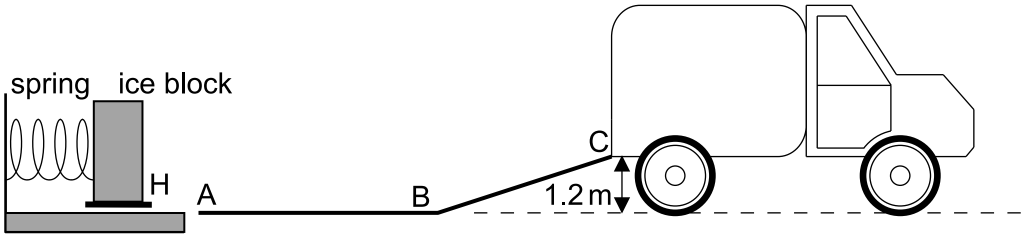
Answer **all** questions. Write your answers in the boxes provided.

1. A company designs a spring system for loading ice blocks onto a truck. The ice block is placed in a holder H in front of the spring and an electric motor compresses the spring by pushing H to the left. When the spring is released the ice block is accelerated towards a ramp ABC. When the spring is fully decompressed, the ice block loses contact with the spring at A. The mass of the ice block is 55 kg.



Assume that the surface of the ramp is frictionless and that the masses of the spring and the holder are negligible compared to the mass of the ice block.

(a) (i) The block arrives at C with a speed of $0.90\,\text{m s}^{-1}$. Show that the elastic energy stored in the spring is 670 J. [2]

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(ii) Calculate the speed of the block at A. [2]

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(This question continues on the following page)

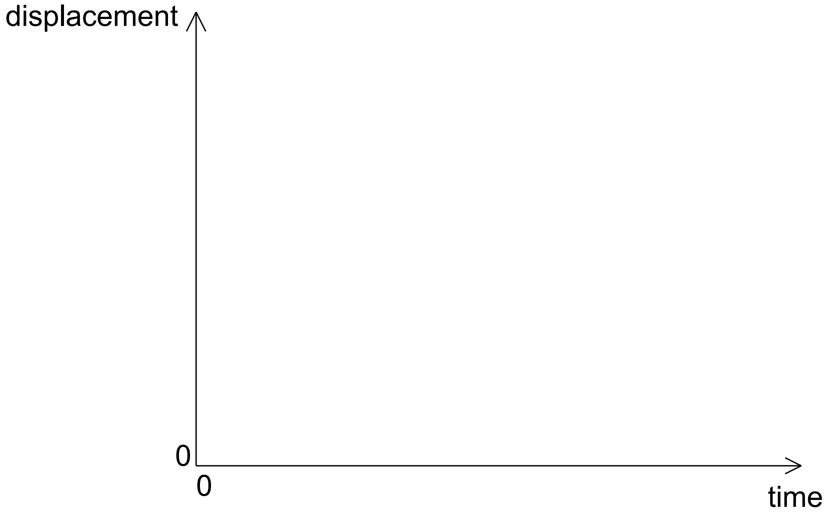
(Question 1 continued)

(b) Describe the motion of the block

(i) from A to B with reference to Newton's first law. [1]

(ii) from B to C with reference to Newton's second law. [2]

(c) On the axes, sketch a graph to show how the displacement of the block varies with time from A to C. (You do not have to put numbers on the axes.) [2]



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(Question 1 continued)

(d) The spring decompression takes 0.42 s. Determine the average force that the spring exerts on the block. [2]

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(e) The electric motor is connected to a source of potential difference 120 V and draws a current of 6.8 A. The motor takes 1.5 s to compress the spring.

Estimate the efficiency of the motor. [2]

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(f) On a particular day, the ice blocks experience a frictional force because the section of the ramp from A to B is not cleaned properly. The coefficient of dynamic friction between the ice blocks and the ramp AB is 0.030. The length of AB is 2.0 m.

Determine whether the ice blocks will be able to reach C. [2]

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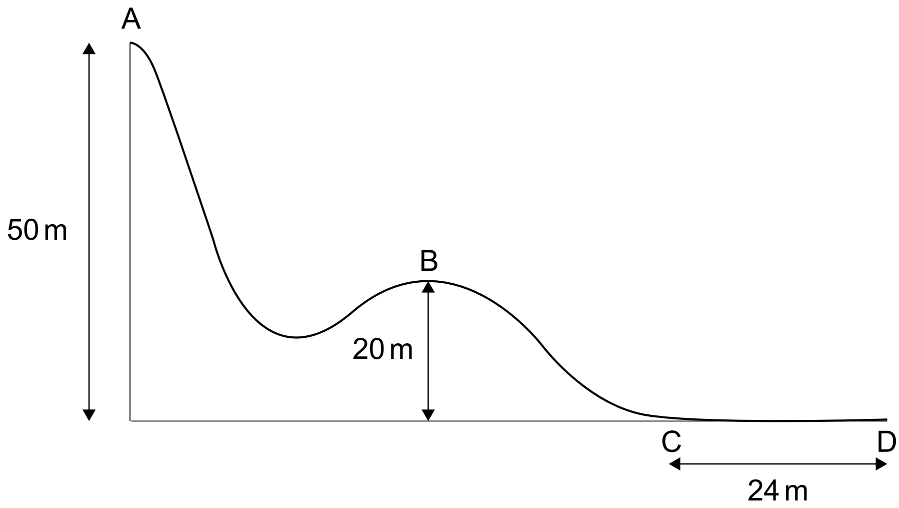
Answer **all** questions. Answers must be written within the answer boxes provided.

1. The diagram below shows part of a downhill ski course which starts at point A, 50 m above level ground. Point B is 20 m above level ground.



(a) A skier of mass 65 kg starts from rest at point A and during the ski course some of the gravitational potential energy transferred to kinetic energy.

(i) From A to B, 24 % of the gravitational potential energy transferred to kinetic energy. Show that the velocity at B is 12 m s^{-1}. [2]

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(ii) Some of the gravitational potential energy transferred into internal energy of the skis, slightly increasing their temperature. Distinguish between internal energy and temperature. [2]

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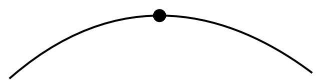
(Question 1 continued)

(b) (i) The dot on the following diagram represents the skier as she passes point B. Draw and label the vertical forces acting on the skier. [2]



(ii) The hill at point B has a circular shape with a radius of 20 m. Determine whether the skier will lose contact with the ground at point B. [3]

(c) The skier reaches point C with a speed of $8.2\,\text{m}\,\text{s}^{-1}$. She stops after a distance of 24 m at point D.

Determine the coefficient of dynamic friction between the base of the skis and the snow. Assume that the frictional force is constant and that air resistance can be neglected. [3]

(This question continues on the following page)

(Question 1 continued)

(d) At the side of the course flexible safety nets are used. Another skier of mass 76 kg falls normally into the safety net with speed $9.6\,\mathrm{m\,s^{-1}}$.

(i) Calculate the impulse required from the net to stop the skier and state an appropriate unit for your answer. [2]

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(ii) Explain, with reference to change in momentum, why a flexible safety net is less likely to harm the skier than a rigid barrier. [2]

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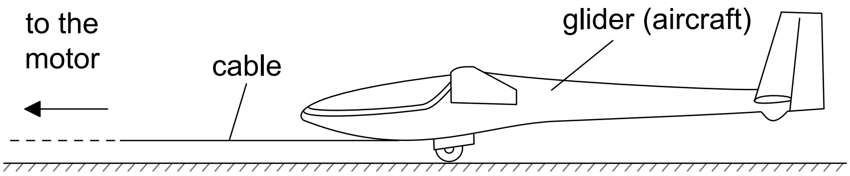
Answer **all** questions. Answers must be written within the answer boxes provided.

1. A glider is an aircraft with no engine. To be launched, a glider is uniformly accelerated from rest by a cable pulled by a motor that exerts a horizontal force on the glider throughout the launch.



(a) The glider reaches its launch speed of 27.0 m s^{-1} after accelerating for 11.0 s. Assume that the glider moves horizontally until it leaves the ground. Calculate the total distance travelled by the glider before it leaves the ground. [2]

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(b) The glider and pilot have a total mass of 492 kg. During the acceleration the glider is subject to an average resistive force of 160 N. Determine the average tension in the cable as the glider accelerates. [3]

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(Question 1 continued)

(c) The cable is pulled by an electric motor. The motor has an overall efficiency of 23 %. Determine the average power input to the motor. [3]

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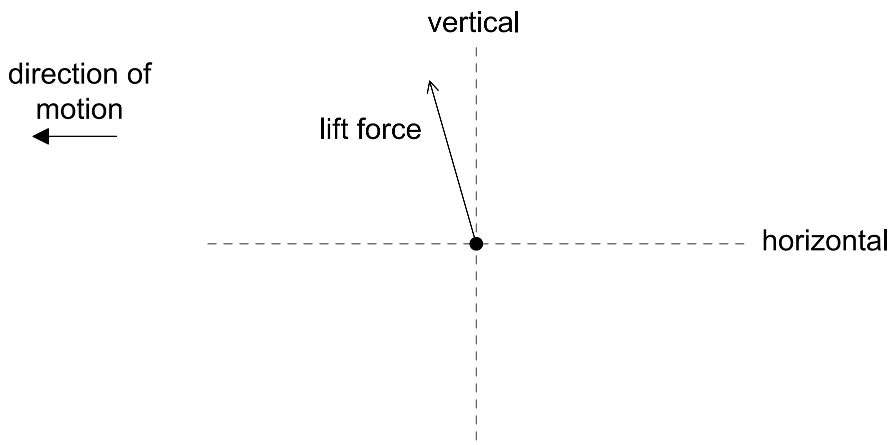
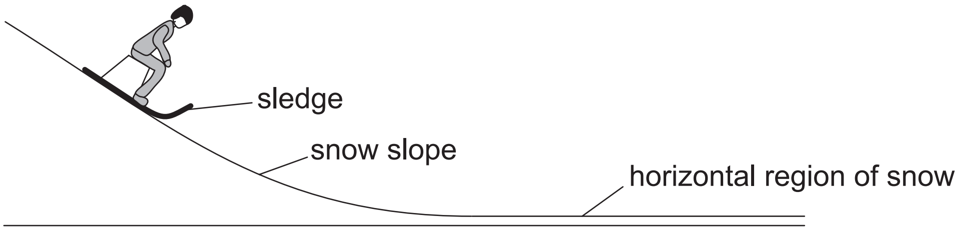
(d) After takeoff the cable is released and the unpowered glider moves horizontally at constant speed. The wings of the glider provide a lift force. The diagram shows the lift force acting on the glider and the direction of motion of the glider.



Draw the forces acting on the glider to complete the free-body diagram. The dotted lines show the horizontal and vertical directions. [2]

Answer **all** questions. Answers must be written within the answer boxes provided.

1. A girl on a sledge is moving down a snow slope at a uniform speed.



(a) Draw the free-body diagram for the sledge at the position shown on the snow slope. [2]

(b) After leaving the snow slope, the girl on the sledge moves over a horizontal region of snow. Explain, with reference to the physical origin of the forces, why the vertical forces on the girl must be in equilibrium as she moves over the horizontal region. [3]

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(Question 1 continued)

(c) When the sledge is moving on the horizontal region of the snow, the girl jumps off the sledge. The girl has no horizontal velocity after the jump. The velocity of the sledge immediately after the girl jumps off is $4.2\,\text{m}\,\text{s}^{-1}$. The mass of the girl is 55 kg and the mass of the sledge is 5.5 kg. Calculate the speed of the sledge immediately before the girl jumps from it. [2]

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(d) The girl chooses to jump so that she lands on loosely-packed snow rather than frozen ice. Outline why she chooses to land on the snow. [3]

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(Question 1 continued)

(e) The sledge, without the girl on it, now travels up a snow slope that makes an angle of 6.5° to the horizontal. At the start of the slope, the speed of the sledge is 4.2 m s^{-1}. The coefficient of dynamic friction of the sledge on the snow is 0.11.

(i) Show that the acceleration of the sledge is about -2 m s^{-2}. [3]

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(ii) Calculate the distance along the slope at which the sledge stops moving. Assume that the coefficient of dynamic friction is constant. [2]

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(f) The coefficient of static friction between the sledge and the snow is 0.14. Outline, with a calculation, the subsequent motion of the sledge. [2]

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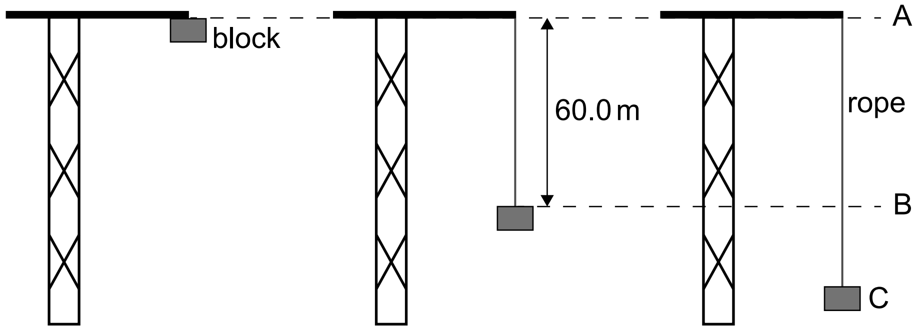
Answer **all** questions. Answers must be written within the answer boxes provided.

1. An elastic climbing rope is tested by fixing one end of the rope to the top of a crane. The other end of the rope is connected to a block which is initially at position A. The block is released from rest. The mass of the rope is negligible.

diagram not to scale



The unextended length of the rope is 60.0 m. From position A to position B, the block falls freely.

(a) At position B the rope starts to extend. Calculate the speed of the block at position B. [2]

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(b) At position C the speed of the block reaches zero. The time taken for the block to fall between B and C is 0.759 s. The mass of the block is 80.0 kg.

(i) Determine the magnitude of the average resultant force acting on the block between B and C. [2]

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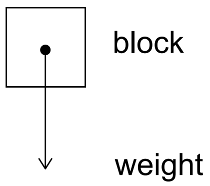
(This question continues on the following page)

(Question 1 continued)

(ii) Sketch on the diagram the average resultant force acting on the block between B and C. The arrow on the diagram represents the weight of the block. [2]



(iii) Calculate the magnitude of the average force exerted by the rope on the block between B and C. [2]

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(This question continues on the following page)

(Question 1 continued)

(c) For the rope and block, describe the energy changes that take place

(i) between A and B. [1]

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(ii) between B and C. [1]

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(d) The length reached by the rope at C is 77.4 m. Suggest how energy considerations could be used to determine the elastic constant of the rope. [2]

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(e) In another test, the block hangs in equilibrium at the end of the same elastic rope. The elastic constant of the rope is 400 $N m^{-1}$. The block is pulled 3.50 m vertically below the equilibrium position and is then released from rest.

(i) Calculate the time taken for the block to return to the equilibrium position for the first time. [2]

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(Question 1 continued)

(ii) Calculate the speed of the block as it passes the equilibrium position. [2]

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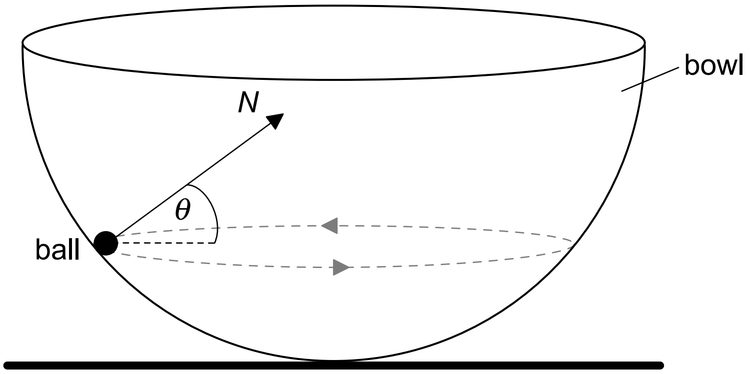
Answer **all** questions. Answers must be written within the answer boxes provided.

1. (a) A small ball of mass m is moving in a horizontal circle on the inside surface of a frictionless hemispherical bowl.



The normal reaction force N makes an angle θ to the horizontal.

(i) State the direction of the resultant force on the ball. [1]

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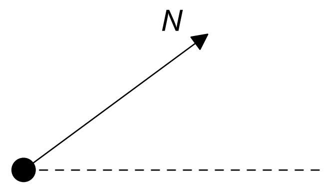
(ii) On the diagram, construct an arrow of the correct length to represent the weight of the ball. [2]



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(Question 1 continued)

(iii) Show that the magnitude of the net force F on the ball is given by the following equation. [3]

$$F = \frac{mg}{\tan\theta}$$

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(b) The radius of the bowl is 8.0 m and $\theta = 22^{\circ}$. Determine the speed of the ball. [4]

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(c) Outline whether this ball can move on a horizontal circular path of radius equal to the radius of the bowl. [2]

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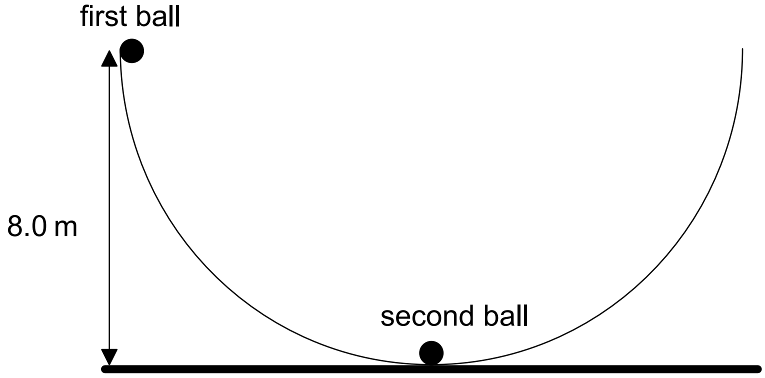
(Question 1 continued)

(e) A second identical ball is placed at the bottom of the bowl and the first ball is displaced so that its height from the horizontal is equal to 8.0 m.



The first ball is released and eventually strikes the second ball. The two balls remain in contact. Calculate, in m, the maximum height reached by the two balls. [3]

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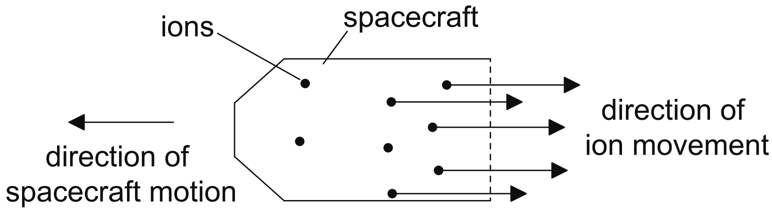
Answer **all** questions. Answers must be written within the answer boxes provided.

1. Ion-thrust engines can power spacecraft. In this type of engine, ions are created in a chamber and expelled from the spacecraft. The spacecraft is in outer space when the propulsion system is turned on. The spacecraft starts from rest.



The mass of ions ejected each second is 6.6×10^{-6} kg and the speed of each ion is $5.2 \times 10^{4}\ \text{m s}^{-1}$. The initial total mass of the spacecraft and its fuel is 740 kg. Assume that the ions travel away from the spacecraft parallel to its direction of motion.

(a) Determine the initial acceleration of the spacecraft. [2]

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(This question continues on the following page)

(Question 1 continued)

(b) An initial mass of 60 kg of fuel is in the spacecraft for a journey to a planet. Half of the fuel will be required to slow down the spacecraft before arrival at the destination planet.

(i) Estimate the maximum speed of the spacecraft. [2]

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(ii) Outline why the answer to (b)(i) is an estimate. [1]

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(iii) Outline why scientists sometimes use estimates in making calculations. [1]

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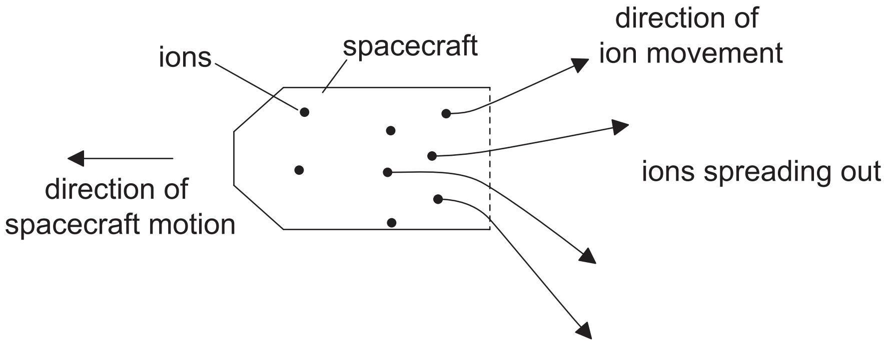
(This question continues on page 5)

(Question 1 continued from page 3)

(c) In practice, the ions leave the spacecraft at a range of angles as shown.



(i) Outline why the ions are likely to spread out. [2]

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(ii) Explain what effect, if any, this spreading of the ions has on the acceleration of the spacecraft. [2]

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3. (a) Define *impulse*. [1]

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(b) A chicken's egg of mass 58 g is dropped onto grass from a height of 1.1 m. Assume that air resistance is negligible and that the egg does not bounce or break.

(i) Show that the kinetic energy of the egg just before impact is about 0.6 J. [1]

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(ii) The egg comes to rest in a time of 55 ms. Determine the magnitude of the average decelerating force that the ground exerts on the egg. [4]

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(Question 3 continued)

(iii) Explain why the egg is likely to break when dropped onto concrete from the same height. [2]

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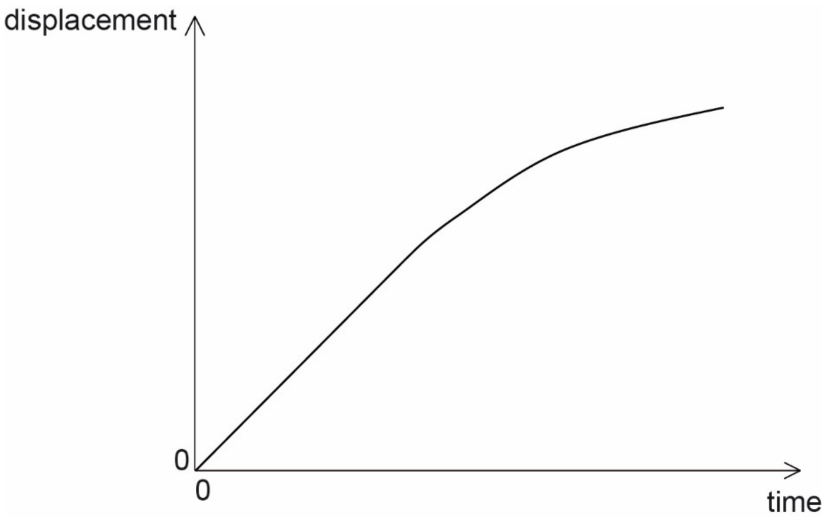
Question			Answers	Notes	Total
1	a	i	«E_{el} =» $\frac{1}{2}mv^2 + mgh$ ***OR*** «E_{el} =» $E_P + E_K$ ✓ «E_{el} =» $\frac{1}{2}\times 55\times 0.90^2 + 55\times 9.8\times 1.2$ ***OR*** 669 J ✓ «$E_{el} = 669 \approx 670$ J»	*Award **[1 max]** for use of $g = 10$ N kg $^{-1}$, gives 682 J.*	2
	a	ii	$\frac{1}{2}\times 55\times v^2 = 670$ J ✓ $v =$ «$\sqrt{\frac{2\times 670}{55}} =$» 4.9 m s^{-1} ✓	*If 682 J used, answer is 5.0 m s^{-1}.*	2
	b	i	no force/friction on the block, hence constant motion/velocity/speed ✓		1
	b	ii	force acts on block ***OR*** gravity/component of weight pulls down slope ✓ velocity/speed decreases ***OR*** it is slowing down ***OR*** it decelerates ✓	*Do not allow a bald statement of "N2" or "F = ma" for MP1.* *Treat references to energy as neutral.*	2

Question			Answers	Notes	Total
1	c		straight line through origin for at least one-third of the total length of time axis **covered by candidate line** ✓ followed by curve with decreasing positive gradient ✓ 	*Ignore any attempt to include motion before A.* *Gradient of curve must always be less than that of straight line.*	**2**
	d		$F =$ «$\frac{\Delta p}{\Delta t}$ =» $\frac{55 \times 4.9}{0.42}$ ✓ $F = 642 \approx 640$ N ✓	*Allow ECF from (a)(ii).*	**2**
	e		«energy supplied by motor =»$120 \times 6.8 \times 1.5$ ***or*** 1224 J ***OR*** «power supplied by motor =»120×6.8 ***or*** 816 W ✓ e = 0.55 ***or*** 0.547 ***or*** 55 % ***or*** 54.7 % ✓	*Allow ECF from earlier results.*	**2**

Question			Answers	Notes	Total
1	f		«energy dissipated in friction =» $0.03 \times 55 \times 9.8 \times 2.0$ «= 32.3» ✓ hence use result to show that block cannot reach C ✓ ***FOR EXAMPLE*** total energy at C is $670 - 32.3 - 646.8 = -9.1\,\text{J}$ ✓ negative value of energy means cannot reach C ✓	*Allow ECF from (a)(ii).* *Allow calculation of deceleration (a = −0.29 m s^{-2}) using coefficient of dynamic friction. Hence KE available at B = 628 J.*	**2**

2	a		two arrows each along the line connecting the planet to its star ***AND*** directed towards each star ✓ arrow lines straight and of equal length ✓	*Do not allow kinked, fuzzy curved lines.*	**2**
	b		$g =$ «$\frac{GM}{r^2} = \frac{6.67\times10^{-11}\times2.0\times10^{30}}{(6.0\times10^{11})^2}$» ***OR*** $3.7\times10^{-4}\,\text{N kg}^{-1}$ ✓ $g_{\text{net}} =$ «$2g\cos\theta = 2\times3.7\times10^{-4}\times\frac{\sqrt{6.0^2-3.4^2}}{6.0}$ =» $6.1\times10^{-4}\,\text{N kg}^{-1}$ ✓ directed vertically down «page» ***OR*** towards midpoint between two stars ***OR*** south ✓	*Allow rounding errors.*	**3**

Question			Answers	Notes	Total
1	a	i	$\frac{1}{2}v^2 = 0.24\,\mathrm{gh}$ ✓ $v = 11.9$ «$\mathrm{m\,s^{-1}}$» ✓	*Award GPE lost $= 65 \times 9.81 \times 30 =$ «$19130\,J$».* *Must see the 11.9 value for MP2, not simply 12.* *Allow g = 9.8 ms^{-2}.*	**2**
	a	ii	internal energy is the total KE «and PE» of the molecules/particles/atoms in an object ✓ temperature is a measure of the average KE of the molecules/particles/atoms ✓	*Award **[1 max]** if there is no mention of molecules/particles/atoms.*	**2**
	b	i	arrow vertically downwards from dot labelled weight/W/mg/gravitational force/F_g/$F_{gravitational}$ ***AND*** arrow vertically upwards from dot labelled reaction force/R/normal contact force/N/F_N ✓ W > R ✓	*Do not allow gravity.* *Do not award MP1 if additional 'centripetal' force arrow is added.* *Arrows must connect to dot.* *Ignore any horizontal arrow labelled friction.* *Judge by eye for MP2. Arrows do not have to be correctly labelled or connect to dot for MP2.*	**2**

Question			Answers	Notes	Total
1	b	ii	***ALTERNATIVE 1*** recognition that centripetal force is required / $\frac{mv^2}{r}$ seen ✓ = 468 «N» ✓ W/640 N (weight) is larger than the centripetal force required, so the skier does not lose contact with the ground ✓ ***ALTERNATIVE 2*** recognition that centripetal acceleration is required / $\frac{v^2}{r}$ seen ✓ a = 7.2 «m s^{-2}» ✓ *g* is larger than the centripetal acceleration required, so the skier does not lose contact with the ground ✓ ***ALTERNATIVE 3*** recognition that to lose contact with the ground centripetal force ≥ weight ✓ calculation that v ≥ 14 «ms^{-1}» ✓ comment that 12 «ms^{-1}» is less than 14 «ms^{-1}» so the skier does not lose contact with the ground ✓ ***ALTERNATIVE 4*** recognition that centripetal force is required / $\frac{mv^2}{r}$ seen ✓ calculation that reaction force = 172 «N» ✓ reaction force > 0 so the skier does not lose contact with the ground ✓	*Do not award a mark for the bald statement that the skier does not lose contact with the ground.*	**3**

Question			Answers	Notes	Total
1	c		***ALTERNATIVE 1*** $0 = 8.2^2 + 2 \times a \times 24$ therefore $a =$ «–»1.40 «m s^{-2}» ✓ friction force $= ma = 65 \times 1.4 = 91$ «N» ✓ coefficient of friction $= \frac{91}{65 \times 9.81} = 0.14$ ✓ ***ALTERNATIVE 2*** $KE = \frac{1}{2}mv^2$ = 0.5 x 65 x 8.2^2 = 2185 «J» ✓ friction force = KE/distance =2185/24 = 91«N» ✓ coefficient of friction $= \frac{91}{65 \times 9.81} = 0.14$ ✓	*Allow ECF from MP1.*	**3**
	d	i	«76×9.6» $= 730$ ✓ Ns ***OR*** kg ms^{-1} ✓		**2**
	d	ii	safety net extends stopping time ✓ $F = \frac{\Delta p}{\Delta t}$ therefore F is smaller «with safety net» ***OR*** force is proportional to rate of change of momentum therefore F is smaller «with safety net» ✓	*Accept reverse argument.*	**2**

Question			Answers	Notes	Total
1.	**a**		correct use of kinematic equation/equations ✓ 148.5 ***or*** 149 ***or*** 150 «m» ✓	*Substitution(s) must be correct.*	**2**
	b		$a=\frac{27}{11}$ ***or*** 2.45 «$m\ s^{-2}$» ✓ $F-160=492\times 2.45$ ✓ 1370 «N» ✓	*Could be seen in part (a).* *Award **[0]** for solution that uses $a=9.81\ m\ s^{-2}$*	**3**

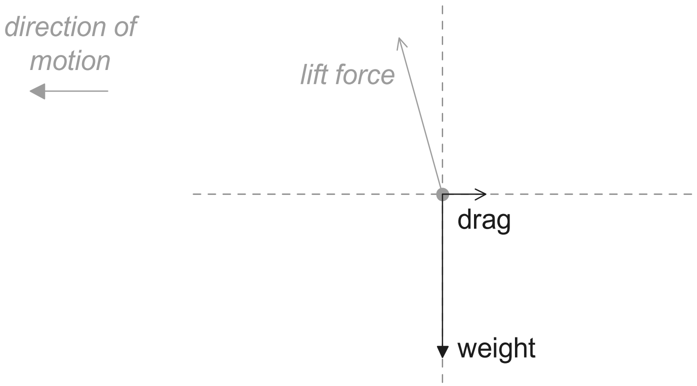
(continued…)

(Question 1 continued)

Question			Answers	Notes	Total
	c		***ALTERNATIVE 1*** «work done to launch glider» $= 1370 \times 149$ «$= 204$ kJ» ✓ «work done by motor» $= \dfrac{204 \times 100}{23}$ ✓ «power input to motor» $= \dfrac{204 \times 100}{23} \times \dfrac{1}{11} = 80$ ***or*** 80.4 ***or*** 81 k«W» ✓ ***ALTERNATIVE 2*** use of average speed 13.5 m s^{-1} ✓ «useful power output» = force × average speed «$= 1370 \times 13.5$» ✓ power input $=$ «$1370 \times 13.5 \times \dfrac{100}{23} =$» 80 ***or*** 80.4 ***or*** 81 k«W» ✓ ***ALTERNATIVE 3*** work required from motor = KE + work done against friction «$= 0.5 \times 492 \times 27^2 + (160 \times 148.5)$» $= 204$ «kJ» ✓ «energy input» $= \dfrac{\text{work required from motor} \times 100}{23}$ ✓ power input $= \dfrac{883000}{11} = 80.3$ k«W» ✓	Award ***[2 max]*** for an answer of 160 k«*W*».	**3**

(continued…)

(Question 1 continued)

Question			Answers	Notes	Total
	d		 drag correctly labelled and in correct direction ✓ weight correctly labelled and in correct direction ***AND*** no other incorrect force shown ✓	*Award **[1 max]** if forces do not touch the dot, but are otherwise OK.*	**2**

Question			Answers	Notes	Total
1.	**a**		arrow vertically downwards labelled weight «of sledge and/or girl»/*W*/mg/gravitational force/F_g/$F_{gravitational}$ ***AND*** arrow perpendicular to the snow slope labelled reaction force/*R*/normal contact force/N/F_N ✓ friction force/*F*/*f* acting up slope «perpendicular to reaction force» ✓	*Do not allow G/g/"gravity".* *Do not award MP1 if a "driving force" is included. Allow components of weight if correctly labelled. Ignore point of application or shape of object.* *Ignore "air resistance".* *Ignore any reference to "push of feet on sledge".* *Do not award MP2 for forces on sledge on horizontal ground* *The arrows should contact the object*	**2**
1.	**b**		gravitational force/weight from the Earth «downwards» ✓ reaction force from the sledge/snow/ground «upwards» ✓ no vertical acceleration/remains in contact with the ground/does not move vertically as there is no resultant vertical force ✓	*Allow naming of forces as in (a)* *Allow vertical forces are balanced/equal in magnitude/cancel out*	**3**
1.	**c**		mention of conservation of momentum ***OR*** $5.5 \times 4.2 = (55 + 5.5)$ «v» ✓ 0.38 «m s^{-1}» ✓	*Allow* $p = p'$ *or other algebraically equivalent statement* *Award **[0]** for answers based on energy*	**2**
1.	**d**		same change in momentum/impulse ✓ the time taken «to stop» would be greater «with the snow» ✓ $F = \frac{\Delta p}{\Delta t}$ therefore *F* is smaller «with the snow» ***OR*** force is proportional to rate of change of momentum therefore *F* is smaller «with the snow» ✓	*Allow reverse argument for ice*	**3**

(continued…)

(Question 1 continued)

Question			Answers	Notes	Total
1.	e	i	«friction force down slope» $= \mu mg\cos(6.5) =$ «5.9N» ✓ «component of weight down slope» $= mg\sin(6.5)$ «= 6.1N» ✓ «so $a = \frac{F}{m}$ » acceleration $= \frac{12}{5.5} = 2.2$ «m s^{-2}» ✓	*Ignore negative signs* *Allow use of $g = 10\,\text{m s}^{-2}$*	**3**
1.	e	ii	correct use of kinematics equation ✓ distance = 4.4 ***or*** 4.0 «m» ✓ ***Alternative 2*** KE lost = work done against friction + GPE ✓ distance = 4.4 ***or*** 4.0 «m» ✓	*Allow ECF from (e)(i)* *Allow **[1 max]** for GPE missing leading to 8.2 «m»*	**2**
1.	f		calculates a maximum value for the frictional force = «$\mu R =$» 7.5 «N» ✓ sledge will not move as the maximum static friction force is greater than the component of weight down the slope ✓	*Allow correct conclusion from incorrect MP1* *Allow 7.5 > 6.1 so will not move*	**2**

2.	a		«$v = \sqrt{\frac{Gm_E}{r}}$» $= \sqrt{\frac{6.67\times10^{-11}\times6.0\times10^{24}}{6600\times10^{3}}}$ ✓ 7800 «m s^{-1}» ✓	*Full substitution required* *Must see 2+ significant figures.*	**2**
2.	b	i	Y has smaller orbit/orbital speed is greater so time period is less ✓	*Allow answer from appropriate equation* *Allow converse argument for X*	**1**

(continued…)

Question			Answers	Notes	Total
1.	**a**		use of conservation of energy ***OR*** $v^2 = u^2 + 2as$ ✓ $v =$ «$\sqrt{2 \times 60.0 \times 9.81}$» $= 34.3$ «ms^{-1}» ✓		**2**
1.	**b**	**i**	use of impulse $F_{ave} \times \Delta t = \Delta p$ ***OR*** use of $F = ma$ with average acceleration ***OR*** $F = \frac{80.0 \times 34.3}{0.759}$ ✓ 3620 «N» ✓	*Allow ECF from (a).*	**2**
1.	**b**	**ii**	upwards ✓ clearly longer than weight ✓	*For second marking point allow ECF from (b)(i) providing line is upwards.*	**2**
1.	**b**	**iii**	$3620 + 80.0 \times 9.81$ ✓ 4400 «N» ✓	*Allow ECF from (b)(i).*	**2**

(continued…)

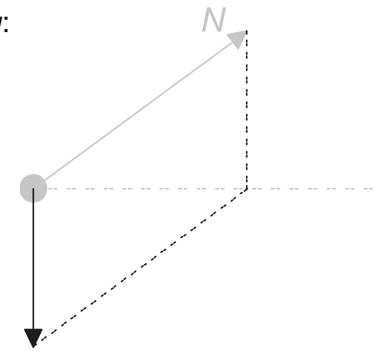
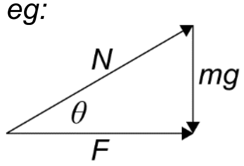
(Question 1 continued)

1.	**c**	**i**	(loss in) gravitational potential energy (of block) into kinetic energy (of block) ✓	*Must see names of energy (gravitational potential energy and kinetic energy) – Allow for reasonable variations of terminology (eg energy of motion for KE).*	**1**
1.	**c**	**ii**	(loss in) gravitational potential and kinetic energy of block into elastic potential energy of rope ✓	*See note for 1(c)(i) for naming convention.* *Must see either the block or the rope (or both) mentioned in connection with the appropriate energies.*	**1**
1.	**d**		k can be determined using $\text{EPE} = \frac{1}{2}kx^2$ ✓ correct statement or equation showing GPE at A = EPE at C ***OR*** (GPE + KE) at B = EPE at C ✓	*Candidate must clearly indicate the energy associated with either position A or B for MP2.*	**2**

(continued…)

(Question 1 continued)

1.	**e**	**i**	$T = 2\pi\sqrt{\frac{80.0}{400}} = 2.81$ «s» ✓ $\text{time} = \frac{T}{4} = 0.702$ «s» ✓	*Award **[0]** for kinematic solutions that assume a constant acceleration.*	**2**
1.	**e**	**ii**	***ALTERNATIVE 1*** $\omega = \frac{2\pi}{2.81} = 2.24$ «rad s^{-1}» ✓ $v = 2.24 \times 3.50 = 7.84$ «ms^{-1}» ✓ ***ALTERNATIVE 2*** $\frac{1}{2}kx^2 = \frac{1}{2}mv^2$ ***OR*** $\frac{1}{2}400 \times 3.5^2 = \frac{1}{2}80v^2$ ✓ $v = 7.84$ «ms^{-1}» ✓	*Award **[0]** for kinematic solutions that assume a constant acceleration.* *Allow ECF for T from (e)(i).*	**2**

Question			Answers	Notes	Total
1.	**a**	**i**	towards the centre «of the circle» / horizontally to the right ✓	*Do not accept towards the centre of the bowl*	**1**
1.	**a**	**ii**	downward vertical arrow of any length ✓ arrow of correct length ✓	*Judge the length of the vertical arrow by eye. The construction lines are not required. A label is not required* *eg*: 	**2**
1.	**a**	**iii**	***ALTERNATIVE 1*** $F = N\cos\theta$ ✓ $mg = N\sin\theta$ ✓ dividing/substituting to get result ✓ ***ALTERNATIVE 2*** right angle triangle drawn with *F*, *N* and *W/mg* labelled ✓ angle correctly labelled and arrows on forces in correct directions ✓ correct use of trigonometry leading to the required relationship ✓	*eg:*  $tan\,\theta = \frac{O}{A} = \frac{mg}{F}$ $F = \frac{mg}{tan\,\theta}$	**3**

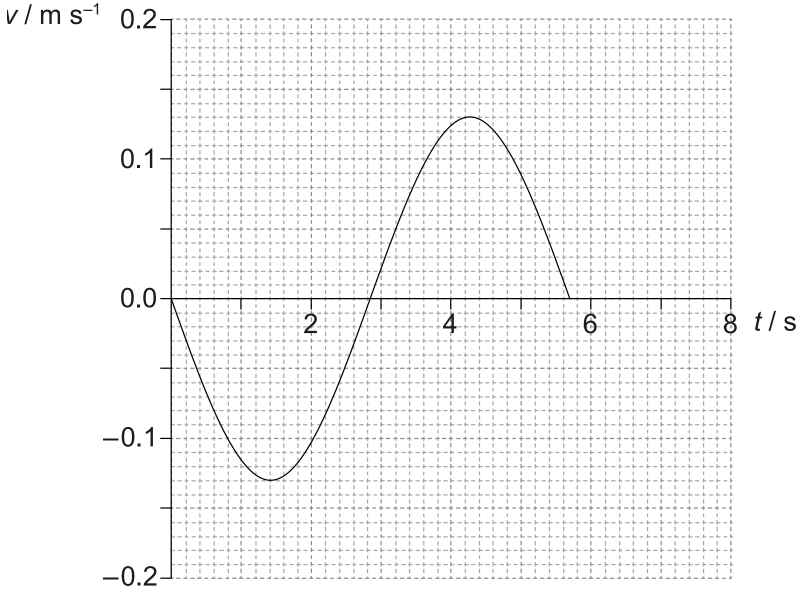
(continued…)

(Question 1 continued)

Question			Answers	Notes	Total
1.	**b**		$\frac{mg}{\tan\theta} = m\frac{v^2}{r}$ ✓ $r = R\cos\theta$ ✓ $v = \sqrt{\frac{gR\cos^2\theta}{\sin\theta}}$ / $\sqrt{\frac{gR\cos\theta}{\tan\theta}}$ / $\sqrt{\frac{9.81\times 8.0\cos 22}{\tan 22}}$ ✓ $v = 13.4 / 13$ «m s^{-1}» ✓	*Award **[4]** for a bald correct answer* *Award **[3]** for an answer of 13.9/14 «ms^{-1}». MP2 omitted*	**4**
1.	**c**		there is no force to balance the weight/N is horizontal ✓ so no / it is not possible ✓	*Must see correct justification to award MP2*	**2**

(continued…)

(Question 1 continued)

Question			Answers	Notes	Total
1.	**d**	**i**	the «restoring» force/acceleration is proportional to displacement ✓	*Direction is not required*	**1**
1.	**d**	**ii**	$\omega =$ «$\sqrt{\frac{g}{R}}$» $= \sqrt{\frac{9.81}{8.0}}$ «$= 1.107\ \text{s}^{-1}$» ✓ $T =$ «$\frac{2\pi}{\omega} = \frac{2\pi}{1.107} =$» 5.7 «s» ✓	*Allow use of* $g = 9.8$ *or* 10 *Award **[0]** for a substitution into* $T = 2\pi\sqrt{\frac{l}{g}}$	**2**
1.	**d**	**iii**	sine graph ✓ correct amplitude «$0.13\ \text{m s}^{-1}$» ✓ correct period and only 1 period shown ✓	*Accept* $\pm$ *sine for shape of the graph. Accept 5.7 s or 6.0 s for the correct period.* *Amplitude should be correct to* $\pm\frac{1}{2}$ *square for MP2* *eg*: 	**3**

(continued…)

(Question 1 continued)

Question			Answers	Notes	Total
1.	**e**		speed before collision $v =$ «$\sqrt{2gR} =$» 12.5 «$\mathrm{m\,s^{-1}}$» ✓ «from conservation of momentum» common speed after collision is $\frac{1}{2}$ initial speed «$v_c = \frac{12.5}{2} = 6.25\,\mathrm{m\,s^{-1}}$» ✓ $h =$ «$\frac{v_c^2}{2g} = \frac{6.25^2}{2\times 9.81}$» 2.0 «m» ✓	*Allow 12.5 from incorrect use of kinematics equations* *Award **[3]** for a bald correct answer* *Award **[0]** for $mg(8) = 2mgh$ leading to $h = 4m$ if done in one step.* *Allow ECF from MP1* *Allow ECF from MP2*	**3**

Question			Answers	Notes	Total
1.	a		change in momentum each second $= 6.6 \times 10^{-6} \times 5.2 \times 10^{4}$ «$= 3.4 \times 10^{-1}$ kg m s^{-1}» ✓ acceleration = «$\frac{3.4 \times 10^{-1}}{740}$ =» 4.6×10^{-4} «m s^{-2}» ✓		2
1.	b	i	***ALTERNATIVE 1*:** (considering the acceleration of the spacecraft) time for acceleration $= \frac{30}{6.6 \times 10^{-6}}$ = «4.6×10^{6}» «s» ✓ max speed = «answer to (a) $\times 4.6 \times 10^{6}$ =» 2.1×10^{3} «m s^{-1}» ✓ ***ALTERNATIVE 2*:** (considering the conservation of momentum) (momentum of 30 kg of fuel ions = change of momentum of spacecraft) $30 \times 5.2 \times 10^{4} = 710 \times$ max speed ✓ max speed = 2.2×10^{3} «m s^{-1}» ✓		2
1.	b	ii	as fuel is consumed total mass changes/decreases so acceleration changes/increases ***OR*** external forces (such as gravitational) can act on the spacecraft so acceleration isn't constant ✓		1

(continued…)

(Question 1 continued)

Question			Answers	Notes	Total
1.	**b**	**iii**	problem may be too complicated for exact treatment ✓ to make equations/calculations simpler ✓ when precision of the calculations is not important ✓ some quantities in the problem may not be known exactly ✓		**1 max**
1.	**c**	**i**	ions have same (sign of) charge ✓ ions repel each other ✓		**2**
1.	**c**	**ii**	the forces between the ions do not affect the force on the spacecraft. ✓ there is no effect on the acceleration of the spacecraft. ✓		**2**

Question			Answers	Notes	Total
3.	a		force $\times$ time ***OR*** change in momentum ✓		**1**
3.	b	i	$E_k = mgh = 0.058 \times 9.81 \times 1.1 = 0.63$ J ✓	*Allow use of g = 10 m s^{-2} (which gives 0.64 «J»)* *Substitution and at least 2 SF must be shown*	**1**
3.	b	ii	***ALTERNATIVE 1:*** initial momentum $= mv = \sqrt{2 \times 0.058 \times 0.63}$ «$= 0.27$ kg m s^{-1}» ***OR*** $mv = 0.058 \times \sqrt{2 \times 9.81 \times 1.1}$ «$= 0.27$ kg m s^{-1}» ✓ force $=$ «$\frac{\text{change in momentum}}{\text{time}} =$» $\frac{0.27}{0.055}$ ✓ 4.9 «N» ✓ $F - mg = 4.9$ so $F = 5.5$ «N» ✓ ***ALTERNATIVE 2:*** «$E_k = \frac{1}{2}mv^2 = 0.63$ J» $v = 4.7$ m s^{-1} ✓ acceleration $=$ «$\frac{\Delta v}{\Delta t} =$» $\frac{4.7}{55 x 10^{-3}} =$ «85 m s^{-2}»✓ 4.9 «N» ✓ $F - mg = 4.9$ so $F = 5.5$ «N» ✓	*Accept negative acceleration and force.*	**4**

(continued…)