how the current in the circuit varies with the frequency of the supply. Numerical values are not required. **1**

39. A student sets up an LC circuit, as shown in Figure 15A.

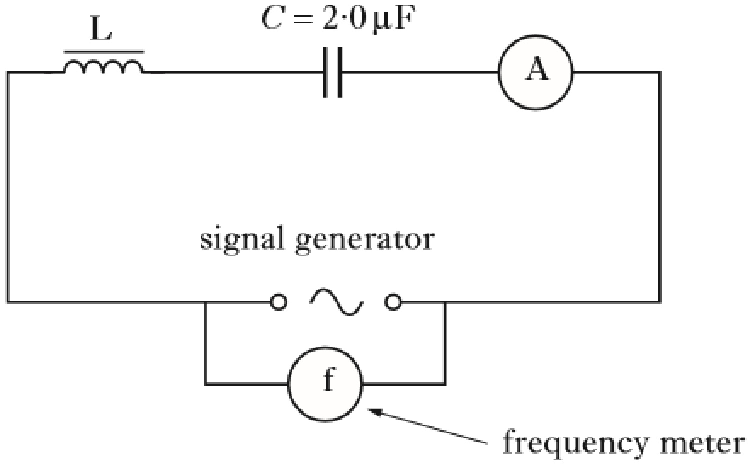


Figure 15A

Maximum current occurs at the resonant frequency f_0. Resonance occurs when the capacitive reactance equals the inductive reactance. The student varies the supply frequency and records the corresponding current. A graph of current against frequency is shown in Figure 15B.

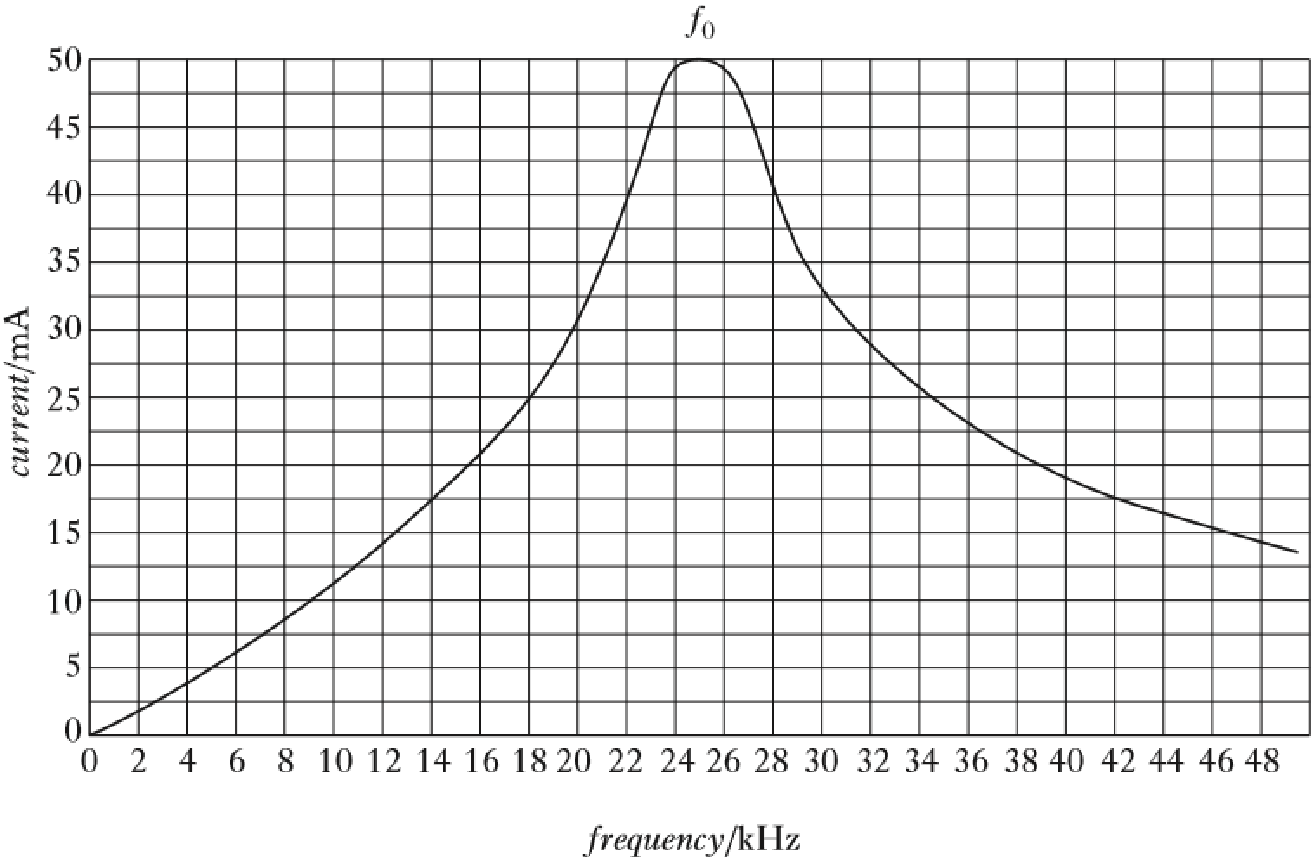


Figure 15B

P.T.O.

39. Continued

(*a*) Show that the resonant frequency f_0 is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}}.$$ **1**

(*b*) The capacitance of C is 2·0 μF. Calculate the inductance of L. **2**

(*c*) The student wants to change the design of this circuit in order to double the resonant frequency. Describe, in detail, a change the student could make to achieve this. **2**

40. (*a*) A teacher investigates the electric field between two parallel metal plates X and Y using the apparatus shown in Figure 10A.

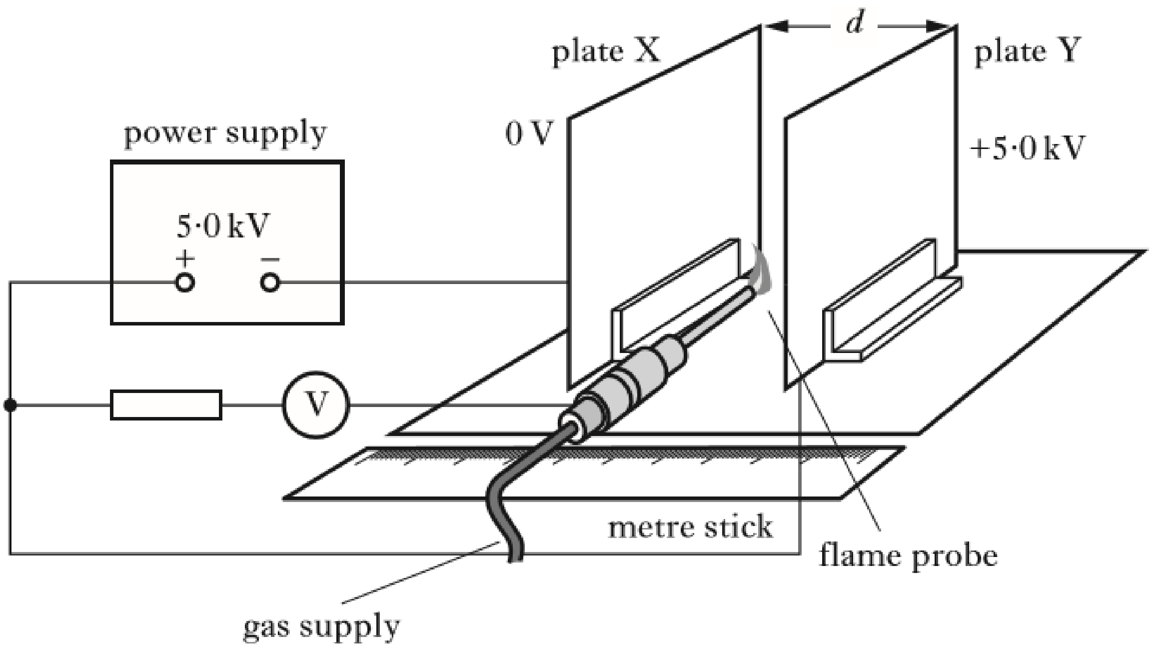


Figure 10A

The plates are connected to a 5·0 kV supply and are separated by a distance *d*.

A calibrated flame probe and voltmeter measure the potential relative to plate X. The probe is placed at different points between the plates. The distance from plate X and the potential at each point are measured.

The results are used to plot the graph shown in Figure 10B.

40. Continued

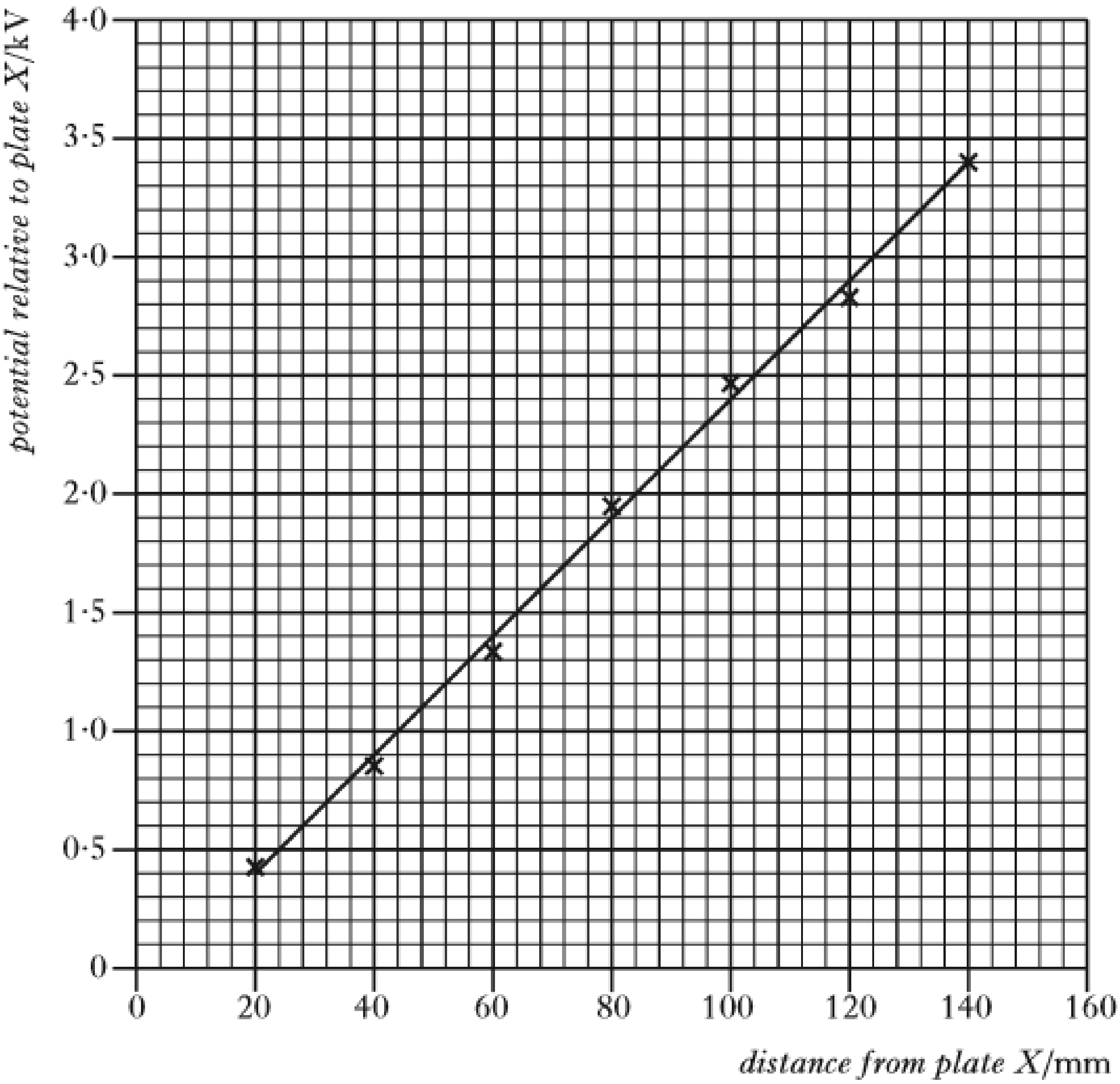


Figure 10B

(i) The electric field strength in the region between the plates is considered to be uniform. Explain the meaning of the term *uniform electric field*. **1**

(ii) Using information from the graph, determine the electric field strength between the plates. **2**

(iii) Calculate the separation *d* of the plates. **2**

(iv) In theory the best fit line for this graph should pass through the origin. Suggest why the line on the graph in Figure 10B does not pass through the origin. **1**

41. The apparatus shown in Figure 17 is set up to measure the speed of transverse waves on a stretched string.

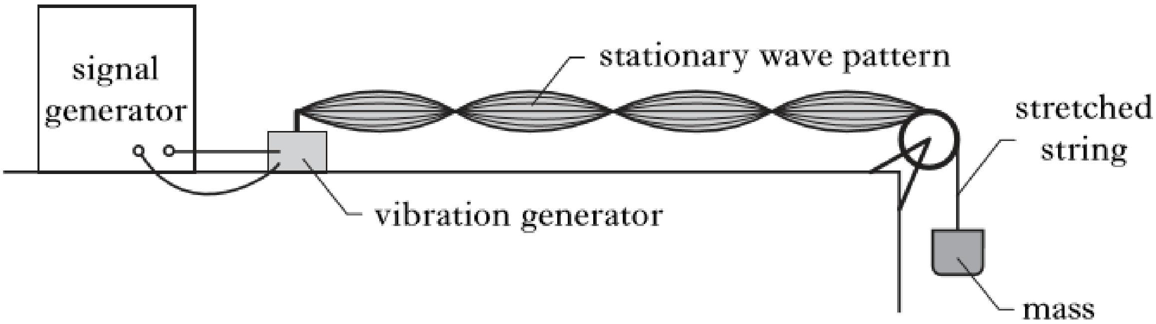


Figure 17

The following data are obtained.

Distance between adjacent nodes = (0·150 ± 0·005) m
Frequency of signal generator = (250 ± 10) Hz

(*a*) Show that the wave speed is $75\,\text{m}\,\text{s}^{-1}$. **2**

(*b*) Calculate the absolute uncertainty in this value for the wave speed. Express your answer in the form $(75 \pm \quad)\,\text{m}\,\text{s}^{-1}$. **3**

(*c*) (i) In an attempt to reduce the absolute uncertainty, the frequency of the signal generator is increased to (500 ± 10) Hz. Explain why this will **not** result in a reduced absolute uncertainty. **1**

(ii) State how the absolute uncertainty in wave speed could be reduced. **1**

42. A student carries out an experiment to determine Young's modulus for a wire. The experimental set up is shown in Figure 15.

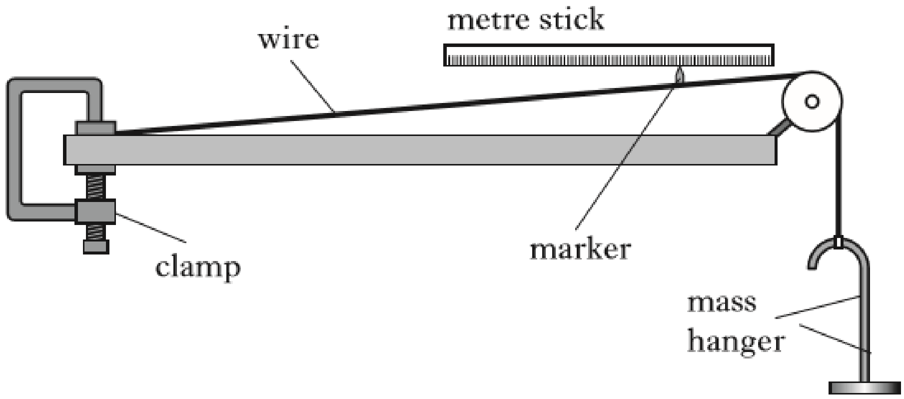


Figure 15

Young's modulus E can be determined by applying the formula

$$E = \frac{FL_o}{A_o \Delta L}.$$

Where F = force applied

L_o = distance from clamp to marker

ΔL = length of extension of wire

A_o = original cross sectional area of wire

The student attaches a mass hanger to the wire and fixes a marker on the wire at a distance of 2·00 m from the clamp. Masses are added to the hanger and the extension of the wire is measured by noting the distance moved by the marker along the metre stick. The masses are removed and the experiment repeated.

The length of the wire is measured using a tape measure.
The diameter of the wire is measured using a micrometer gauge.

42. Continued

An extract from the student's workbook is shown.

Uncertainties : Combined scale and calibration

tape measure ± 5 mm
metre stick ± 1 mm
balance ± 0·1 kg
micrometer ± 0·01 mm

Mass (kg)	*Force* (N)	*Wire extension* (mm)			E ($\times 10^9$ N m^{-2})
		1	2	Mean	
0·8	7·84	3	3	3	69
1·2	11·76	4	5	4·5	69
1·6	15·68	5	5	5	83
2·0	19·6	7	7	7	74
2·4	23·52	8	9	8·5	73

Wire diameter = 0·31 mm   Area = $7{\cdot}6 \times 10^{-8}$ N m^{-2}
Distance from clamp to marker = 2·00 m

Conclusion – The mean value of E is 74×10^9 N m^{-2}.

(*a*) Suggest **two** improvements that could be made to the experimental procedures. **2**

(*b*) Which quantity should the student measure more precisely to have the most significant impact on the percentage uncertainty?

Justify your answer. **2**

(*c*) The student realises that calculating the mean of the individual measurements of E is an inappropriate method for estimating Young's modulus of the wire and so plots a graph of F against ΔL.

Explain how the value of E can be determined from this graph. **2**