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OCR A LEVEL PHYSICS A (H556): QUESTIONS BY TOPIC

Materials (3.4)

A Level Physics A (H556) · Module 3: Forces and motion

23 questions · 138 marks · Mark schemes included

OCR A Level Physics A (H556), June 2017 – June 2025

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HOW TO USE THIS BOOKLET

Questions are grouped by specification sub-topic and run from the lowest mark tariff to the highest within each one.

Click any row below to jump straight to that sub-topic or question.

On every question page, click ANSWER in the top-right corner to jump to its mark scheme.

Diagrams, graphs, tables and data are printed exactly as they appeared in the original papers.

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QUESTIONS

23 questions · 138 marks · 2 sub-topics



SUB-TOPIC 3.4.1

SPRINGS AND HOOKE'S LAW

Sub-topic 3.4.1 · 11 questions · 85 marks · lowest tariff first



11 A tensile force of 4.5 N is applied to a spring. The spring extends elastically by 3.2 cm.

What is the elastic potential energy of the spring?

A 0.072 J

B 0.14 J

C 2.4 J

D 14 J

Your answer

[1]

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Turn over



- 7 One end of a spring is fixed and a force F is applied to its other end. The elastic potential energy in the extended spring is E . The spring obeys Hooke's law.

What is the extension x of the spring?

A $x = \frac{E}{F}$

B $x = \frac{F}{E}$

C $x = \frac{2E}{F}$

D $x = \frac{F}{2E}$

Your answer

[1]

- 10 A spring is stretched by hanging on it a variable mass m . The mass m is always at rest. The spring obeys Hooke's law.

What is the relationship between the elastic potential energy E in the spring and the mass m ?

A $E \propto m^{-1}$

B $E \propto m^{-2}$

C $E \propto m$

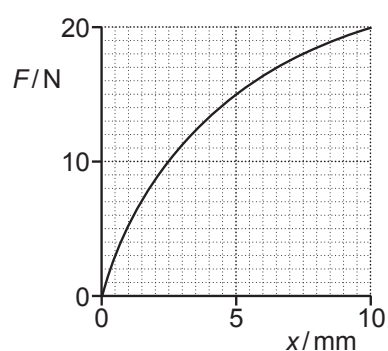
D $E \propto m^2$

Your answer

[1]



13 The force F against extension x graph for a material being stretched is shown.



What is best estimate for the energy stored in the material when the extension is 10 mm?

- A 0.07 J
- B 0.10 J
- C 0.13 J
- D 0.20 J

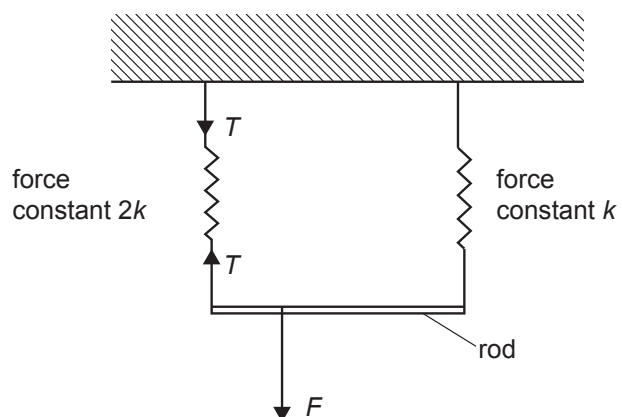
Your answer

[1]

- 4 A light rod is hung from a horizontal ceiling using 2 springs, one attached to each end. The springs have force constants k and $2k$.

A downwards force F is applied closer to one end of the rod such that the rod is horizontal.

What is the tension T in the spring with the force constant $2k$?

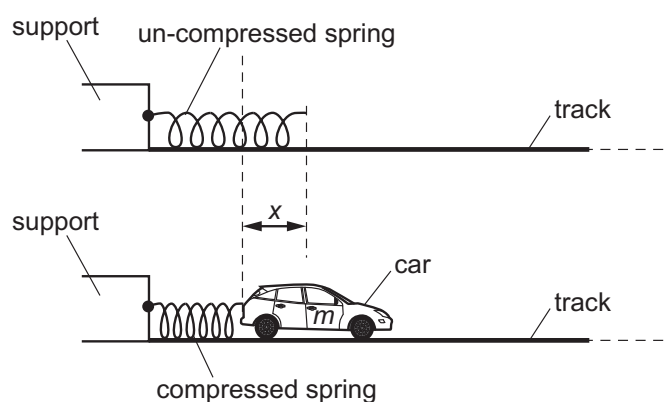


- A $\frac{F}{3}$
B $\frac{F}{2}$
C $\frac{2F}{3}$
D F

Your answer

[1]

- 21 (a) One end of a spring is fixed to a support. A toy car, which is on a smooth horizontal track, is pushed against the free end of the spring. The spring compresses. The car is then released. The car accelerates to the right until the spring returns back to its original length.



The car moves with **simple harmonic motion** as the spring returns to its original length.

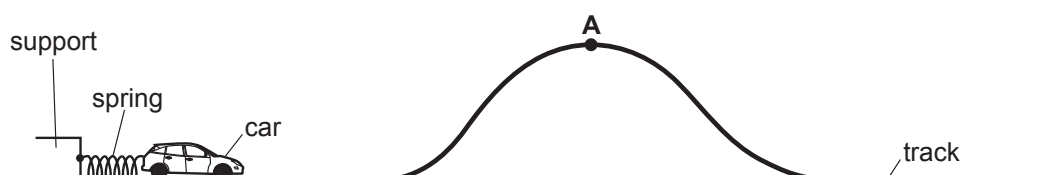
The acceleration of the car is given by the expression $a = -\left(\frac{k}{m}\right)x$, where m is the mass of the car, k is the force constant of the spring and x is the compression of the spring.

Use the data below to calculate the time t it takes for the spring to return to its original length after the car is released.

- mass of car $m = 80 \text{ g}$
- force constant k of the spring $= 60 \text{ N m}^{-1}$.

$t = \dots\dots\dots \text{ s}$ [4]

- (b) The arrangement in (a) is used to propel the toy car along a smooth track.



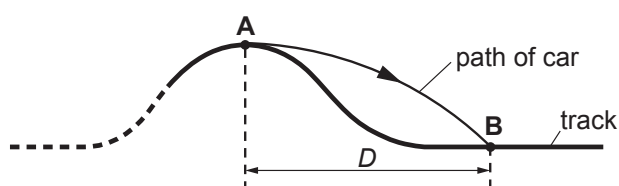
- (i) Point **A** is at the top of the track.
The launch speed of the car is now adjusted until the car just reaches **A** with zero speed.
The height of **A** is 0.20 m above the horizontal section of the track.

All the elastic potential energy of the spring is transferred to gravitational potential energy of the car.

Calculate the initial compression x of the spring.

$x = \dots\dots\dots$ m [3]

- (ii) At a specific speed, the car leaves point **A** horizontally and lands on the track at point **B**.
The horizontal distance between **A** and **B** is D .



Air resistance has negligible effect on the motion of the car between **A** and **B**.

- 1 Explain how the time of flight between **A** and **B** depends on the speed of the car at **A**.

.....

 [2]

- 2 Explain how the distance D depends on the speed of the car at **A**.

.....

 [2]

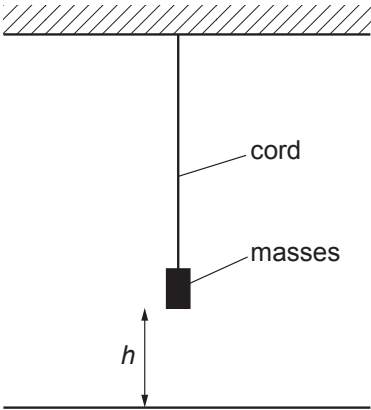
18 Mats made from rubber are often used in laboratories where heavy objects might be dropped.

A rubber cord is tested to determine the material's mechanical characteristics.

(a) The cord is suspended from a ceiling and masses can be attached to the free end.

The apparatus is set up as shown in Fig. 18.1.

Fig. 18.1

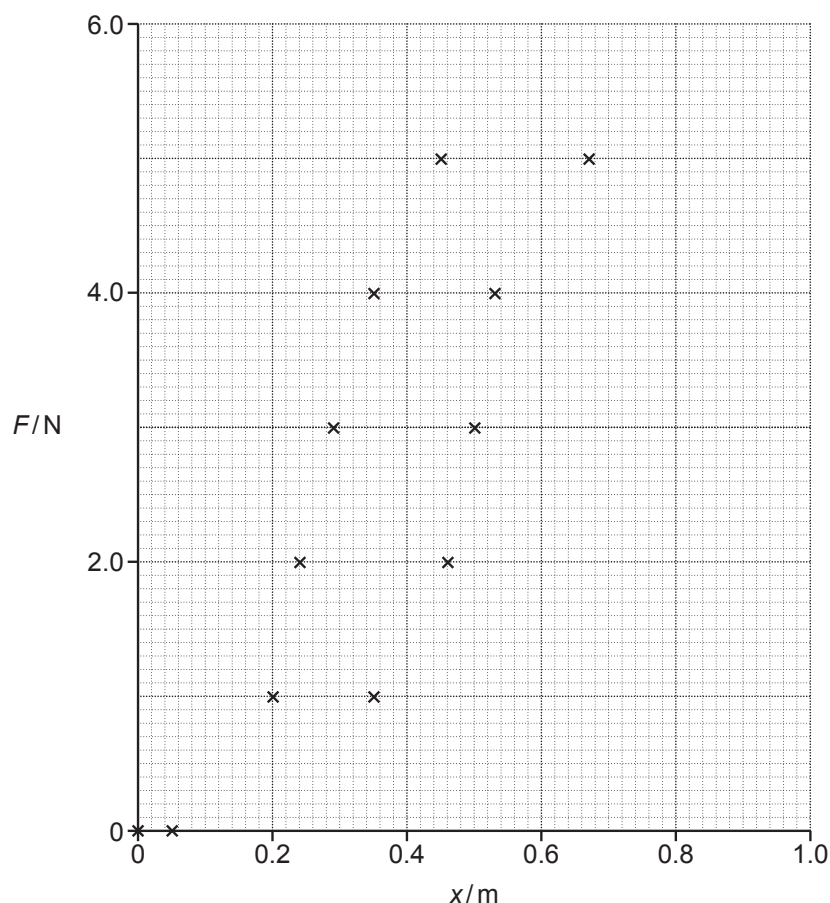


Masses are added and the height, h , of the base of the bottom mass from the floor is measured. The extension of the cord is x when the tension in the cord is F . After six masses have been added, they are removed one at a time and h measured each time.

The table shows the data collected.

F/N	h/m	x/m
0.0	1.80	0.00
1.0	1.60	0.20
2.0	1.56	0.24
3.0	1.51	0.29
4.0	1.45	0.35
5.0	1.35	0.45
6.0	0.81	
5.0	1.13	0.67
4.0	1.37	0.53
3.0	1.30	0.50
2.0	1.34	0.46
1.0	1.45	0.35
0.0	1.75	0.05

(i) Complete the final column of the table. [1]



(ii) Plot the data point for $F = 6.0\text{ N}$ on the graph above. The other points have been plotted.

Draw and label **two** curves to show the loading and unloading of the cord.

[3]

(iii) Discuss whether Hooke's law can be applied to the cord.

.....

..... [2]

(iv) There is an area between the two curves that you have drawn on the graph.

1. State the **name** of the derived SI unit of this area.

..... [1]

2. Explain the significance of this area to the planned use of the rubber.

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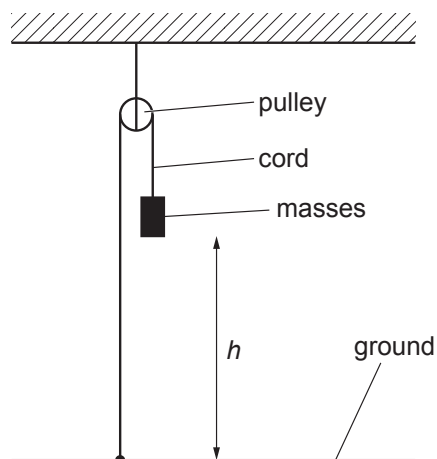
.....

..... [2]

(b) An alternative arrangement for the experiment is to use a pulley as shown in **Fig. 18.2**.

The arrangement makes it possible to cover a larger range of extensions.

Fig. 18.2



The cord is fixed to the ground.

Describe **two** factors that would affect the accuracy of the results obtained using this alternative arrangement.

- 1
- 2

[2]

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- 6 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

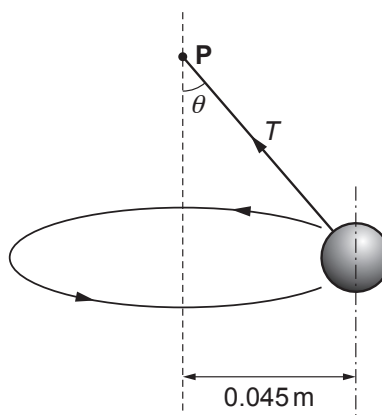


Fig. 6.2 (not to scale)

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 .

- (a) 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. [3]

$x = \dots\dots\dots\text{ m}$ [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.

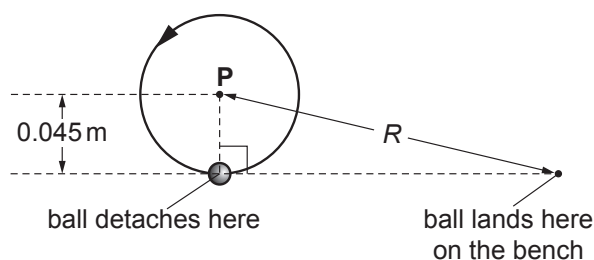


Fig. 6.3

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.

$R = \dots\dots\dots$ 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]

- 16 (a) Describe how an experiment can be carried out to determine the force constant of an elastic cord in the laboratory by plotting a suitable graph. You may assume that the cord obeys Hooke's law.

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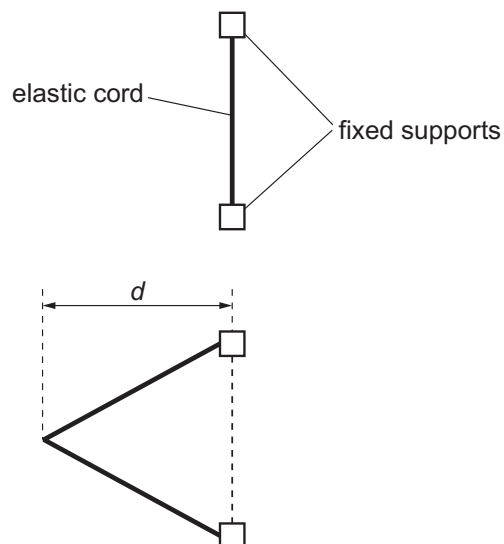
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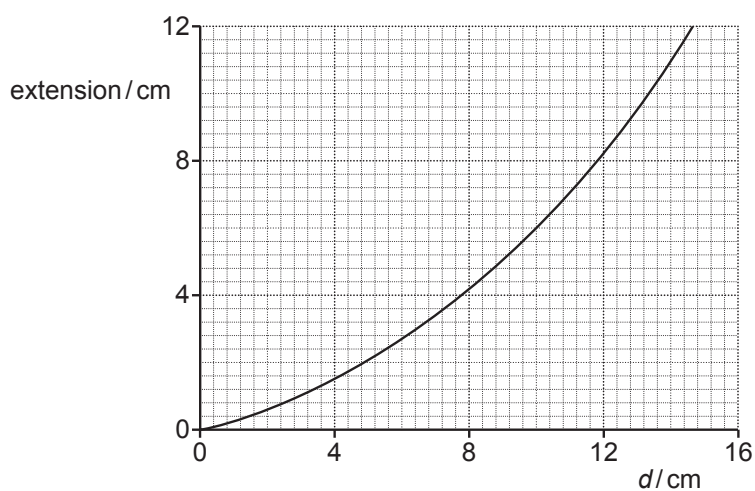
- (b) A simple catapult is made by an elastic cord fixed to two supports, as shown below.



The unstretched length of the cord is the same as the distance between the supports.
The distance that the centre of the cord has been pulled back is d .

The cord has a force constant of 500 N m^{-1} .

The variation of the extension of the cord with distance d is shown below.



A small ball of mass 30 g is placed at the centre of the cord and drawn back with $d = 10$ cm.

The ball is released and launched horizontally from a height of 1.5 m above the horizontal ground.

- (i) Use the graph to show that the elastic potential energy E in the cord is about 1 J.

[3]

- (ii) Show that the maximum speed at which the ball leaves the catapult is about 8 m s^{-1} .

[2]

- (iii) Calculate the horizontal distance R travelled by the ball before it strikes the horizontal ground.
Ignore the effects of air resistance in your calculation.

$R = \dots\dots\dots$ m [3]

- (iv) Explain how the value of R calculated in (iii) compares with the actual value.

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..... [2]

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The force F is removed.

- (i) Calculate the magnitude of the block's initial acceleration at the instant that the force F is removed.

Assume that the spring is not extended beyond its limit of proportionality.

acceleration = ... ms^{-2} [3]

- (ii) The block now moves with simple harmonic motion.

Calculate the frequency of this motion.

frequency = ... Hz [3]

- (c) The block is replaced by a strong magnet **L** of slightly greater mass.

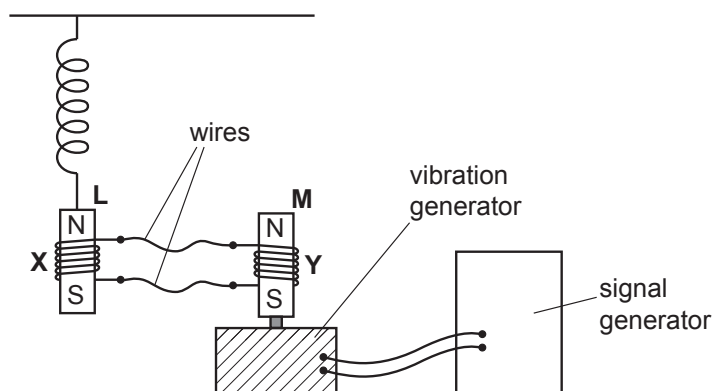
The oscillation frequency of this new arrangement is 2.5 Hz.

The magnet **L** is placed inside a coil **X** of insulated copper wire.

The coil **X** is connected with long wires to a second, identical coil **Y**.

A second strong magnet **M** is placed inside **Y** and attached to a vibration generator.

The vibration generator is then forced to oscillate with a frequency of approximately 2.5 Hz by adjusting the signal generator.



- (i) As magnet **M** oscillates, it moves in and out of coil **Y**.

The magnet **L** also begins to oscillate.

Explain why **L** oscillates.

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..... [3]

- (ii) The frequency of the vibration generator is now varied between 0.5 Hz and 5.0 Hz.

Suggest how the amplitude and frequency of the oscillations of **L** will change as the frequency of the generator is varied.

You may draw a diagram to support your answer.

.....

.....

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.....

..... [3]

21 (a) Fig. 21.1 shows a stationary glider of mass m on an air track.

The glider has identical springs with force constant k attached to each end which are secured to fixed posts.

The air track blower is turned on and the glider is displaced a small distance x_0 , as seen in Fig. 21.2. It is then released.

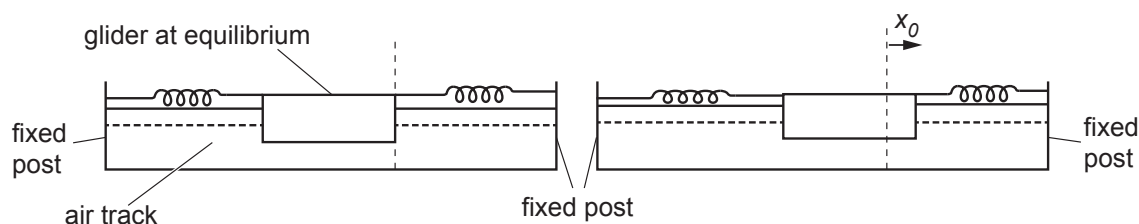
The glider moves horizontally in simple harmonic motion.

The springs remain in tension throughout the motion.

The time taken for 20 complete oscillations is measured, and the period T calculated.

Fig. 21.1

Fig. 21.2



The relationship between the period T , the mass of the glider m and the force constant k is described by the equation

$$T^2 = \frac{2\pi^2 m}{k}.$$

- (i) Show that the equation above is homogeneous by reducing the equation to SI base units.

[2]

- (ii) Explain why the magnitude of the resultant force F on the glider is given by $F = 2kx$ where x is the displacement at any time.

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..... [2]

- (iii) State and explain the effect, if any, of increasing the initial displacement on the period of the subsequent motion.

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 [2]

- (b) Masses are added to the glider, and the measurement of $20T$ repeated.

The results table is below.

m/kg	$20T/\text{s}$	T	T^2
0.200	12.2	0.61	0.372
0.300	13.6	0.68	0.462
0.400	15.6	0.78	0.608
0.500	17.6	0.88	0.774
0.600	18.9	0.945	0.893
0.700	20.0	1	1

- (i) Describe **two** different errors in the table.

1

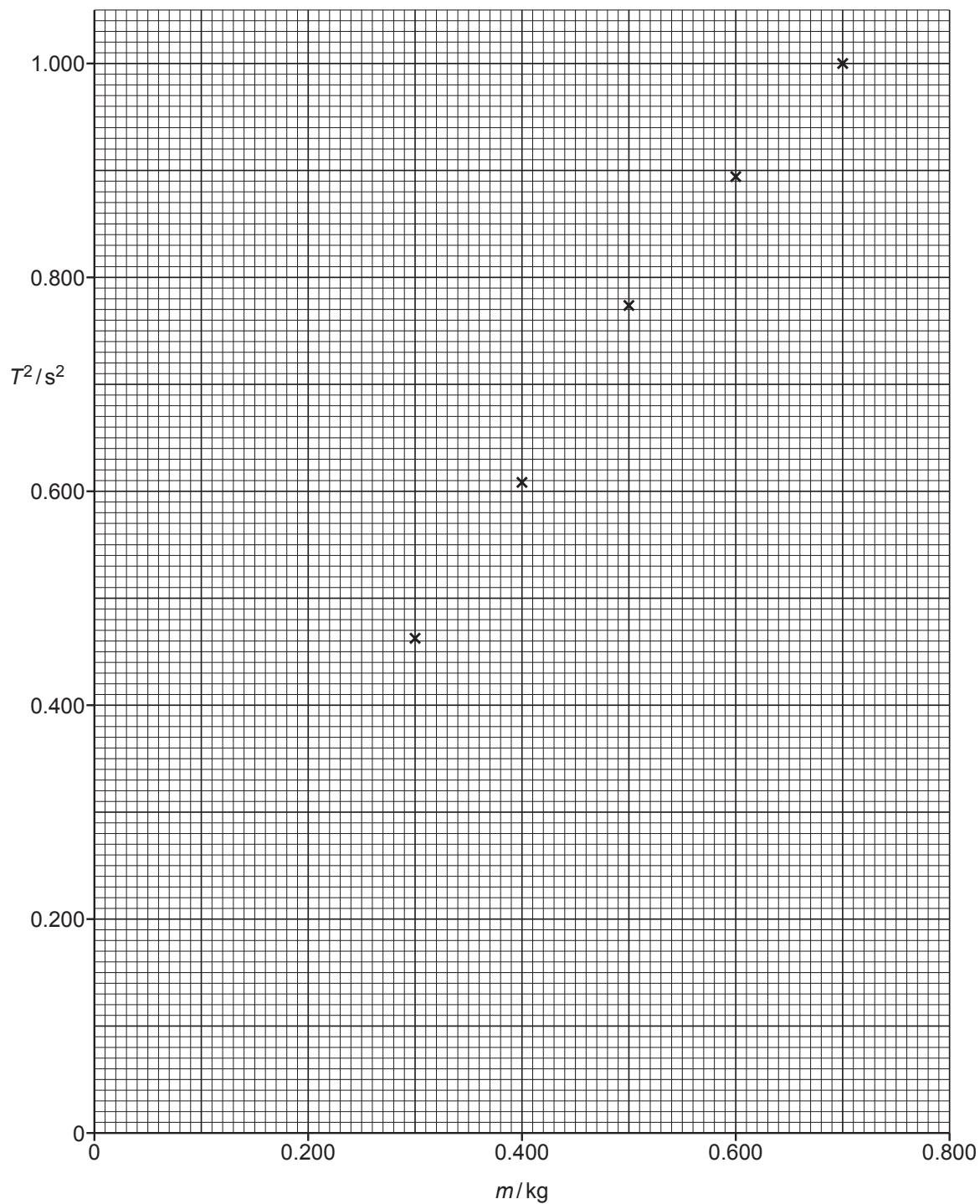
 2
 [2]

(ii) Plot the **first** data point from the table on the graph below.

The other points have all been plotted. The table of results is repeated on the opposite page.

Include on your graph a line of best fit.

[2]



m/kg	$20T/\text{s}$	T	T^2
0.200	12.2	0.61	0.372
0.300	13.6	0.68	0.462
0.400	15.6	0.78	0.608
0.500	17.6	0.88	0.774
0.600	18.9	0.945	0.893
0.700	20.0	1	1

(iii) Use the graph to determine the value of k .

$k = \dots\dots\dots \text{Nm}^{-1}$ [3]

- (c) When the initial displacement is increased, one spring increases its extension while the extension of the other spring decreases.

Explain why the **maximum** kinetic energy of the motion increases.

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..... [4]

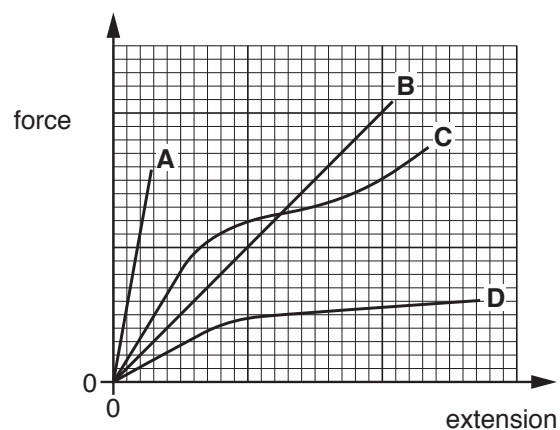
SUB-TOPIC 3.4.2

MECHANICAL PROPERTIES OF MATTER

Sub-topic 3.4.2 · 12 questions · 53 marks · lowest tariff first



- 2 Four materials **A**, **B**, **C** and **D** have the same length and cross-sectional area. The force against extension graph for each material up to the breaking point is shown below.

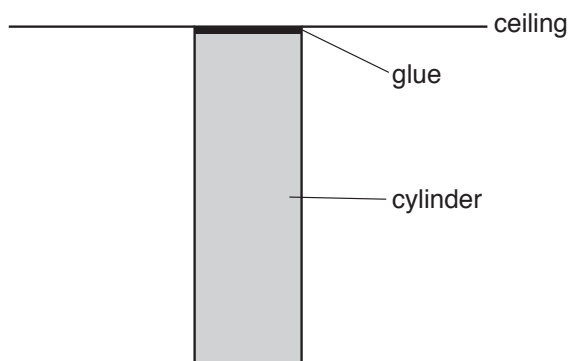


Which material is brittle and has the greatest ultimate tensile strength?

Your answer

[1]

- 6 The flat end of a uniform steel cylinder of weight 7.8 N is glued to a horizontal ceiling. The cylinder hangs vertically. The breaking stress for the glue is 130 kPa.



The glue only just holds the cylinder to the ceiling.

What is the cross-sectional area of the cylinder?

- A** $6.0 \times 10^{-2} \text{ m}^2$
B $6.0 \times 10^{-5} \text{ m}^2$
C $1.7 \times 10^{-2} \text{ m}^2$
D $1.7 \times 10^1 \text{ m}^2$

Your answer

[1]

- 11 The table below shows some data on two wires **X** and **Y**.

Wire	Young modulus of material / GPa	Cross-sectional area of wire / mm ²
X	120	1.0
Y	200	2.0

The wires **X** and **Y** have the same original length. The tension in each wire is the same. Both wires obey Hooke's law.

What is the value of the ratio $\frac{\text{extension of X}}{\text{extension of Y}}$?

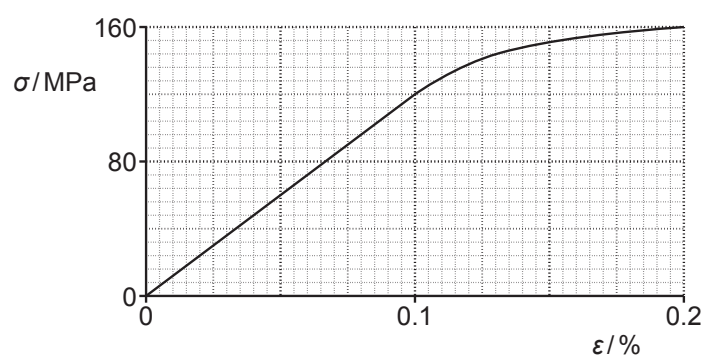
- A** 0.30
B 1.7
C 2.0
D 3.3

Your answer

[1]



12 A graph showing the variation of the stress σ with strain ϵ for a material is shown below.



What is the Young modulus of the material?

- A $6.0 \times 10^4 \text{ Pa}$
- B $1.2 \times 10^9 \text{ Pa}$
- C $8.0 \times 10^{10} \text{ Pa}$
- D $1.2 \times 10^{11} \text{ Pa}$

Your answer

[1]

2 Which pair of quantities have the same S.I. base units?

- A force, strain
- B force, stress
- C pressure, stress
- D strain, upthrust

Your answer

[1]



- 13 The Young modulus E of a metal can be determined using the expression $E = \frac{4F}{\varepsilon\pi d^2}$, where F is the tension in the wire, d is the diameter of the wire and ε is the strain of the wire.

Here is some data.

Quantity	Percentage uncertainty
F	5.3
ε	1.2
d	1.0

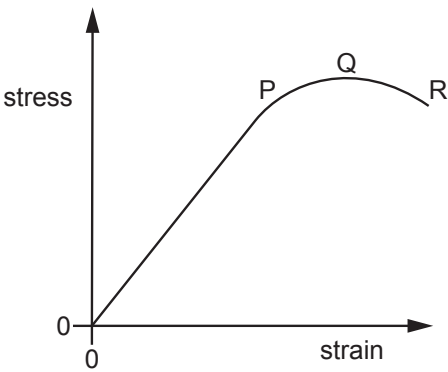
What is the percentage uncertainty in the calculated value of E ?

- A** 2.1 %
B 6.4 %
C 7.5 %
D 8.5 %

Your answer

[1]

4 Which row in the table correctly identifies the elastic limit, fracture and ultimate tensile strength in the graph below?



	Elastic limit	Fracture	Ultimate tensile strength
A	P	Q	R
B	P	R	Q
C	P	R	R
D	Q	R	P

Your answer

[1]

– Answered by user: 2023-06-29 12:56:29. Question ID: 504631. The correct answer is: B



- 5 A wire of cross-sectional area $3.9 \times 10^{-6} \text{ m}^2$ carries a load of 240 N. The strain in the wire is 0.30%.

Which value of the Young modulus, in Pa, is correct and expressed to an appropriate number of significant figures?

A 2.05×10^8

B 2.1×10^8

C 2.05×10^{10}

D 2.1×10^{10}

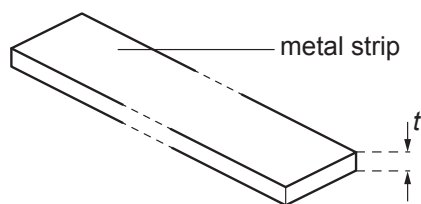
Your answer

[1]

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- 17 (a) A metal strip has thickness t , as shown below.



Five measurements of the thickness t at different positions along the length of the strip are shown below.

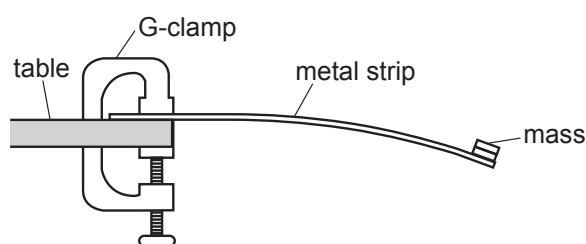
1.86 mm 1.88 mm 1.85 mm 1.89 mm 1.88 mm

Determine the percentage uncertainty in the thickness t .

percentage uncertainty = ... % [3]

- (b)* A student wants to determine the Young modulus E of the metal of the strip in (a).

The student clamps the metal strip to the edge of a table using a G-clamp. A mass is **permanently** fixed to the end of the strip as shown.



The mass oscillates freely when it is moved away from its equilibrium position and then released.

The Young modulus E of the metal can be determined using the equation $E = \frac{16\pi^2 mL^3}{wt^3 T^2}$, where m is the mass fixed to the end of the strip, L is the length of the strip from the end of the table to the centre of the mass, w is the width of the strip, t is the thickness of the strip, and T is the period of oscillations.

Describe how an experiment may be safely conducted, and how the data can be analysed to determine an accurate value for E . [6]

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Additional answer space if required.

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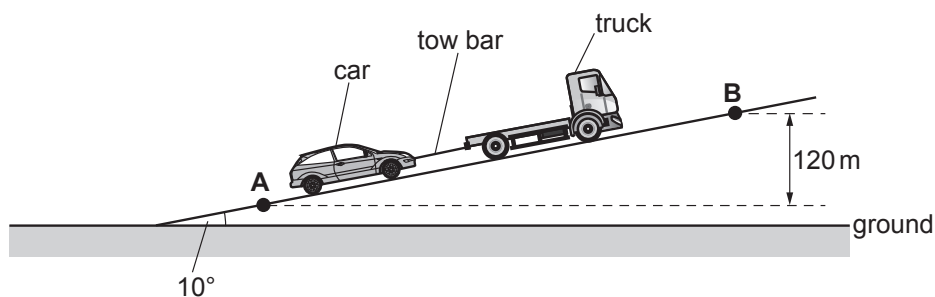
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- 16 A truck pulls a car up a slope at a **constant** speed.
The truck and the car are joined with a steel tow bar, as shown in the diagram.



The diagram is **not** drawn to scale.

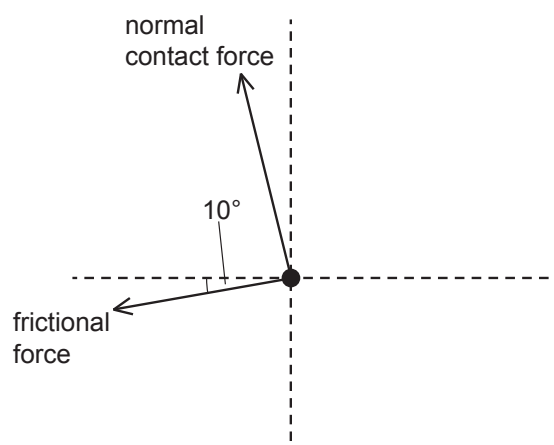
The slope is 10° to the horizontal ground.

The mass of the car is 1100 kg.

The car travels from **A** to **B**. The vertical distance between **A** and **B** is 120 m.

- (a) There are four forces acting on the **car** travelling up the slope.

Complete the free-body diagram below for the car and label the missing forces.



[2]

(b) Show that the component of the weight of the car W_s acting down the slope is about 1900 N.

[1]

(c) The total frictional force acting on the car as it travels up the slope is 300 N.

Calculate the force provided by the tow bar on the car.

force = ... N [1]

(d) Calculate the work done by the force provided by the tow bar as the car travels from **A** to **B**.

work done = ... J [3]



- (e) The steel tow bar used to pull the car has length 0.50 m and diameter 1.2×10^{-2} m. The Young modulus of steel is 2.0×10^{11} Pa.

Calculate the extension x of the tow bar as the car travels up the slope.

$x = \dots\dots\dots$ m [3]

- 16 (a) Explain what is meant by the **ultimate tensile strength** of a material.

.....
 [1]

- (b) A footbridge is supported by a number of metal cables of the same length. Each cable has uniform cross-section and diameter 4.20 mm as shown in Fig. 16.1.

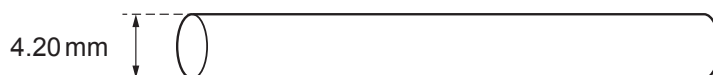


Fig. 16.1 (not to scale)

A group of engineers investigate how the extension x varies with applied force F for one of the cables.

The results of the investigation are shown in Fig. 16.2.

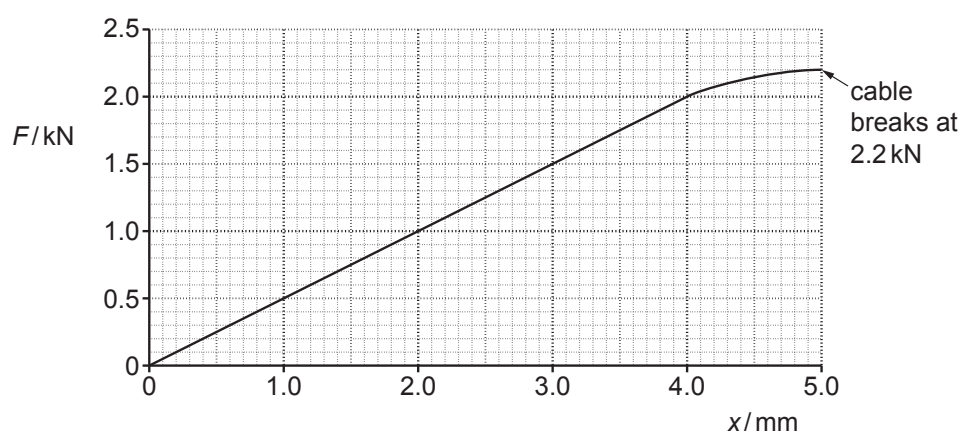


Fig. 16.2

The cable breaks when the force is 2.2 kN.

- (i) Describe how a suitable measuring device may have been used by the engineers to demonstrate that the cable had uniform cross-section.

.....

 [2]

(ii) State any value of F when the cable behaves

1. elastically

$F = \dots\dots\dots$ kN

2. plastically.

$F = \dots\dots\dots$ kN
[2]

(iii) Use Fig. 16.2 to determine the force constant k in N m^{-1} of the cable.

$k = \dots\dots\dots$ N m^{-1} [2]

(c) Determine the breaking stress σ of the cable.

Assume that the cross-sectional area of the cable remains constant during the test.

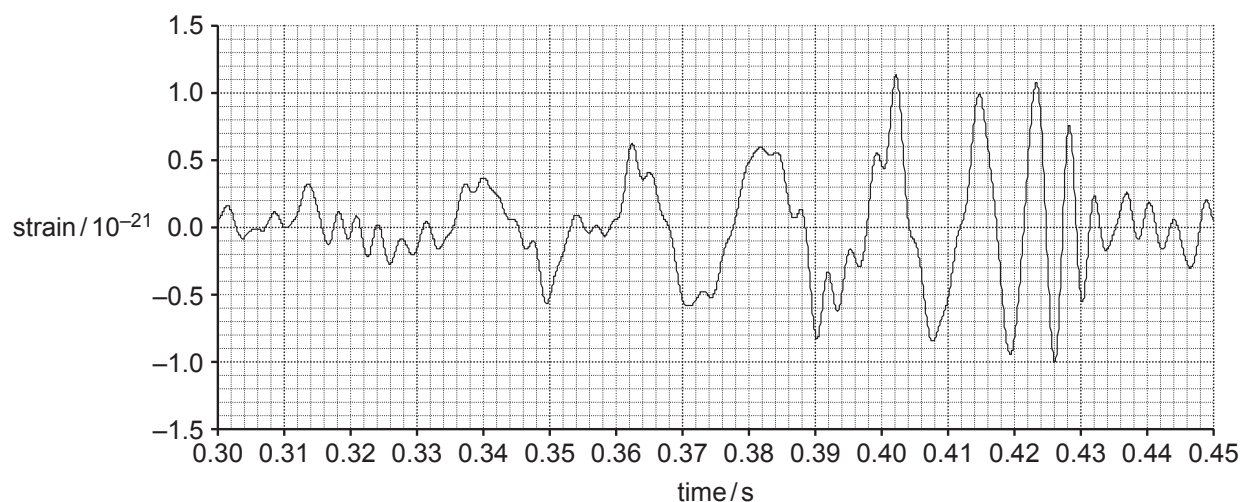
$\sigma = \dots\dots\dots$ Pa [2]

(d) Explain why the work done on the cable when its extension changes from 3.0 mm to 4.0 mm is greater than when its extension changes from 1.0 mm to 2.0 mm.

.....
.....
..... [2]

- 6 Gravitational waves are disturbances in space-time that are produced by violent astrophysical events.
- (a) They are detected by measuring the change in length of a detector as the wave passes through. The change in length is reported as a strain.

The graph shows the variation in time of the strain due to the gravitational waves emitted by the collision of two black holes.



- (i) Define **strain**.

.....
 [1]

- (ii) The maximum strain shown on the graph is approximately 10^{-21} .

Calculate the force that would produce the same strain in a copper wire of diameter 2 mm.

Young modulus of copper = 130 GPa

force = ... N [3]

- (iii) By considering the answer to (ii), suggest why it is very difficult to detect the strain caused by gravitational waves.

.....

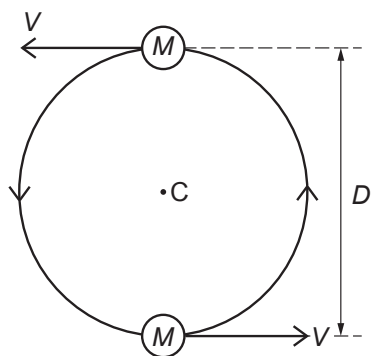
.....

..... [2]

- (b) In this part of the question you will use Newtonian physics to estimate the power output of the black hole collision.

The diagram shows two identical black holes, each of mass M , orbiting each other with period T .

Prior to colliding, the black holes move at speed V in identical circular orbits of diameter D about the central point C .



- (i) Write down an expression for the gravitational force, F , acting between the black holes in terms of M , D and the universal gravitational constant, G .

$F =$ [1]

- (ii) The total orbital energy, E , of the black holes is the sum of their kinetic energy and gravitational potential energy. Show that E is given by the expression:

$$E = k (\pi^2 G^2 M^5)^{1/3} (1/T^{2/3})$$

where k is a numerical constant.

.....

.....

.....

.....

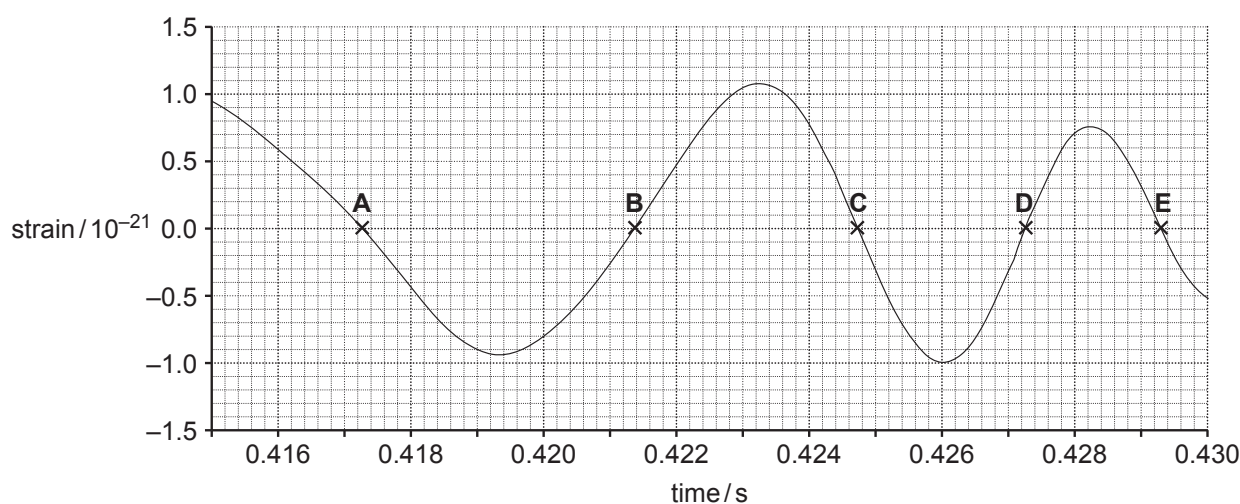
.....

..... [3]

- (iii) The graph below shows detail from the graph in (a).

The black holes spiral towards one another before colliding. As they do so their orbit period decreases.

The orbit period is equal to the period of the gravitational waves.



By considering the time periods **AC** and **CE**, estimate the orbital energy lost by the black holes between these two orbits.

Use $k (\pi^2 G^2 M^5)^{1/3} = -2.04 \times 10^{46}$

energy lost = ... J [3]

- (iv) By considering times **B** and **D**, use your answer to (iii) to estimate the power radiated as gravitational waves in this time interval.

power = ... W [2]



MARK SCHEMES

official mark schemes



11	A		1	
----	---	--	---	--



7	C		1	
---	---	--	---	--



10	D	1	
----	---	---	--



13	C	1	
----	---	---	--



4	C	1	
-	-	-	



21	(a)		$\omega^2 = k/m$ or 60/0.080 or $\omega^2 = 750$ $T = 2\pi/27.39$ or $T = 0.2295$ (s) $t = \frac{1}{4} \times 0.2295$ $t = 0.057$ (s)	C1 C1 C1 A1	Allow correct algebraic expression for T Allow incorrect value for omega Allow incorrect value of T
	(b)	(i)	$E = \frac{1}{2}kx^2$ or $E = mgh$ or $0.080 \times 9.81 \times 0.20$ or $\frac{1}{2} \times 60 \times x^2$ $0.080 \times 9.81 \times 0.20 = \frac{1}{2} \times 60 \times x^2$ $x = 0.072$ (m)	C1 C1 A1	
		(ii)1	Time of flight is independent of speed/AW Because distance of fall is the same and initial velocity vertically is zero / velocity is horizontal at X	B1 B1	Allow algebraic answers that assume initial vertical velocity is zero/velocity is horizontal at X.
		(ii)2	D increases as speed at X increases because the time of flight is constant/AW D is directly proportional to speed at X	M1 A1	Allow $d = vt$ idea “ D is directly proportional to speed at X because the time of flight is constant” scores 2.
			Total	11	

Question	Answer	Marks	Guidance
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18	a	i	0.99	A1	Award mark for all candidates as some centres may not have seen the erratum for this question.
		ii	Data plotted at 6.0, 0.99 within half a small square	B1	ecf from (a)(i) treat use of 0.81 from table as ecf if candidate has left 18 (a)(i) blank
			Two trendlines drawn	B1	NOT straight lines connecting data points NOT straight line(s) of best fit
			Clear indication that upper curve's data is during loading and that lower curve's data is during unloading	B1	e.g Correct arrow direction or label 'loading' on upper curve and correct direction arrow or label 'unloading' on lower curve.
		iii	Any TWO from: Not a straight line / AW (hence) not directly proportional Correct reference to plastic deformation when unloaded	B1 B1 B1	 allow 'k / spring constant not constant' allow Hooke's Law should be (directly) proportional e.g. Mention of line not passing through origin when unloaded

Question			Answer	Mark	Guidance
		iv 1	joule	B1	Not J; since name is required. Allow joules NB if more than one answer given, mark first answer as per rubric on page 3
		iv 2	(the area is) increase in thermal or in internal energy of the rubber reference to reduction in the energy of the object or in the force applied to the object or the force applied to the floor	B1 B1	ignore unqualified 'energy' or 'work done' allow change in work done on rubber between loading and unloading e.g. the energy absorbed by the rubber / not returned to the object e.g. energy dissipated as heat or energy not transferred back to KE e.g. The object will not bounce as high e.g. object less likely to be damaged because the force on object is smaller e.g. floor is less likely to be damaged because the force on the floor is smaller e.g. the larger the area between the curves the lower the damage caused

Question		Answer	Mark	Guidance
	b	Any TWO from pulley adds friction / the load values would no longer equal the weights	B1	ignore plastic deformation
		Greater lengths being used will reduce (%) uncertainty	B1	
		Reference to pulley's suspension rope reduces h because it is not inextensible	B1	
		Larger range of h may make eye level more difficult	B1	
		Larger h makes effect of non-vertical ruler more prominent	B1	
		TOTAL	10	

Question	Answer	Mark	Guidance
6	arrow down through centre of ball labelled weight or W or mg or 1.2 N	B1	zero if any other arrows or forces present
(b) (i)	(horizontally) mv^2/r (or $mr\omega^2$) = $T \sin \theta$ and (vertically) W or mg = $T \cos \theta$ ($\tan \theta = v^2/rg$ or $r\omega^2/g$) $\tan \theta = 0.045 \times 4 \times 9.87 \times 2.2/9.81$ or $0.48/1.2$ (= 0.40) $\theta = 22^\circ$	M1 A1 A0	accept figures in place of algebra, $r = 0.045$ m $v = 0.42$ m s ⁻¹ $\omega = 3\pi$ 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 <i>show that</i> 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) ($T = mg / \cos \theta = kx$ giving) $x = 1.2 / 24 \cos 22$ $x = 0.054$ (m)	C1 C1 A1	or solution by ratios
(c)	($y = \frac{1}{2}gt^2 \Rightarrow 0.18 = 0.5 \times 9.81 \times t^2$ giving $t = 0.19$ (s) ($x = vt \Rightarrow 0.42 \times 0.19 = 0.08$ (m) distance = $\sqrt{r^2 + x^2} = \sqrt{0.0020 + 0.0064} = 0.092$ (m)	C1 C1 C1 A1	alt: projectile motion: $x = vt$, $y = \frac{1}{2}gt^2$ $y = \frac{1}{2}g(x/v)^2$ ecf (b)i for v ; $x^2 = 2yv^2/g = 2 \times 0.18 \times 0.42^2/9.81$
(d)	T increases or string stretches or angle θ increases to provide/create a larger centripetal force	M1 A1	allow mv^2/r or $mr\omega^2$ in place of <i>centripetal force</i> causality must be implied to gain the A mark
	Total	12	

16	a		Hang (known) masses/weights on the cord or pull with a newtonmeter to different tensions Determine the extension Graph of force against extension Force constant is the gradient (of force-extension graph)	B1 B1 B1 B1	Allow mention of spring Allow measure the length Allow length for extension Note if axes swapped, must be 1/gradient
	b	i	Extension (from graph) is 6.0 (cm) Use of $E = \frac{1}{2} kx^2$ elastic potential energy = 0.90 (J)	M1 M1 A1	Allow Use of $E = \frac{1}{2} Fx$ and $F = kx$ Allow 1 SF of 0.9 (J)
		ii	($KE = \frac{1}{2} mv^2$) $0.90 = \frac{1}{2} \times 0.030 \times v^2$ $v = 7.7 \text{ (m s}^{-1}\text{)}$	M1 A1	Allow 1 J instead of 0.90 J Note using 1 J gives an answer of 8.2 m s^{-1} Note allow possible ECF with energy approx 1 J
		iii	$1.5 = \frac{1}{2} gt^2$ $t = 0.55 \text{ (s)}$ ($R = 7.7 \times 0.55$) $R = 4.2 \text{ (m)}$	C1 C1 A1	Allow 8 m s^{-1} or 8.2 m s^{-1} instead of 7.7 m s^{-1} i.e. 4.4, 4.5 (m) Possible ECF from (b)(ii)



Question			Answer	Marks	Guidance
		iv	(Actual distance is smaller than calculated R) Valid explanation The velocity /speed (in flight) smaller than expected or The initial velocity / speed will be smaller than expected	M1 A1	Examples of valid explanation include: For velocity / speed decreases • drag/air resistance For initial velocity /speed is smaller • not all the energy transfers to the ball • the cord also has KE • hysteresis (so cord heats up) Ignore references to efficiency and unqualified energy dissipation.
			Total	14	

4	(a)	3 out of the following 4: • Extension (or length) measured using a ruler • Extension = stretched length – original length • Force (weight of load) determined using a forcemeter or $W = mg$ • (k is) gradient of graph of force against extension	B1 x 3 Ignore any incorrect statements unless contradictory Allow tape measure Could be shown on a labelled diagram Allow 4cm or 0.04m for original length Allow extension is change in length from original This mark may be scored by saying a graph of mass against extension would give gradient = k/g Allow k = gradient of graph of force against length Allow k/g = gradient of graph of mass against extension Allow k = load divided by extension, calculated for a single load
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4	(b)	(i) Method 1 $d = 8.5 - 3.2 (= 5.3(\text{cm}))$ $(F = kd \text{ so}) F = 0.62 \times 5.30 (= 3.3 (\text{N}))$ $a = \frac{F}{m} \text{ so } a = \frac{3.3}{0.20}$ $a = 17 (\text{m s}^{-2})$ Method 2 $(F = kd \text{ so}) F = 0.62 \times 8.50 (= 5.27(\text{N}))$ $F_R = (0.62 \times 8.50) - (0.20 \times 9.81) (= 3.3 (\text{N}))$ $a = \frac{F}{m} \text{ so } a = \frac{3.3}{0.20}$ $a = 17 (\text{m s}^{-2})$ Method 3 $(F = kd \text{ so}) F = 0.62 \times 8.5 (= 5.27(\text{N}))$ $\left(a = \frac{F}{m} \text{ so}\right) a = \frac{5.27}{0.20} = 26 (\text{m s}^{-2})$ $a_{\text{initial}} = 26.35 - 9.81 = 17 (\text{m s}^{-2})$	Mark whichever method leads to the most marks C1 $d = 5.3\text{cm}$ does not need to be calculated explicitly but seeing 5.3 implies first C1 mark C1 $F = 3.3\text{N}$ does not need to be calculated explicitly but seeing 3.3 implies both C1 marks Allow $k = 0.61 (\text{N cm}^{-1})$ leading to $F = 3.2 (\text{N})$ A1 and $a = 16 (\text{m s}^{-2})$ (C1) $F = 5.27(\text{N})$ does not need to be calculated explicitly but seeing 5.27 or 5.3 implies first C1 mark Allow $k = 0.61 (\text{N cm}^{-1})$ leading to $F = 5.19 (\text{N})$ (C1) $F = 3.3(\text{N})$ does not need to be calculated explicitly but seeing 3.3 implies both C1 marks Allow $k = 0.61 (\text{N cm}^{-1})$ leading to $F = 3.2 (\text{N})$ (A1) and $a = 16 (\text{m s}^{-2})$ (C1) $F = 5.27(\text{N})$ does not need to be calculated explicitly but seeing 5.27 or 5.3 implies first C1 mark Allow $k = 0.61 (\text{N cm}^{-1})$ leading to $F = 5.19 (\text{N})$ (C1) Note: $a = 26 (\text{ms}^{-2})$ is an intermediate calculation for a_{initial} in this method only and is not the A1 mark (A1) Allow $k = 0.61$ leading to $F = 5.19$ and $a = 16$
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4	(b)	(ii)	Use of $a = (-)\omega^2 x$ Use of $f = \frac{\omega}{2\pi}$ $f = 2.8$ (Hz) Alternative method: $(a = F / m = kx / m \text{ and } a = (-) \omega^2 x \text{ gives})$ $\omega^2 = \frac{k}{m}$ $f = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$ $= \frac{1}{2\pi} \sqrt{\frac{0.62 \times 100}{0.2}}$ $f = 2.8$ (Hz)	The two C1 marks are independent and XP in one does not imply XP in the other C1 Not just formula alone Expect $a = 17$ but allow ECF of a from (b)(i) Allow any value for x C1 Not just formula alone Use of $a = (-)(2\pi f)^2 x$ scores both C1 marks A1 Allow $f = 2.9$ (Hz) (C1) Allow $T = 2\pi \sqrt{\frac{m}{k}}$ $f = \frac{1}{T}$ (C1) (A1) Allow $f = 2.9$ (Hz)
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4	(c)	(i)	(motion of magnet M causes) a change of flux (linkage) in coil Y (inducing an e.m.f.) there is an (induced) <u>current</u> in (or through) coil X alternating current / field / flux in coil X interacts with the field of magnet L (causing an alternating force)	B1	Allow field (lines of M) cuts (turns of) coil Y Allow the coil or Y or solenoid for coil Y B1 Allow the coils or the wire(s) or X for coil X Ignore (induced) e.m.f. B1 Not changing or varying or oscillating for alternating Allow current / field / flux in coil X interacts with field of magnet L to cause an alternating force Allow changing direction for alternating Allow combines for interacts Allow cuts across for interacts with
	(c)	(ii)	frequency of magnet L (always) equals (forcing/driving) frequency of vibration generator / magnet M resonance occurs at / close to 2.5 Hz amplitude is maximum at resonance	B1 B1 B1	Allow frequency of magnet increases with frequency of vibration generator May be seen from a labelled graph of amplitude against frequency Allow resonance occurs when forcing / driving frequency = natural frequency May be seen from a labelled graph of amplitude against frequency
			Total	15	

21	(a)	(i)	newton in base units is kg m s^{-2}	C1	
			Substitution and cancelling of kg and m arriving at $\text{s}^2 \rightarrow \text{s}^2$	A1	
		(ii)	One force is increased by kx and one is reduced by kx /AW Some working to include $kx - (-kx)$	B1 B1	reject 2 springs in series or 2 springs in parallel idea XP. accept one extension is reduced by x and one is increased by x / AW
		(iii)	period is independent of <u>amplitude</u> / AW No effect	M1 A1	Allow isochronous
	(b)	(i)	Units omitted from T and T^2 Valid statement about significant figures	B1 B1	allow correct statement about individual data points or decimal place or "precision" e.g. sf of T does not match sf of $20T$ or sf of T not consistent throughout column or idea that 1 sf never enough
		(ii)	Correct plotting within half a small square Correct line of best fit	B1 B1	ECF for incorrect plotting. NB Same number of points above and below the line AND fair distribution of distances from line

		(iii)	Gradient between 1.22 and 1.44	C1	reject use of data table
			$k=2\pi^2 \div \text{gradient}$	C1	ECF use of candidate's line
			k between 13.7 and 16.2	A1	ECF use of candidate's gradient as per rubric
	(c)		maximum four from: EPE gain (in stretched spring) > EPE lost (in relaxed spring) EPE is dependent on x^2 Total energy increases (and so KE increases since EPE → KE) Max KE when the system has minimum EPE / at equilibrium position/when $x=0$ Minimum EPE is unchanged Omega is same, amplitude has increased $v_{\max}$ when $x=0$ so $v_{\max}$ has increased ($\omega^2 = \sqrt{A^2 - x^2}$) $v_{\max}$ increased so $KE_{\max}$ increased	4 x B1	Allow EPE max is dependent on A^2 NOT EPE dependent on x alone Allow EPE dependent on x and F which is dependent on x (EPE = $\frac{1}{2}Fx$ idea) KE = $\frac{1}{2}kx^2$ is XP
			TOTAL	17	

2	B		1	
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6	B	1	
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11	D		1	
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12	D	1	
----	---	---	--



2	C	1	
---	---	---	--



13	D	1	
----	---	---	--



4	B	1	
---	---	---	--



5	D	1	
---	---	---	--



17	(a)	(mean) = 1.87(2) (mm)	C1	
		(range) = 0.04 mm	C1	Allow use of resolution of micrometer (gives percentage uncertainty of 0.5%) Allow use of maximum or minimum deviation from the mean
		(percentage uncertainty) = $\frac{0.02}{1.872} \times 100$ percentage uncertainty = 1 (%)	A1	Allow 2 or 3 SF answer



	(b)*	Level 3 (5–6 marks) Clear description and clear analysis <i>There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.</i> Level 2 (3–4 marks) Some description and some analysis or Clear description or Clear analysis <i>There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.</i> Level 1 (1–2 marks) Limited description or Limited analysis <i>There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.</i> 0 marks No response or no response worthy of credit.	B1 × 6	Use level of response annotation in RM Assessor. Indicative scientific points may include: Description • Determine T by measuring several oscillations • Independent and dependent variables identified (e.g. L and T) • Variables kept constant (e.g. for L and T experiment, m is kept constant) • Repeating to determine average T • Measure length L and width w with ruler • Measure thickness t with a vernier (calliper) / micrometer • Use video/phone camera / stopwatch / data-logger and motion sensor / light gates and timer • Use top-pan balance / scales to measure m Analysis • Plot an <u>appropriate</u> graph, e.g. T^2 against L^3 or tabulate $T^2 \div L^3$ • Gradient of best line determined or average of $T^2 \div L^3$ • Use a large triangle to determine gradient • Gradient (or equivalent) related to E, e.g. gradient = $16\pi^2 m / wEt^3$ for T^2 against L^3 graph
		Total	9	

16	(a)	Arrow vertical down <u>and</u> an arrow opposite to the frictional force. Both arrows labelled correctly.	M1 A1	Allow weight / mg / W for the downward arrow <u>and</u> tension / T / 'force in rod' / 'force in tow bar' / 'driving force' for the 'upward' arrow
	(b)	$(W_s =) 1100 \times 9.81 \times \sin 10^\circ$ or $1100 \times 9.81 \times \cos 80^\circ$ $(W_s = 1874 \text{ N or } 1900 \text{ N})$	C1 A0	Allow g instead of value
	(c)	force = $1900 + 300$ force = 2200 (N)	A1	Allow $1870 + 300 = 2170 \text{ (N)}$
	(d)	(distance =) $120 / \sin 10^\circ$ or 691 (m) (work done =) 2200×691 work done = $1.5 \times 10^6 \text{ (J)}$	C1 C1 A1	Allow ECF from (c) Allow ECF from an incorrect attempt at first mark.
	(e)	$(A =) \pi \times 0.006^2$ or $1.1 \times 10^{-4} \text{ (m}^2\text{)}$ (stress =) $\frac{2200}{\pi \times 0.006^2}$ and $2.0 \times 10^{11} = \frac{\text{stress}}{\text{strain}}$ $x = 4.8 \times 10^{-5} \text{ (m)}$	C1 C1 A1	Allow ECF from (c) Allow $x (=FL/EA) = \frac{2174 \times 0.5}{2.0 \times 10^{11} \times 1.1 \times 10^{-4}}$ Allow 2 marks for 1.2×10^{-5} ; $1.2 \times 10^{-2} \text{ m}$ used as radius Allow answer between 4.7 and $5.1 \times 10^{-5} \text{ (m)}$
		Total	10	



16	(a)		The maximum (tensile) stress a material can withstand (before it breaks)	B1	
	(b)	(i)	Use a micrometer / (Vernier) caliper Measure the diameter along its length in different directions (to ensure uniform cross-section) AW	B1 B1	Allow either along length or in different directions
		(ii)	1. Any value between 0 and 2.0 (kN) 2. Any value between 2.0 and 2.2 (kN)	B1 B1	
		(iii)	$k = \text{gradient}$ $k = 5.0 \times 10^5 \text{ (N m}^{-1}\text{)}$	C1 A1	Allow 1 mark for 5.0×10^n ; $n \neq 5$ Allow $5 \times 10^5 \text{ (N m}^{-1}\text{)}$
	(c)		$(A =) \pi \times 0.0021^2$ or $1.39 \times 10^{-5} \text{ (m}^2\text{)}$ $(\sigma) = 2200 / \pi \times 0.0021^2$ $\sigma = 1.6 \times 10^8 \text{ (Pa)}$	C1 A1	Allow 1 marks for $4(.0) \times 10^7$; diameter used as radius Answer is $1.59 \times 10^8 \text{ Pa}$ to 3sf
	(d)		Greater area under the graph (from 3 mm to 4 mm) / greater average force from (3 mm to 4 mm) Mention of work done = average force $\times$ distance or work done = area under graph	B1 B1	ORA Allow: labelled/annotated diagram Allow energy (transferred) instead of work done Allow 2 marks for arguments including reference to $W = \frac{1}{2} kx^2$ and constant k and greater average x
			Total	11	

6	(a)	(i)	$\text{strain} = \frac{\text{extension}}{\text{original length}}$	B1	Allow (strain is) extension per unit length Allow compression for extension Allow $\varepsilon = \frac{x}{L}$ with terms defined
6	(a)	(ii)	use of area = πr^2 $F = \text{Young modulus} \times \text{strain} \times \text{area}$ $F = 130 \times 10^9 \times 10^{-21} \times \pi \times (1.0 \times 10^{-3})^2$ $4(.08) \times 10^{-16} \text{ (N)}$	C1 C1 A1	Allow use of $\pi d^2/4$ or $\pi (d/2)^2$ Note area = $3.14 \times 10^{-6} \text{ (m}^2\text{)}$ Allow calculation using $E = \frac{F}{A}$ and $F = EA$ i.e. stress = $130 \times 10^9 \times 10^{-21} = 1.3 \times 10^{-10}$ and $F = 1.3 \times 10^{-10} \times \pi \times (1.0 \times 10^{-3})^2$ Allow 2 marks for $4(.08) \times 10^n \text{ (N)}$
6	(a)	(iii)	strain is <u>very small</u> / <u>very small</u> force required to produce similar strain difficult to distinguish signal from background noise / signal will be hidden by the effect of other forces	B1 B1	Ignore references to measuring instruments/detectors

6	(b)	(i)	$F = -\frac{GM^2}{D^2}$	B1	Accept correct formula without negative sign
6	(b)	(ii)	one from: $\frac{Mv^2}{D/2} = \frac{GM^2}{D^2}$ $v = \frac{\pi D}{T}$ one from: $E = -\frac{GM^2}{D} + 2\left(\frac{1}{2}Mv^2\right)$ $E = -\frac{GM^2}{D} + 2\left(\frac{1}{4}\frac{GM^2}{D}\right)$ steps leading to $E = k (\pi^2 G^2 M^5)^{1/3} (1/T^{2/3})$	M1 M1 A1	Allow m for M throughout GPE must be negative for this marking point Note this comes from substituting $v^2 = \frac{GM}{2D}$ eg use of $v^2 = \frac{GM}{2D}$ and $v = \frac{\pi D}{T}$ to obtain $D^3 = \frac{GMT^2}{2\pi^2}$ and $E^3 = -\frac{G^3 M^6}{8D^3}$

6	(b)	(iii)	A to C = $0.4247 - 0.4173 (= 7.4 \times 10^{-3})$ or C to E = $0.4293 - 0.4247 (= 4.6 \times 10^{-3})$ E = $-2.04 \times 10^{46} \times (7.4 \times 10^{-3})^{-2/3} (= -5.38 \times 10^{47})$ or E = $-2.04 \times 10^{46} \times (4.6 \times 10^{-3})^{-2/3} (= -7.38 \times 10^{47})$ $(7.38 - 5.37) \times 10^{47} = 2.0 \times 10^{47} \text{ J}$	C1	Accept 7.2×10^{-3} to 7.6×10^{-3} Accept 4.4×10^{-3} to 4.8×10^{-3}
				C1	Accept -5.28×10^{47} to -5.47×10^{47} Accept -7.17×10^{47} to -7.60×10^{47}
				A1	Accept 1.69×10^{47} to 2.32×10^{47}
6	(b)	(iv)	$\Delta t = 0.4273 - 0.4214 = 5.9 \times 10^{-3} \text{ s}$ $P (= \frac{E}{t}) = \frac{2.01 \times 10^{47}}{5.9 \times 10^{-3}} = 3.4 \times 10^{49} \text{ (W)}$	C1	Accept 5.8×10^{-3} to 6.1×10^{-3}
				A1	Allow calculation using value of E calculated in 6(b)iii Expect 3.30×10^{49} to 3.47×10^{49} if 2.01×10^{47} used
Total				15	

