1 A satellite moves in a circular orbit of radius 15 300 km from the centre of the Earth.

(i) State one of the main benefits satellites have on our lives.

____

____ **[1]**

(ii) Calculate the gravitational field strength g at the radius of 15 300 km.

g = ______________ N kg^{-1} **[2]**

(iii) Calculate the period of the orbiting satellite.

period = ______________ s **[3]**

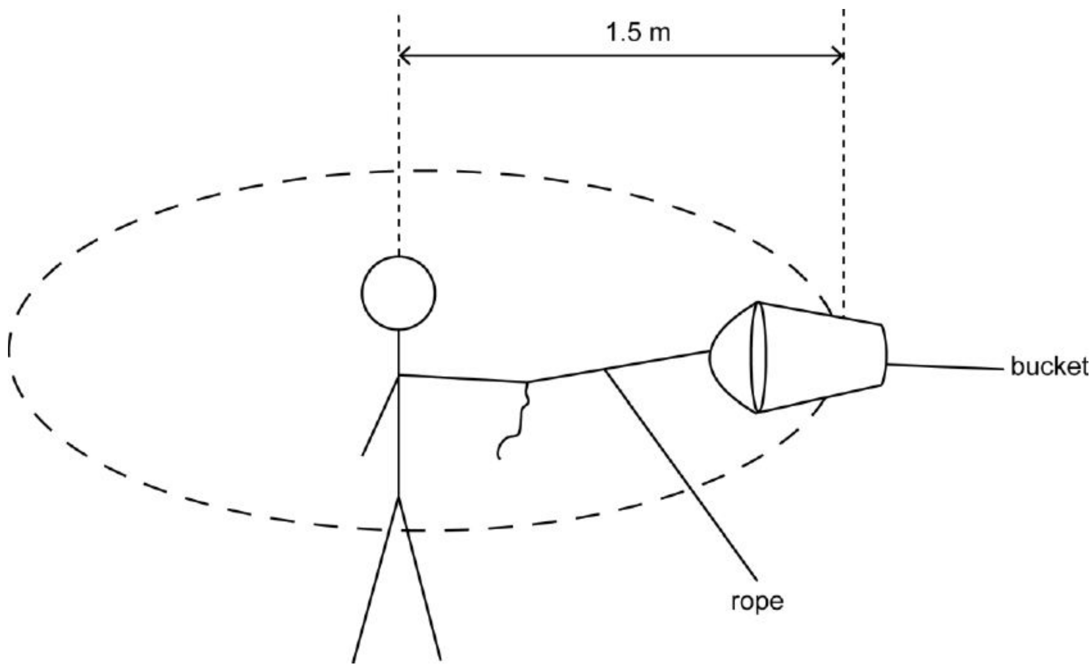
2(a) For a mass *m* moving at constant speed *v* in a circle of radius *r*, the expression for the centripetal force *F* is

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

Explain the term *centripetal force*.

-- [1]

(b) A rope is attached to a bucket. A man swings the bucket in a horizontal circle of radius 1.5 m. The bucket has a constant speed of 4.8 m s^{-1}. The mass of the bucket is 5.0 kg.



(i) Calculate the tension *F* in the rope.

F = ______________________________ N **[2]**

(ii) Calculate the angular velocity ω of the rotating bucket.

ω = ______________________________ rad s^{-1} **[2]**

(c)

* A student wishes to test the equation $F = \frac{mv^2}{r}$ for a constant force F using a whirling bung in the laboratory.

Describe with the aid of a labelled diagram how an experiment can be conducted, and how the data can be analysed to test the validity of this equation for a constant force.

-- [6]

3(a) Fig. 2.1 shows the circular path described by a helium nucleus in a region of uniform magnetic field in a vacuum.

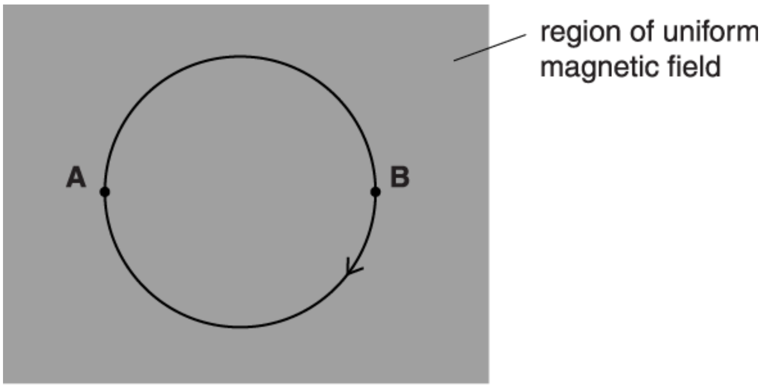


Fig. 2.1

The direction of the magnetic field is perpendicular to the plane of the paper. The magnetic flux density of the magnetic field is 0.20 mT. The radius of the circular path is 15 cm. The helium nucleus has charge + 3.2×10^{-19} C and mass 6.6×10^{-27} kg.

Explain why the helium nucleus

(i) travels in a circular path

____

____ [1]

(ii) has the same kinetic energy at **A** and **B**.

____

____

____ [1]

(b) Calculate the magnitude of the momentum of the helium nucleus.

momentum = ____________________________ kg m s^{-1} **[3]**

4 Fig. 3.1 shows a simple pendulum consisting of a steel sphere suspended by a light string from a rigid support.

The sphere is displaced 50 mm from its vertical equilibrium position and released at time $t = 0$.

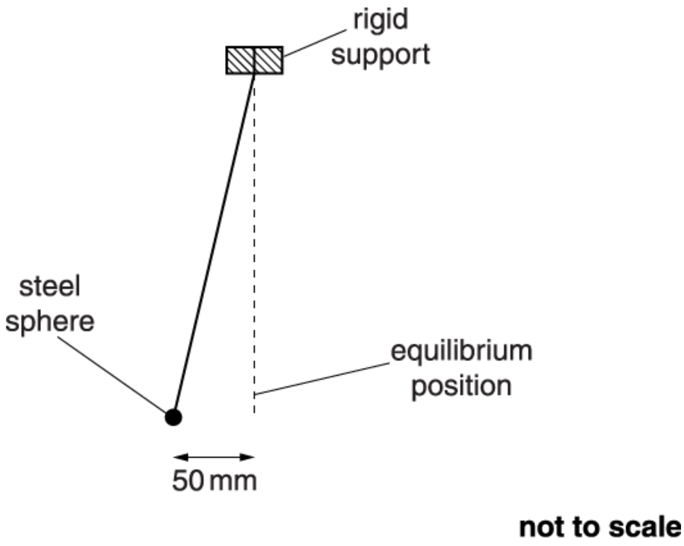


Fig. 3.1

Fig. 3.2 shows the graph of displacement x of the sphere against time t.

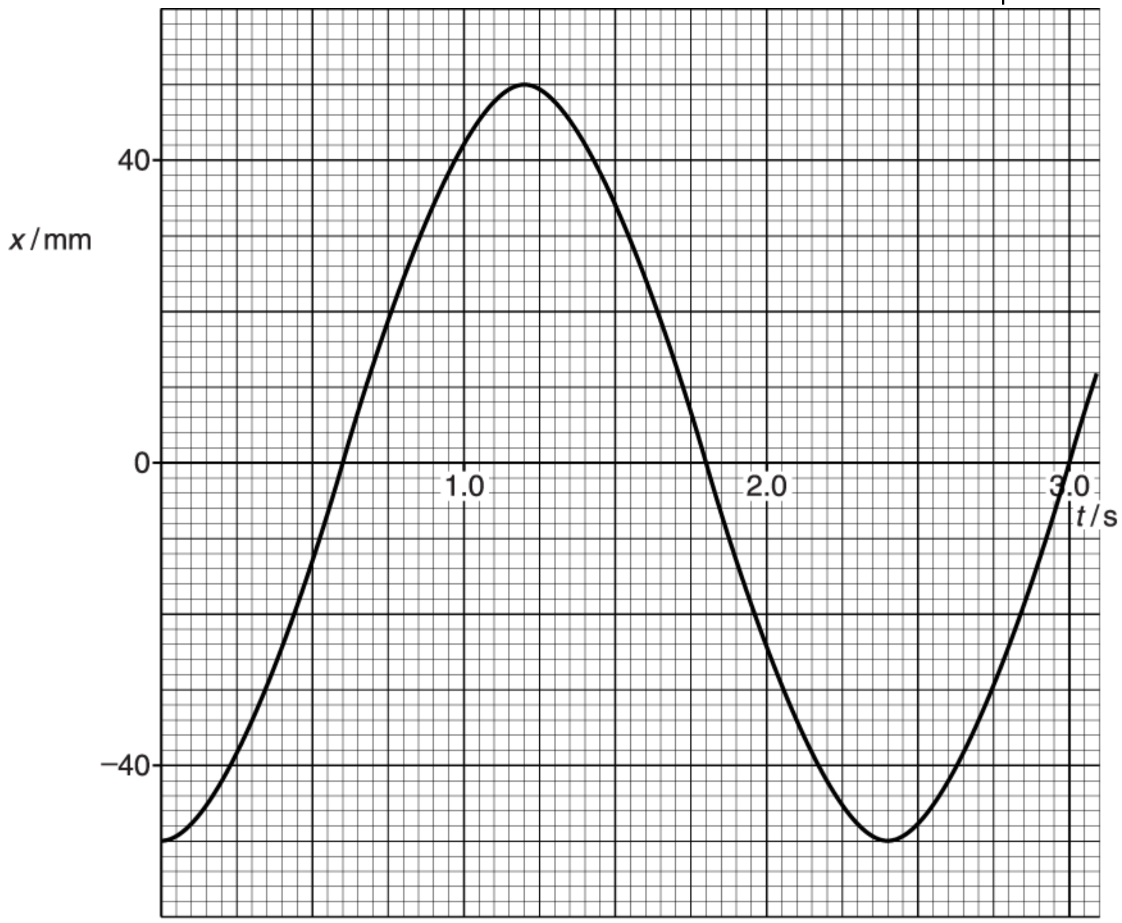


Fig. 3.2

The sphere is released from rest with a displacement x = 25 mm.
State with a reason, the change if any in

(i) the frequency of the oscillations

--- **[1]**

(ii) the maximum kinetic energy of the sphere.

----

[2]

5(a) **Fig. 22.1** shows the circular track of a positron moving in a uniform magnetic field.

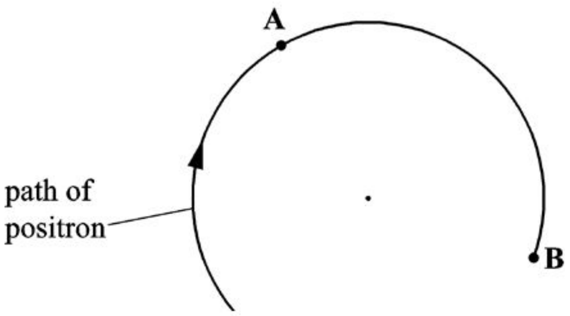


Fig. 22.1

The magnetic field is perpendicular to the plane of **Fig. 22.1**.
The speed of the positron is 5.0×10^7 m s^{-1} and the radius of the track is 0.018 m.

State the direction of the force acting on the positron when at point **A** and explain why this force does **not** change the speed of the positron.

____

____

____ [2]

(b) Calculate the magnitude of the magnetic flux density of the magnetic field.

magnetic flux density = ____________________ T [3]

6 Fluorodeoxyglucose (FDG) is a radioactive tracer often used for PET scans. It contains radioactive fluorine-18, which is a positron-emitter. Some information about FDG and fluorine-18 is given below.

- 9.9% of the mass of FDG is fluorine-18.
- The half-life of fluorine-18 is 6600 s.
- The molar mass of fluorine-18 is 0.018 kg mol^{-1}.

A patient is injected with FDG. The initial activity of FDG is 400 MBq.

Use the information given to calculate the initial mass of FDG given to the patient.

mass = ____________________ kg **[4]**

7(a) An astronomer uses a spectrometer and diffraction grating to view a hydrogen emission spectrum from a star. The light is incident normally on the grating.

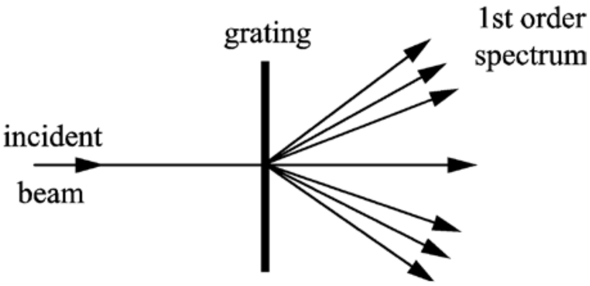


Fig. 6.1

First order diffraction maxima are observed at angles of 12.5°, 14.0° and 19.0° to the direction of the incident light as shown in **Fig. 6.1.**

Two of the wavelengths are 4.33×10^{-7} m and 4.84×10^{-7} m.

Calculate the wavelength of the third line.

wavelength = ____________________ m **[2]**

(b) In order to increase the accuracy of the values for wavelength, the student decides to look for higher order diffraction maxima.

(i) State how this increases the accuracy.

____

____ **[1]**

(ii) Calculate how many orders *n* can be observed for the shorter wavelength given in **(a)**.

n = ____________________ **[2]**

(c) These three emission lines all arise from transitions to the same final energy level. The part of the energy level diagram of hydrogen relevant to these transitions is shown in **Fig. 6.2**.

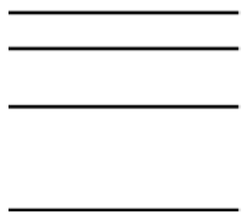


Fig. 6.2

(i) Draw lines between the energy levels to indicate the transitions which cause the three emission lines and label them with their wavelengths.

[1]

(ii) There are other possible transitions between the energy levels shown in **Fig. 6.2**. The least energetic of these produces photons of 4.8×10^{-20} J.

Calculate the wavelength of these photons.

State in which region of the electromagnetic spectrum this wavelength is found.

wavelength ____________________ m

region: ____

[3]

8(a) The International Space Station (ISS) circles the Earth at a height of 4.0×10^5 m.

Its mass is 4.2×10^5 kg.

The radius of the Earth is 6.4×10^6 m.

(i) Show that the speed of the ISS in orbit is about 8 km s^{-1}.

[3]

(ii) Calculate the total energy of the ISS.

total energy = ____________________ J **[2]**

(b) * A supply rocket, with its engines shut down, is trying to dock with the ISS. Initially it is moving in the same circular orbit above the Earth and at the same speed as the ISS. The two craft are separated by a distance of a few kilometres. The rocket is behind the ISS. It can move closer to the ISS using the following procedure.

The rocket engines are fired in reverse for a few seconds to slow the rocket down. This action causes the rocket to fall into an orbit nearer to the Earth.

After an appropriate time, the rocket engines are fired forwards for a few seconds to move the rocket back into the original orbit closer to the ISS.

Use your knowledge of gravitational forces and uniform motion in a circular orbit to explain the physics of this procedure.

[6]

9(a) Fig. 11.1 shows a diagram of Andromeda, our nearest galaxy.

Fig. 11.1

Andromeda is 2.4×10^{22} m from the Earth. It has a diameter of 1.3×10^{20} m.

All the stars in Andromeda rotate about its centre. Some stars in Andromeda are moving towards us and some are moving away from us. The outermost stars in Andromeda have a rotational speed of 2.5×10^{5} m s^{-1}.
The wavelength of the hydrogen-alpha spectral line in the laboratory is 656.3 nm. The wavelength of this spectral line from the outermost stars is Doppler shifted when observed from the Earth.
Calculate the change in wavelength of this spectral line due to this rotation.

change in wavelength = ____________________________ nm **[2]**

(b) The circular motion of the outermost stars is due to the gravitational attraction of all the stars in Andromeda. Assume that the mass of Andromeda providing the gravitational force on these outermost stars is all at the centre of this galaxy.

The average mass of a star is 2.0×10^{30} kg.

Estimate the total number of stars in Andromeda.

number of stars = ______________________________ **[4]**

10 The Earth takes 1 day to rotate once about its axis.

What is the angular velocity of a point on the surface of the Earth?

A 2.0×10^{-7} rad s^{-1}

B 7.3×10^{-5} rad s^{-1}

C 4.4×10^{-3} rad s^{-1}

D 2.6×10^{-1} rad s^{-1}

Your answer ☐

[1]

11 An object of mass m is attached to a string and then whirled in a horizontal circle. The speed of the object is slowly increased from zero. The string breaks when the object has a maximum speed of 1.00 m s^{-1}.

The experiment is repeated with an identical string but with an object of mass 1.5 m. The radius of the circle is kept constant.

What is the maximum speed of this object when the string breaks?

A 0.67 m s^{-1}

B 0.82 m s^{-1}

C 1.22 m s^{-1}

D 1.50 m s^{-1}

Your answer

[1]

12(a) Fig. 2.1 shows a jet aircraft preparing for take-off along a horizontal runway. The engine of the jet is running but the brakes are applied. The jet is not yet moving.

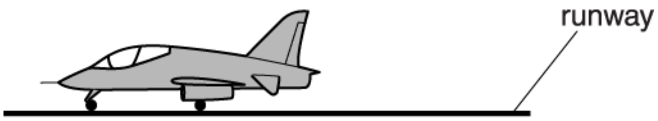


Fig. 2.1

On Fig. 2.1 draw an arrow to show each of the following forces acting on the jet:

(i) the weight of the jet (label this **W**)

(ii) the force produced by the engine (label this **T**)

(iii) the **total** force exerted by the runway on the jet (label this **F**).

[2]

(b) The brakes are released. A jet plane is taking off. The maximum force produced by the engine is 28 kN. The take-off speed of the jet is 56 m s^{-1}. The mass of the jet is 6200 kg.

(i) Calculate the minimum distance the jet travels from rest to the point where it takes off.

distance = ______________________________ m **[3]**

(ii) Explain why the runway needs to be longer than the distance calculated in **(i)**.

____

____

____

____

____ **[2]**

(c) The A jet is to be used in a flying display in which the pilot will be required to fly the jet in a **horizontal** circle of radius *r*, at a constant speed of 86 m s^{-1}. This is achieved by flying the jet with its wings at 35° to the horizontal. With the jet flying in this way, the two forces acting on the jet are the lift *L* and the weight *W*, as shown in Fig. 2.2. Air resistance has negligible effect on the motion of the jet during this manoeuvre.

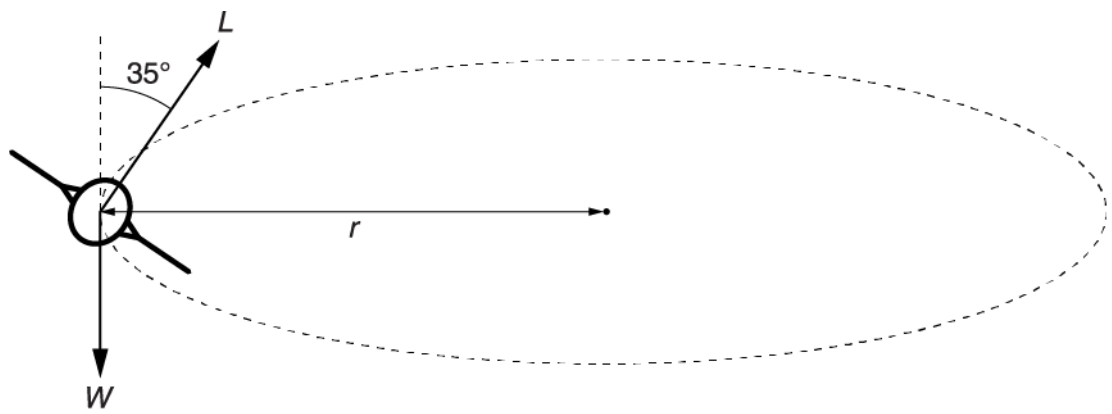


Fig. 2.2

(i) Show that the magnitude of the force *L* is about 74 kN.

____ **[1]**

(ii) Calculate the radius *r*.

radius = ______________________________ m **[3]**

(d) In a more complex manoeuvre (loop the loop), the a pilot is required to fly in a vertical circle at a constant speed as shown in Fig. 2.3.

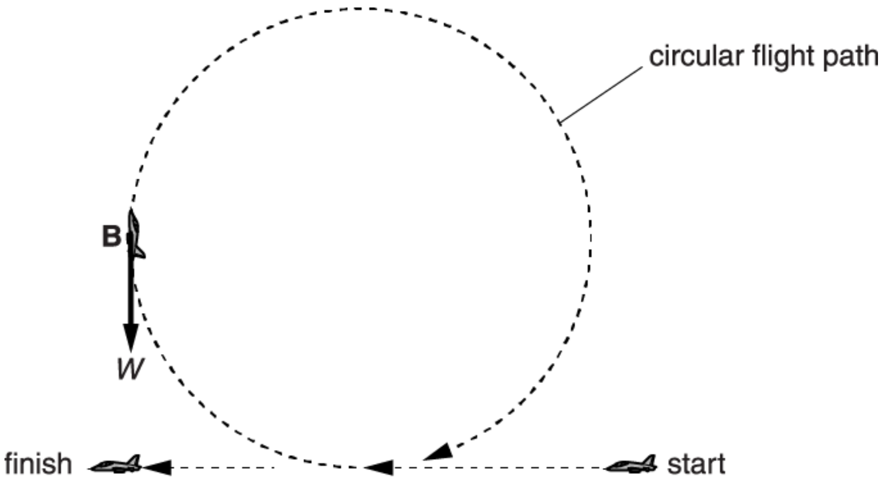


Fig. 2.3

(i) For a certain speed, the pilot can experience a sensation of weightlessness at a particular point along the circular path.

1 On Fig. 2.3, mark with a cross labelled **A**, the point where the pilot experiences the sensation of weightlessness.

[1]

2 State the magnitude of the vertical component of the contact force exerted by the seat on the pilot at **A**.

force = ____________________________ N **[1]**

(ii) In this manoeuvre it is convenient to analyse the motion of the jet in terms of two forces:

- a constant weight *W*
- a variable force *P*.

P is the resultant of the engine thrust, the lift from the wings and air resistance.

At the point **B** in Fig. 2.3 the jet is flying vertically upwards.

Explain why the force *P* is not directed towards the centre of the circular path.

[1]

13(a) This question is about the motion of a ball suspended by an elastic string above a bench. The mass of the string is negligible compared to that of the ball. Ignore air resistance.

Fig. 6.1

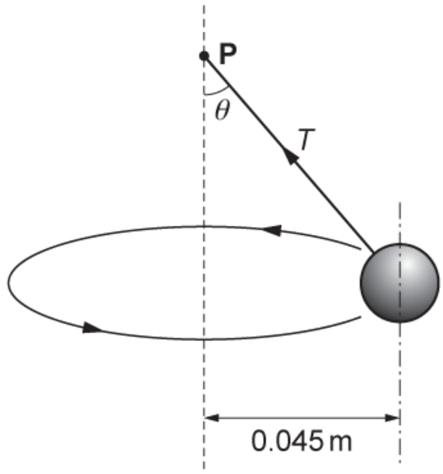


Fig. 6.2 (not to scale)

In Fig. 6.1 the ball of weight 1.2 N hangs vertically at rest from a point **P**. The extension of the string is 0.050 m. The string obeys Hooke's law.

In Fig. 6.2 the ball is moving in a horizontal circle of radius 0.045 m around a vertical axis through **P** with a period of 0.67 s. The string is at an angle θ to the vertical. The tension in the string is T.

On Fig. 6.2 draw and label one other force acting on the ball. **[1]**

(b)

(i) Resolve the tension T horizontally and vertically and show that the angle θ is 22°.

[2]

(ii) Calculate the extension x of the string shown in Fig. 6.2.

x = ____________________ m **[3]**

(c) Whilst rotating in the horizontal plane the ball suddenly becomes detached from the string. The bottom of the ball is 0.18 m above the bench at this instant. The ball falls as a projectile towards the bench beneath. Fig. 6.3 shows the view from above.

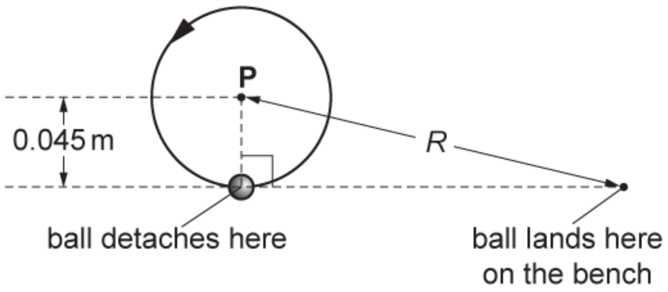


Fig. 6.3

Calculate the horizontal distance *R* from the point on the bench vertically below the point **P** to the point where the ball lands on the bench.

R = ____________________ m **[4]**

(d) Returning to the situation shown in Fig. 6.2, state and explain what happens when the rate of rotation of the ball is increased.

[2]

Phobos is one of the two moons orbiting Mars. Fig. 17.1 shows Phobos and Mars.

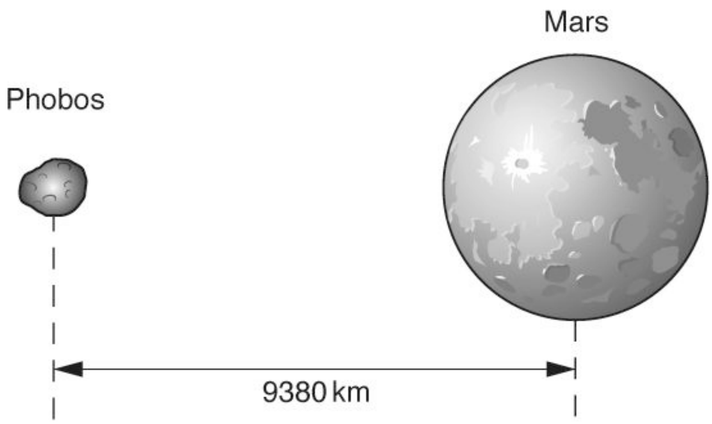


Fig. 17.1

The orbit of Phobos may be assumed to be a circle. The centre of Phobos is at a distance 9380 km from the centre of Mars and it has an orbital speed 2.14×10^3 m s^{-1}.

(i) On Fig. 17.1, draw an arrow to show the direction of the force which keeps Phobos in its orbit. **[1]**

(ii) Calculate the orbital period *T* of Phobos.

T = ____________________________________ s **[2]**

(iii) Calculate the mass *M* of Mars.

M = ____________________________________ kg **[3]**

15(a) Fig. 21 shows the drum of a washing machine.

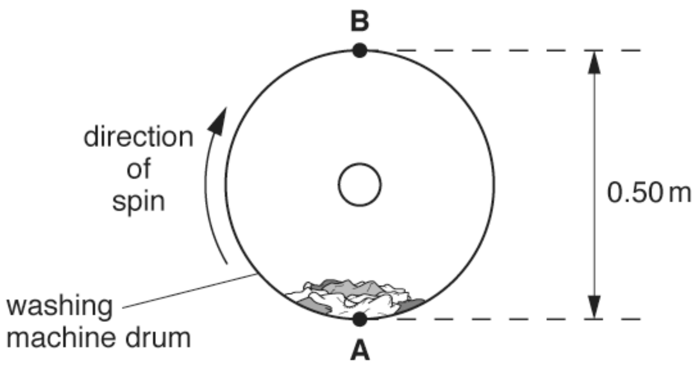


Fig. 21

The clothes inside the drum are spun in a **vertical** circular motion in a clockwise direction.

The drum has diameter 0.50 m. The manufacturer of the washing machine claims that the drum spins at 1600 ± 100 revolutions per minute.

Calculate the speed of rotation of the drum and the absolute uncertainty in this value.

speed = ... ± .... ms^{-1} **[3]**

(b) The washing machine is switched off and the speed of the drum slowly decreases. The clothes at the top of the drum at point **B** start to drop off at a certain speed *v*.

At this speed *v*, the normal contact force on the clothes is zero.

Calculate the speed *v*.

V = ... ms^{-1} **[3]**

16 A binary star is a pair of stars which move in circular orbits around their common centre of mass.

In this question consider the stars to be point masses situated at their centres.

Fig. 3.1 shows a binary star where the mass of each star is *m*. The stars move in the same circular orbit.

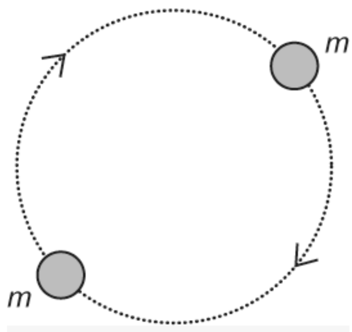


Fig. 3.1

(i) Explain why the stars of equal mass must always be diametrically opposite as they travel in the circular orbit.

____

____

____

____

____ [2]

(ii) The centres of the two stars are separated by a distance of $2R$ equal to 3.6×10^{10} m, where R is the radius of the orbit. The stars have an orbital period T of 20.5 days. The mass of each star is given by the equation

$$m = \frac{16\pi^2 R^3}{GT^2}$$

where G is the gravitational constant.

Calculate the mass m of each star in terms of the mass $M_{\odot}$ of the Sun.

1 day = 86400 s
$M_{\odot} = 2.0 \times 10^{30}$ kg

m = ... $M_{\odot}$ **[3]**

(iii) The stars are viewed from Earth in the plane of rotation.
The stars are observed using light that has wavelength of 656 nm in the laboratory. The observed light from the stars is Doppler shifted.

Calculate the maximum change in the observed wavelength $\Delta\lambda$ of this light from the orbiting stars. Give your answer in nm.

$\Delta\lambda$ = ... nm **[2]**

17 At an airport, the conveyor belt for suitcases moves at a constant speed of 1.5 m s^{-1}.

In Fig. 4.1, a suitcase of mass 8.0 kg has reached the line labelled **XX'**.

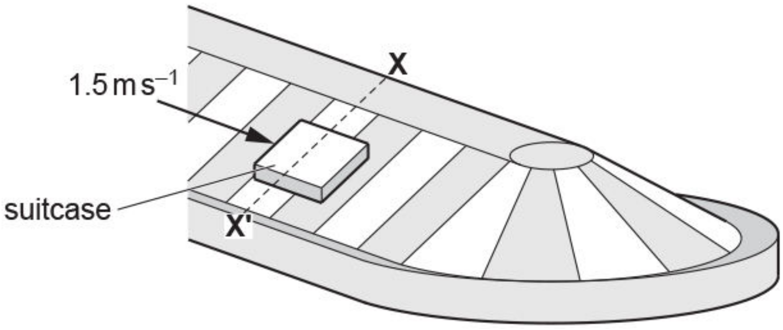


Fig. 4.1

Fig. 4.2 shows the situation in vertical cross-section. The frictional force *F* prevents the suitcase of weight *W* from sliding to the bottom of the belt.

The normal contact force on the suitcase is *R*.

The belt is inclined at an angle of 30° to the horizontal.

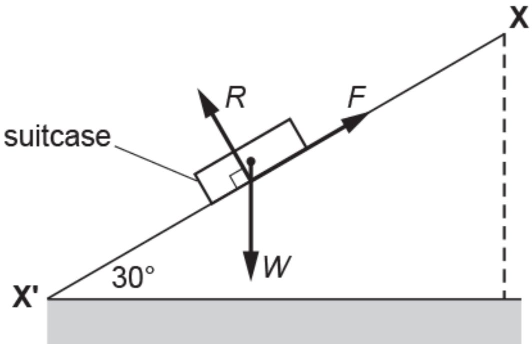


Fig. 4.2 (not to scale)

Fig. 4.3 shows the suitcase and the forces acting on it at the line labelled **YY'**.

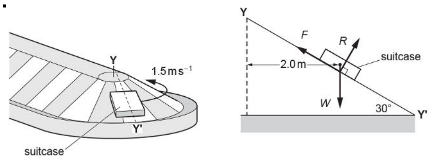


Fig. 4.3

The centre of mass of the suitcase is now moving at 1.5 m s^{-1} along a semi-circular arc of radius 2.0 m.

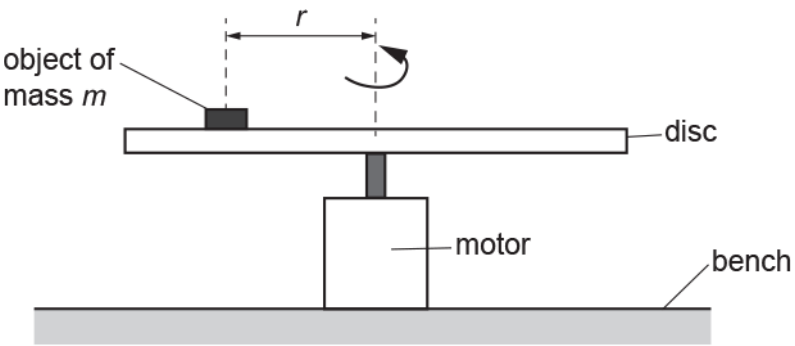
(i) Calculate the magnitude of the centripetal force acting on the suitcase.

centripetal force = ... N **[2]**

(ii) When the suitcase is at line YY', the magnitude of force *F* is larger and the magnitude of force *R* is smaller than at XX'.
Explain why this is so.

[4]

18(a) A small object of mass m is placed on a rotating horizontal metal disc at a distance r from the centre of the disc.



The frequency of rotation is adjusted using a motor attached to the disc.

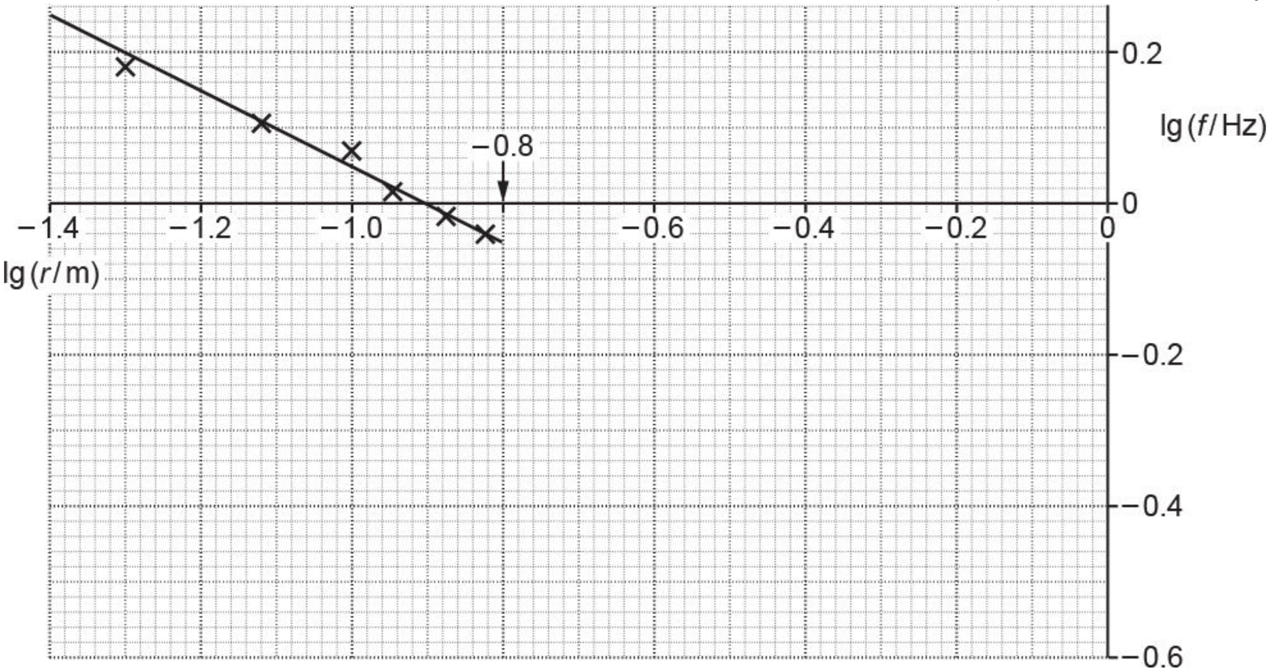
The frequency of rotation of the disc is slowly increased from zero, until the object slips off. At this point, the friction F acting on the object is equal to the centripetal force.

The friction F is given by the expression $F = kmg$, where k is a constant and g is the acceleration of free fall. The constant k has no units.

Show that the frequency f at which the object slips off is given by the equation $f^2 = \left(\frac{gk}{4\pi^2}\right) \times \frac{1}{r}$.

[3]

(b) A student plots a graph of lg (f / Hz) against lg (r / m).



For this graph: *y*-intercept $= \frac{1}{2} \times \lg\left(\frac{gk}{4\pi^2}\right)$

Use the graph to determine the constant *k*. Write your answer to 2 significant figures.

k = ... **[4]**

19(a) The International Space Station (ISS) orbits the Earth at a height of 4.1×10^5 m **above** the Earth's surface.

The radius of the Earth is 6.37×10^6 m. The gravitational field strength g_0 at the Earth's surface is 9.81 N kg^{-1}.

Both the ISS and the astronauts inside it are in free fall.

Explain why this makes the astronauts feel **weightless**.

[1]

(b)

(i) Calculate the value of the gravitational field strength g at the height of the ISS above the Earth.

g = ... N kg^{-1} **[3]**

(ii) The speed of the ISS in its orbit is 7.7 km s^{-1}. Show that the period of the ISS in its orbit is about 90 minutes.

[2]

(c) Use the information in **(b)(ii)** and the data below to show that the root mean square (r.m.s.) speed of the air molecules inside the ISS is approximately 15 times smaller than the orbital speed of the ISS.

- molar mass of air = 2.9×10^{-2} kg mol^{-1}
- temperature of air inside the ISS = 20 °C

[3]

(d) The ISS has arrays of solar cells on its wings. These solar cells charge batteries which power the ISS. The wings always face the Sun.

Use the data below and your answer to **(b)(ii)** to calculate the **average** power delivered to the batteries.

- The total area of the cells facing the solar radiation is 2500 m^2.
- 7% of the energy of the sunlight incident on the cells is stored in the batteries.
- The intensity of solar radiation at the orbit of the ISS is 1.4 kW m^{-2} outside of the Earth's shadow and zero inside it.
- The ISS passes through the Earth's shadow for 35 minutes during each orbit.

average power = ... W **[4]**

END OF QUESTION PAPER

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
1		i	Any sensible suggestion, e.g. Satellites used for global communication, instant access to news, weather forecasting etc.	B1	
		ii	$g = (6400/15300)^2 \times 9.81$	C1	
		ii	$g = 1.72$ (N kg^{-1})	A1	
		iii	Acceleration towards centre = 1.72 ms^{-2} or centripetal force = mass of satellite × 1.72 N	C1	ecf (b)(i)
		iii	$T^2 = 4 \times \pi^2 \times 1.53 \times 10^7 / 1.72$	C1	
		iii	$T = 1.87 \times 10^4$ (s)	A1	Allow 1.9
			Total	6	
2	a		(Resultant) Force acts perpendicularly to the direction of motion	B1	
	b	i	$F = 5.0 \times 4.8^2 / 1.5$	C1	
		i	$F = 77$ (N)	A1	**Allow** 76.8 (N)
		ii	$\omega = v / r = 4.8 / 1.5$	C1	**Allow** alternative e.g. $F = m \omega^2 r$
		ii	$\omega = 3.2$ (rad s^{-1})	A1	

Question			Answer/Indicative content	Marks	Guidance
	c		* Level 3 (5–6 marks) A labelled diagram including all equipment required and a detailed description of the method leading to an appropriate analysis of data. *There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.* Level 2 (3–4 marks) A labelled diagram including most of the equipment required and a description of the method leading to an appropriate graph but with some misunderstanding of the relationship. *There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.* Level 1 (1–2 marks) A diagram is included with most of the equipment required and a description of the method leading to an attempt of identifying an appropriate graph or relationship. *The information is basic and communicated in an unstructured way. The information is supported by limited evidence and the relationship to the evidence may not be clear.*	B1 × 6	Equipment / labelled diagram(E) 1 String / cord (passed through a tube) with bung at one end and load at other (accept a labelled diagram) 2 Stopwatch to measure time period 3 Suitable scale / marker to measure radius Method (M) 1 Whirl bung with constant frequency and radius (in horizontal circle) 2 Measure time for several time periods 3 Measure radius either using cord markers or stopping the cord at the tube and measuring with a ruler 4 Vary frequency and new radius Analysis (A) 1 Expect $v^2 \propto r$, or $r \propto T^{-2}$ 2 Plot graph; e.g r against T^{-2} 3 Expect straight line through origin
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
3	a	i	A (constant) force acts at right angles to the velocity / motion (of the helium nucleus).	B1	**Note** : The answer must be in terms of force and not acceleration. **Allow** 'force is towards the centre of the circle'. **Not** 'there is a *centripetal* force' - unless explained. **Not** 'force is right angles to speed'. **Examiner's Comments** Candidates answered this question well, with many making reference to either a force at right angles to the velocity of the helium nucleus or a force that was directed towards the centre of the circle.
		ii	No work done (by the force) / no acceleration in the direction of motion / no force in direction of motion	B1	**Allow** force / acceleration is at right angles to velocity / motion. **Examiner's Comments** There were some excellent answers in terms of no work done by the force acting on the helium nucleus, but equally, there were some simplistic answers such as the 'speed at A and B is the same, hence the kinetic energy remains constant'. The modal mark for this question was unexpectedly zero.
	b		$BQv = \frac{mv^2}{r}$ or $mv = BQr$ momentum = $0.20 \times 10^{-3} \times 3.2 \times 10^{-19} \times 0.15$	C1 C1	 **Allow** $v = 1.45.. \times 10^3$ (m s^{-1}); $p = 1.45.. \times 10^3 \times 6.6 \times 10^{-27}$

Question			Answer/Indicative content	Marks	Guidance
			momentum = 9.6×10^{-24} (kg m s^{-1})	A1	**Examiner's Comments** Most candidates successfully secured full marks. The analytical answers were wellstructured and easy to follow. Most candidates used first principles to show that the momentum was given by the equation $mv = BQr$. A small number of candidates determined the speed v of the helium nucleus first and then used mv to calculate the momentum. This method was a bit longer, but the final answer was still the same. A very small number of candidates were using Coulomb's law instead of $F = BQv$. Candidates are reminded that no marks will be awarded for substitution into incorrect equations.
			Total	5	
4		i	frequency is the same / not changed since (in SHM) it is independent of amplitude / (starting) displacement (AW)	B1	**Allow:** …since length of pendulum is unchanged
		ii	(maximum velocity) is reduced because amplitude / (starting) displacement is reduced (AW)	B1	**Allow:** (Max) KE is smaller since amplitude / (starting) displacement is smaller
		ii	(Max) KE is reduced to one quarter / 4 times smaller	B1	**Allow:** (Max) KE is smaller because GPE is smaller **Examiner's Comments** This was another question requiring a reason from candidates and all too often this was not given at all or was only partially stated by the observation that the periodic time had not changed.
			Total	3	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
5	a		The force is towards the centre of the circle. The force is perpendicular to the motion or no component of force in direction of motion; hence no work is done on the particle.	B1 B1	
	b		centripetal force provided by *BQv*; hence $\frac{mv^2}{r} = BQv$ $B = \frac{mv}{Qr} = \frac{9.11 \times 10^{-31} \times 5.0 \times 10^{7}}{1.6 \times 10^{-19} \times 0.018}$ $B = 1.6 \times 10^{-2}$(T)	C1 C1 A1	
			Total	**5**	
6			$\lambda = \frac{\ln 2}{6600} = 1.050 \times 10^{-4}$ (s^{-1}) $N = \frac{400 \times 10^{6}}{1.050 \times 10^{-4}} = 3.809 \times 10^{12}$ mass of FDG = $\frac{3.809 \times 10^{12}}{6.02 \times 10^{23}} \times 0.018 \div 0.099$ mass of FDG = 1.15×10^{-12} (kg) or 1.2×10^{-12} (kg)	C1 C1 C1 A1	Correct use of $A = \lambda N$
			Total	**4**	

Question			Answer/Indicative content	Marks	Guidance
7	a		λ_1 = d sin 12.5 = 4.33 × 10^{-7} m giving 1/d = 5 × 10^5 or d = 2 × 10^{-6}	C1	or λ_2 = d sin 14.0 = 4.84 × 10^{-7} (m)
			λ_3 = sin 19.0/5 × 10^5 = 6.51 × 10^{-7} (m) **or** λ_1 = d sin 12.5 = 4.33 × 10^{-7} and λ_3 = d sin 19.0 so λ_3 = 4.33 × 10^{-7} sin 19.0/sin 12.5 = 6.51 × 10^{-7} (m)	A1	or use λ_2 = d sin 14.0 = 4.84 × 10^{-7} m sin 19.0/sin 12.5 = 0.326/0.216 = 1.50
	b	i	the uncertainty in the measurement of angle is the same for all angles and the bigger the angle measured the smaller the % error	B1	
		ii	n_{max} = d sin 90	C1	
		ii	= 1/(5 × 10^5 × 4.33 × 10^{-7}) = 4.6 but n is an integer so n = 4	A1	
	c	i	3 downward arrows correctly labelled.	B1	longest being 4.33 × 10^{-7} (m)
		ii	$\Delta E = hc/\lambda$	C1	
		ii	λ = 6.63 × 10^{-34} × 3 × 10^8/ 4.8 × 10^{-20} = 4.1(4) × 10^{-6} (m)	A1	
		ii	region: infra red	B1	**allow** ecf if wavelength calculation incorrect.
			Total	9	

Question			Answer/Indicative content	Marks	Guidance
8	a	i	$F = GMm/r^2 = mv^2/r$	C1	where $r = 6.8 \times 10^6$ m
		i	$v = (GM/r)^{1/2} = (g/r)^{1/2}R$ (as $g = GM/R^2$)	C1	**N.B.** some working must be shown as a
		i	$v = 7.7$ (km s^{-1}).	A1	*show that* Q
		ii	total energy = $½mv^2 – GMm/r = –GMm/2r$	M1	**no ecf from (i); allow** numerical values
		ii	$E = –gR^2m/2r = –1.2(4) \times 10^{13}$ (J)	A1	with no algebra if clear **no mark for** correct value without the minus sign

Question			Answer/Indicative content	Marks	Guidance
	b		**Level 3 (5–6 marks)** a structured combination of at least 6 statements taken from A, B and C or A and D a combination of at least 5 statements; script of a lower quality **N.B.** bonus given for any of E at any level *The ideas are well structured providing significant clarity in the communication of the science.* **Level 2 (3–4 marks)** a good combination of at least 4 statements taken from A and B or A and C or B and C or A and D a combination of at least 3 statements taken from two sections which are relevant together. *There is partial structuring of the ideas with communication of the science generally clear.* **Level 1 (1–2 marks)** at least 2 statements from A, B, C or D which are relevant together some attempt which is related to the question *The ideas are poorly structured and impede the communication of the science.* **Level 0 (0 marks)** Insufficient or relevant science.	B1	**A initial scenario** • for circular orbit a centripetal force (of magnitude mv^2 / r) is required or AW in terms of accelerations • this is provided by the gravitational force GMm/r^2 **or** G force just pulls radially inwards sufficiently to maintain orbit • the speed in orbit $v = (GM/r)^{1/2}$ **B reverse thrust** • G force causes rocket to spiral towards Earth when rocket slowed; • rocket speeds up in process • v in orbit is larger when radius r is smaller; condition for faster lower orbit can be achieved **or** T smaller because either v is larger or r / circumference is smaller or both or $2\pi r/v$ is smaller **C forward thrust** • when rocket speeds up with engines fired forwards G force insufficient to hold orbit so spirals to larger orbit • slowing as it does so **D energy approach** • some p.e. goes to k.e. when rocket is slowed as it moves towards Earth • so v increases • vice versa when rocket is accelerated **E further comments** • extra corrections needed to obtain circular orbit after manoeuvre (not mentioned in passage) • any other relevant statement not included above

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
			Total	11	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
9	a		$(\frac{\Delta\lambda}{\lambda} = \frac{v}{c})$ $\frac{\Delta\lambda}{656.3} = \frac{2.5\times10^5}{3.0\times10^8}$ (Any subject)	C1	
			Δλ = 0.55(nm)	A1	**Note**: Answer to 3 sf is 0.547 (nm) **Note**: 5.5×10^{-10} on the answer line scores 1 mark **Examiner's Comments** This was another confidently tackled question. The Doppler equation was used well, with most answers for the change in wavelength given in nm. A very small number of candidates struggled to convert their answer of 5.5×10^{-10} m into nm.
	b				**Allow** other correct methods. **Allow** the following for the first two C1 marks: $F = \frac{2.0\times10^{30}\times(2.5\times10^5)^2}{0.65\times10^{20}}$ or 1.92×10^{21} (N) C1 $\frac{GM\times2.0\times10^{30}}{(0.65\times10^{20})^2} = 1.92\times10^{21}$ (Any subject) C1
			$\frac{GMm}{r^2} = \frac{mv^2}{r}$ or $\frac{GM}{r} = v^2$	C1	
			$\frac{GM}{0.65\times10^{20}} = (2.5 \times 10^5)^2$ (any subject)	C1	

Question			Answer/Indicative content	Marks	Guidance
			mass = 6.09×10^{40} (kg) (number of stars = $6.09 \times 10^{40}/2.0 \times 10^{30}$)	C1	**Allow**: 2 out of 3 marks for use of 1.3×10^{20} (m); this gives an answer of 1.2×10^{41} (kg)
			number of stars = 3.0×10^{10}	A1	Possible ECF from incorrect mass of galaxy **Allow** 1 SF answer for the estimation **Examiner's Comments** The modal mark for this question was four and about a third of the candidates scored nothing for their work. A range of methods were used to arrive at the correct answer of 3.0×10^{10} stars in the Andromeda galaxy. The most popular route was starting off with the expression $\frac{GMm}{r^2} = \frac{mv^2}{r}$. A significant number of candidates also successfully used the equation for Kepler's third law. On the whole, candidates demonstrated admirable analytical and calculator skills.
			Total	6	
10			A	1	
			Total	1	
11			B	1	
			Total	1	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
12	a	i	 Correct direction and labelling for W and T	B1	**Both** forces must be correct to score this mark.
		i	Straight line for F Correct direction **not** horizontal or vertical	B1	**Allow:** Freehand sketch of *F* must lie between 15° and 75° to the horizontal to score this mark.
		ii	 Correct direction and labelling for W and T	B1	**Both** forces must be correct to score this mark.
		ii	Straight line for F Correct direction **not** horizontal or vertical	B1	**Allow:** Freehand sketch of *F* must lie between 15° and 75° to the horizontal to score this mark.
		iii	 Correct direction and labelling for W and T	B1	**Both** forces must be correct to score this mark.
		iii	Straight line for F Correct direction **not** horizontal or vertical	B1	**Allow:** Freehand sketch of *F* must lie between 15° and 75° to the horizontal to score this mark. **Examiner's Comments** Most candidates gave correct directions for T and W, although there were a significant number with T towards the right. Only a minority realised that the aircraft was in equilibrium and as such F must act upwards and at an angle to the right of the horizontal.
	b	i	$a = T / m$ $a = 28 \times 10^3 / 6200$ (= 4.516)	C1	Must substitute to score this mark.
		i	$v^2 = u^2 + 2as$ $56^2 = 0 + 2 \times 4.516s$ (any subject)	C1	Answer to 3 sf = 347 (m). **Allow:** max 2 marks if v is not squared but correct formula was quoted. [Expect *s* = 6.2 (m)]

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		i	*s* = 350 (m)	A1	**Allow:** $Fs = ½ mv^2$ [C1] $28 \times 10^3\ s = ½ \times 6200 \times 56^2$ [C1] (any subject) $s = 350$ (m) [A1] **Allow:** $Ft = mv$ $t = 12.4$ (s) [C1] $s = ½\ vt = ½ \times 56 \times 12.4$ [C1] $s = 350$ (m) [A1] **Examiner's Comments** Well answered by all but a small number of candidates who, having determined the time correctly, proceeded to calculate the distance using the product of final velocity and time.
		ii	Air resistance / drag / friction acts on aircraft decreasing **either** the net forward force **or** the acceleration	M1	**Not:** 'slowing the aircraft down'.
		ii	Fs = ΔKE so reduced force must act over a longer distance to produce enough kinetic energy for take-off OR $v^2 = (u^2) + 2as$ so reduced acceleration means longer distance to reach take-off speed.	A1	**Allow** word equation. **Note:** This mark cannot be given if the previous (M1) mark has not been scored. **Examiner's Comments** Most candidates mentioned air resistance and friction but only the minority of very good candidates continued the discussion to give a mathematical reason for the increase in distance. A clear example of the need to read the question carefully.
	c	i	$L \cos 35° = 6200 \times 9.81$		**Allow:** Use of 9.8
		i	$L = \frac{6200 \times 9.81}{\cos 35°}$ OR $L = 7.42 \times 10^4$	M1	

Question			Answer/Indicative content	Marks	Guidance
		i	$L = 7.4 \times 10^4$ (N)	A0	**Note:** There is no mark for the answer as it is given in the question. Marks in 'Show' questions are for the working. **Examiner's Comments** Most candidates handled the calculation well and showed their working clearly.
		ii	$L \sin 35° = mv^2/r$	C1	
		ii	$r = \frac{6200 \times 86^2}{7.4 \times 10^4 \sin 35°}$	C1	Possible ecf from (c)(i).
		ii	r = 1100 (m)	A1	Correct answer to 3 sf = 1.08×10^3 (m). **Allow:** 1 mark for using cos 35° instead of sin 35°. Expect gives an answer of 760 (m). **Allow:** 2 marks for correct working using v = 56 (m s^{-1}) Expect an answer of r = 460 (m). No marks for using tan 35° or for omitting a trig function. **Examiner's Comments** Candidates used a range of approaches to the trigonometry required in this more searching calculation, and although most were successful, a disappointing proportion used the raw value of L from (i) rather than the horizontal component.
	d	i	Indication at 'top' of circle (by eye)	B1	
		i	0 (N)	B1	**Examiner's Comments** The vast majority of candidates showed their understanding of this aspect of motion in a vertical circle by scoring the first mark for the position of A. Many went on to score the mark for the vertical contact force, although there were a variety of incorrect answers from weaker candidates, the most common of which was the weight.

Question			Answer/Indicative content	Marks	Guidance
		ii	P is not the resultant force **OR** Resultant force must be towards centre of circle so *P* must have a component acting vertically upwards, equal in magnitude to *W* (AW)	B1	**Allow:** (Horizontal) component of *P* provides centripetal acceleration and vertical component of *P* is equal to weight. (AW) **Examiner's Comments** Only the best candidates were able to give clear, correct answers to this stretch and challenge question. There were some excellent answers including diagrams to illustrate the situation. One worrying aspect evident in many incorrect answers was the number of candidates who thought that there was no resultant force acting on the aircraft at the point B. The somewhat ambiguous phrase 'balancing forces' was frequently seen where 'zero resultant force' was more appropriate.
			Total	14	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
13	a		arrow down through centre of ball labeled weight **or** W **or** mg **or** 1.2 N	**B1**	zero if any other arrows or forces present **Examiner's Comments** There were some carelessly drawn arrows on the diagram but otherwise this was done well. There were some arrows labelled *centripetal force.*
	b	i	(horizontally) mv^2/r **(or** $mr\omega^2$) = T sin θ **and** (vertically) W **or** mg = T cos θ (tan θ = v^2/rg **or** rw^2/g) tan θ = 0.045 × 4 × 9.87 × 2.2 / 9.81 **or** 0.48 / 1.2 (= 0.40) θ = 22°	**M1** **A1** **A0**	**accept** figures in place of algebra, r = 0.045 m v = 0.42 m s^{-1} ω = 3π rad s^{-1}; $r\omega^2$ = 4.0 m s^{-2} ; W = 1.2 N and m = 0.12 kg and $mr\omega^2$ = 0.48 N **accept** labelled triangle of forces diagram **N.B.** this is a *show that Q* ; sufficient calculation must be present to indicate that the candidate has not worked back from the answer
		ii	k = (mg / x_0 = 1.2 / 0.050) = 24 (N m^{-1}) (T = mg / cos θ = kx giving) x = 1.2 / 24 cos 22 x = 0.054 (m)	**C1** **C1** **A1**	**or** solution by ratios **Examiner's Comments** About half of the candidates completed the angle calculation successfully with a slightly smaller number finding the correct extension of the string.
	c		(y = ½gt^2 =) 0.18 = 0.5 × 9.81 × t^2 giving t = 0.19 (s) (x = vt =) 0.42 × 0.19 = 0.08 (m) distance = √(r^2 + x^2) = √(0.0020 + 0.0064) = 0.092 (m)	**C1** **C1** **C1** **A1**	**alt:** projectile motion: x = vt, y = ½gt^2 y = ½g$(x / v)^2$ **ecf (b)i** for v; $x^2 = 2yv^2/g$ = 2 × 0.18 × 0.42^2/9.81 **Examiner's Comments** About half of the candidates found the time for the ball to fall to the bench. Most then managed to find the horizontal distance from the point of release, but half forgot that the point of reference in the question was the centre of rotation so failing to complete the calculation.

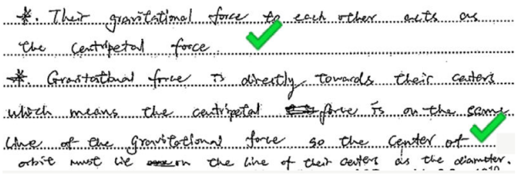
Question			Answer/Indicative content	Marks	Guidance
	d		T increases **or** string stretches **or** angle θ increases	M1	
			to provide / create a larger centripetal force	A1	**allow** mv^2/r **or** $mr\omega^2$ in place of *centripetal force* causality must be implied to gain the A mark **Examiner's Comments** About half of the candidates appreciated that the tension in the string increased or that the angle of the string to the vertical increased. Most answers gave the impression that the *centripetal force* was a *real* force rather than its provision being necessary for the ball to follow a circular path
			Total	12	

Question			Answer/Indicative content	Marks	Guidance
14		i	Horizontal arrow pointing to the right.	B1	Judgement by eye Examiner's Comments The examiners were quite lenient in this series in terms of the precise direction of the arrow, which should point towards the centre of Mars.
		ii	$2.14 \times 10^3 = \frac{2 \times \pi \times 9380 \times 10^3}{T}$ $T = 2.75 \times 10^4$ (s)	C1 A1	 **Allow** 2SF answer **Note:** $2.75\ldots \times 10^n$ scores 1 mark. Examiner's Comments Around four fifths of candidates got this right. Those that did not either poorly converted the radius from km or used the area rather than the circumference of the orbit.

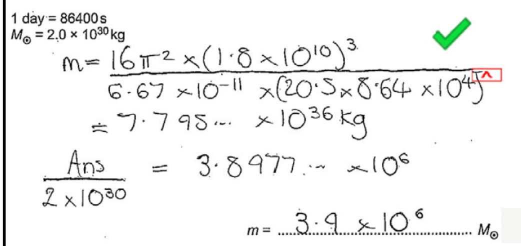
Question			Answer/Indicative content	Marks	Guidance
		iii	$\frac{GMm}{r^2} = \frac{mv^2}{r}$ or $v^2 = \frac{GM}{r}$ $(2.14 \times 10^3)^2 = 6.67 \times 10^{-11} \times M/9380 \times 10^3$ $M = 6.44 \times 10^{23}$ (kg)	C1 C1 A1	**Allow** ecf of answer for T from (a)(ii) **Allow** 2 SF answer **Note:** Use of 2.8×10^4 seconds gives 6.3×10^{23} (kg) for 3 marks. **Alternative Method for C1C1** • $M = 4\pi^2R^3/(T^2G)$ (Databook formula re–arranged with M as subject) • $M = 4\pi^2(9380 \times 10^3)^3/((2.75 \times 10^4)^2 \times 6.67 \times 10^{-11})$ (i.e. M as subject) **Note:** In alternative method, PoT error forgetting km–>m conversion gives 6.46×10^{14} (kg) for 2 marks. Examiner's Comments Many candidates successfully used the equation for Kepler's Third Law, which is encouraging. A quicker route was to find the Phobos's acceleration (from v^2/r) and equating that to the gravitational field strength at Phobos from Mars (GM_{mars}/r^2) and then rearranging to find the mass of Mars.
			Total	6	

Question			Answer/Indicative content	Marks	Guidance
15	a		$T = 60/1600$ or $T = 3.75 \times 10^{-2}$ (s) ($v = \pi \times 0.50/3.75 \times 10^{-2}$) speed = 42 (m s^{-1}) uncertainty = 3 (m s^{-1})	C1 A1 A1	**Allow:** f = 26.7 or $\frac{1600}{60}$ (Hz) or ω = 168 (s^{-1}) **Note:** *v* must be to 2 or more SF **Note:** uncertainty must be to 1 SF **Allow:** ecf on candidate's value for speed i.e. uncertainty = candidate's value / 16 (to 1 SF) **Allow for 2 marks max: 84 ± 5 (m s^{-1})** <u>Examiner's Comments</u> About half of the candidates got this item right or provided clear working to show where they were going. There was much confusion about which quantity was which. 1600 revolutions per minute refers to the frequency of the rotation, not the angular speed, angular frequency or the speed itself. The percentage error of the frequency was 6.25%, prior to rounding. Some candidates multiplied this by their value for the speed to get the correct absolute uncertainty, although good practice is to round uncertainties to 1 SF.

Question			Answer/Indicative content	Marks	Guidance
	b		$mv^2/r = mg$ or $v^2/r = g$	C1	**Allow:** $v^2/r = a$ <u>and</u> $a = g$ or $mv^2/r = ma$ <u>and</u> $a = g$ **Allow:** any subject
			$v^2 = 9.81 \times 0.25$	C1	**Allow:** any subject
			$v = 1.6$ (m s^{-1})	A1	
					Note: qualified 2.21 (ms^{-1}) scores 2 marks. <u>Examiner's Comments</u> This question was answered well by those above the mean result. When the machine is switched off, the clothes are still in circular motion and at point B, the resultant force is still the weight of the clothes plus the normal contact force. This means at the critical speed when the clothes fall off at point B, the centripetal force will equal the weight of the clothes, since the question states that the normal contact force is zero.
			Total	6	

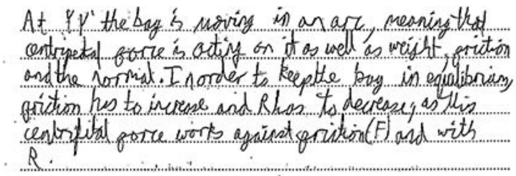
Question			Answer/Indicative content	Marks	Guidance
16		i	(For circular orbit) <u>centripetal</u> force provided by <u>gravitational</u> force (of attraction) (Gravitational / centripetal) force is along line joining stars which must therefore be diameter of circle (AW)	M1 A1	<u>**Examiner's Comments**</u> Only a minority of candidates related the gravitational force between the stars to the centripetal force required for circular motion to occur. This candidate has written the perfect answer (exemplar 5). There were two popular insufficient answers; that if the stars were not diametrically opposite they would collide and that the centre of mass of the system had to be at the centre of the orbit. **Exemplar 5**  *. Their gravitational force to each other acts as the centripetal force. *. Gravitational force is directly towards their centers which means the centripetal force is on the same line of the gravitational force so the center of orbit must be on the line of their centers as the diameter.

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
		ii	$T = 20.5 \times 86400$ ($= 1.77 \times 10^6$ s) **and** $R = 1.8 \times 10^{10}$ (m)	C1	values of T **and** R scores first mark; **both** incorrect 0/3
			$m = 16 \times \pi^2 \times (1.8 \times 10^{10})^3/G \times (20.5 \times 86400)^2$	C1	correct substitution allowing π^2 and G $m = 16 \times 9.87 \times 1.8^3 \times 10^{30}/6.67 \times 10^{-11} \times 1.8^2 \times 10^{12}$
			giving $m = 4.4 \times 10^{30}$ so $m = 2.2\ M_\odot$	A1	using 2R gives $35.2 \times 10^{30} = 17.6\ M_\odot$ or using T = 1 day gives $1850 \times 10^{30} = 930\ M_\odot$ **award** 2/3 __Examiner's Comments__ This question tested the candidates' ability to interpret and substitute data into an elaborate formula and then evaluate it. The most common error was to write the formula with the correct substitutions but then to omit the square symbol against T. Candidates should be encouraged to consider whether their answers are reasonable before moving on to the next question. In the calculation (exemplar 6) shown here, is it possible that these stars could be four million times the mass of the Sun? The correct answer of 2.2 Sun masses seems very plausible and should give candidates confidence. **Exemplar 6** 

Question			Answer/Indicative content	Marks	Guidance
		iii	$v = 2\pi R/T = 2 \times 3.14 \times 1.8 \times 10^{10} / 1.8 \times 10^{6}$ (giving v = 6.3 or 6.4 × 10^{4})	C1	**do not** penalise repeated error for R or T
			$\Delta\lambda = (v/c)\lambda = (6.3/3) \times 10^{-4} \times 656 = 0.14$ (nm)	A1	**ecf** for incorrect v, gives $\Delta\lambda = v \times 2.2 \times 10^{-6}$ $\Delta\lambda$ = 0.28 for 2R; $\Delta\lambda$ = 2.9 for 1 day and $\Delta\lambda$ = 5.7 for both incorrect <u>Examiner's Comments</u> Most of the higher performing candidates completed this problem successfully. Two common errors among the remainder were to equate the formula for central force gravitational potential energy *(GMm/r)* to kinetic energy to find a value for the speed of the stars and to rewrite incorrectly metres in powers of 10 in nanometres.
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
17		i	$F = (mv^2/r =)\ 8.0 \times 1.5^2/2.0$ $F = 9.0$ (N)	C1 A1	**Allow** answer to 1s.f. <u>Examiner's Comments</u> Question 4(b)(ii) proved very difficult and highlighted poor understanding of circular motion. Almost all candidates described the centripetal force as an additional force that had appeared out of nowhere. This centripetal force 'pulled the suitcase inwards' (or, in some cases, outwards) or 'balanced the frictional force' or 'added to the frictional force' and so on. Exemplar 5  At 'Y' the bag is moving in an arc, meaning that centripetal force is acting on it as well as weight, friction and the normal. In order to keep the bag in equilibrium friction has to increase and R has to decrease, as this centrifugal force works against friction (F) and with R. The candidate who gave the response in Exemplar 5 clearly thinks that an additional force, called the centripetal force, now acts on the suitcase. The forces F and R have to adjust in order to keep the suitcase in equilibrium. They have not realised that the suitcase is no longer in equilibrium horizontally but is accelerating. This means that the available forces have to adjust in order to provide a resultant force towards the centre of the circle, while still balancing vertically. Exemplar 6

Question			Answer/Indicative content	Marks	Guidance
					The suitcase is now accelerating towards the center of the semicircle. This means there is a net force acting to the left (on the diagram). W has no component to the left so F must increase so that there is a component to the left allowing it to accelerate allowing it to stay on course. The centripetal force required is 9N so the horizontal component of F must be 9N bigger than the horizontal component of R. The suitcase must not move down or up though so their vertical components must still add to 78.48N so F increases and R decreases. F [4] In contrast, the candidate who wrote the response in Exemplar 6 has a much better grasp of the situation. **AfL** Rather than using the phrase 'centripetal force', candidates could be encouraged to think of motion in a circle as a special case of *F = ma* where the resultant force F points towards the centre of the circle and the acceleration a is given by v^2/r. This should hopefully encourage them to think about which of the forces available in the situation could provide the resultant force for this motion to occur.

Question			Answer/Indicative content	Marks	Guidance
		ii	• Suitcase accelerates / changes its velocity / (constantly) changes direction / has a resultant force acting on it / is no longer in equilibrium • The resultant force must act (horizontally) towards centre of circle / to the left • The centripetal force can only be provided by (an increase in) *F* • Increased vertical component of *F* means the vertical component of *R* must decrease (in order to balance *W*) So *R* must decrease	B1 x 4 A0	Any answer that mentions **centrifugal** force scores 0/4 **Ignore** any statement that treats the centripetal force as an extra force **Allow** net or unbalanced or total for resultant throughout **or** $F\cos30^\circ - R\sin30^\circ$ increases (from 0 to 9.0 (N)) / the (magnitude of the) horizontal component of *F* must exceed the (magnitude of the) horizontal component of *R* **not** a resultant force acts towards **Y** e.g. Friction is the only force able to provide the centripetal force / only F has a component to the left **Allow** *F* provides the centripetal force **Not** the horizontal force must increase / increases **or** $F\sin30^\circ + R\cos30^\circ = W$ / *W* is the vector sum of *F* and *R* / $W = (F^2 + R^2)½$ (and *F* increases while *W* remains constant) Total
			Total	6	
18	a		$F = m\omega^2 r$ **and** $\omega = 2\pi f$ $kmg = m\omega^2 r$ Clear algebra leading to $f^2 = \left(\frac{gk}{4\pi^2}\right) \times \frac{1}{r}$	M1 M1 A1	**Allow** $F = mv^2/r$ **and** $v = 2\pi fr$ **Allow** this mark for $kmg = mv^2/r$
	b		*y*-intercept = – 0.45 $\frac{1}{2}\lg\left(\frac{gk}{4\pi^2}\right) = -0.45$ $\left(\frac{gk}{4\pi^2}\right) = 10^{-0.9}$ $k = \frac{0.126 \times 4 \times \pi^2}{9.81}$ *k* = 0.51	C1 C1 C1 A1	**Allow** ± 0.05 **Allow** attempt at calculating y-intercept using gradient and a point **on the line.** **Not** $e^{-0.9}$ wrong physics Allow k in range 0.48 to 0.63 **Note** Answer must be to 2 SF
			Total	7	

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
19	a		There is no contact force between the astronaut and the (floor of the) space station (so no method of measuring / experiencing weight)	B1	**Allow** astronaut and the space station have same acceleration (towards Earth) / floor is falling (beneath astronaut) <u>Examiner's Comments</u> **Misconception** Experiencing weightlessness is not the same as being in freefall There was a lack of understanding of the nature of feeling weightless. The sensation of 'weightlessness' is a lack of the physiological sensation of 'weight'. The skeletal and muscular systems are no longer in a state of stress. This sensation is caused by a lack of contact forces as a result of the ISS and the astronaut experiencing the same acceleration. Common incorrect responses included: • the astronaut is weightless because he is falling • there is no resultant force on the astronaut • gravity is too weak to have any effect on the astronaut • the ISS orbits in a vacuum where there is no gravity.

Question			Answer/Indicative content	Marks	Guidance
	b	i	$M = 5.97 \times 10^{24}$(kg) **or** ISS orbital radius $R = 6.78 \times 10^6$(m) **or** $g \propto 1/r^2$ (gr^2 = constant so) $g \times (6.78 \times 10^6)^2 = 9.81 \times (6.37 \times 10^6)^2$ g = 8.66 (N kg^{-1})	C1 C1 A1	**or** g (= GM/R^2) = $6.67 \times 10^{-11} \times 5.97 \times 10^{24} / (6.78 \times 10^6)^2$ **Allow** rounding of final answer to 2 SF i.e. 8.7 (N kg^{-1}) <u>Examiner's Comments</u> The simplest method here was to use the fact that g is inversely proportional to r^2, so gr^2 = constant. If this was not used, a value for the mass of the Sun had to be calculated, which introduced a further step. Candidates who omitted this calculation and used a memorised value of the Sun's mass instead were unable to gain full marks, because they invariably knew it to 1 s.f. only, whereas 3 were required. Errors occurred when candidates used the incorrect distance in the formula for g. Common errors included: • forgetting to square the radius • using the Earth's radius rather than the orbital radius of the satellite • calculating $(6.37 \times 10^6 + 4.1 \times 10^5)$ incorrectly.
		ii	$2\pi r / T = v$ **or** $T = 2 \times 3.14 \times 6.78 \times 10^6 / 7.7 \times 10^3$ $T = 5.5 \times 10^3$ s (= 92 min)	M1 A1	**ECF** incorrect value of R from **b(i)**

Mark Scheme

Question			Answer/Indicative content	Marks	Guidance
	c		$\frac{1}{2}Mc^2$ ($\frac{1}{2}N_A mc^2$) $= \frac{3}{2}RT$ = $c^2 = 3 \times 8.31 \times 293 / 2.9 \times 10^{-2} = 2.52 \times 10^5$ $\sqrt{c^2} = 500$ (m s^{-1}) (= 7.7 × 10^3 / 15)	C1 C1 A1 A0	or $\frac{1}{2}mc^2 = \frac{3}{2}kT$ or $c^2 = 3kT/m$ or $c^2 = 3 \times 1.38 \times 10^{-23} \times 6.02 \times 10^{23} \times 293/2.9 \times 10^{-2} = 2.52 \times 10^5$ **not** (7.7 × 10^3 / 15) = 510 (m s^{-1}) **Examiner's Comments** The success in this question depended on understanding the meaning of the term *m* in the formula $\frac{1}{2}m\overline{c^2} = \frac{3}{2}kT$ given in the Data, Formulae and Relationship booklet. A significant number of candidates took *m* to be the mass of one mole (the molar mass, *M*) whereas *m* is actually the mass of one molecule. Candidates who used the formula $\frac{1}{2}M\overline{c^2} = \frac{3}{2}RT$ were usually more successful because the molar mass had been given in the question stem.
	d		power reaching cells (= *IA*) = 1.4 × 10^3 × 2500 = 3.5 × 10^6 W power absorbed = 0.07 × 3.5 × 10^6 = 2.45 × 10^5 W cells in Sun for (92 – 35 =) 57 minutes average power = 57/92 × 2.45 × 10^5 = 1.5 × 10^5 (W)	C1 C1 C1 A1	mark given for multiplication by 0.07 at any stage of calculation (90 – 35 =) 55 minutes using *T* = 90 minutes **ECF** value of *T* from **b(ii)** 55/90 × 2.45 × 10^5 = 1.5 × 10^5 (W) using *T* = 90 minutes **Examiner's Comments** Although this question looked daunting, it was actually quite linear and many candidates who attempted it were able to gain two or three marks even if they did not eventually get to the correct response. Candidates who set out their reasoning and working clearly were more liable to gain these compensatory marks.
			Total	13	