Exam Answers
Chapter 2·1 & 2·2 - Gravitational Fields & Forces
Answer 1 2010:1:8

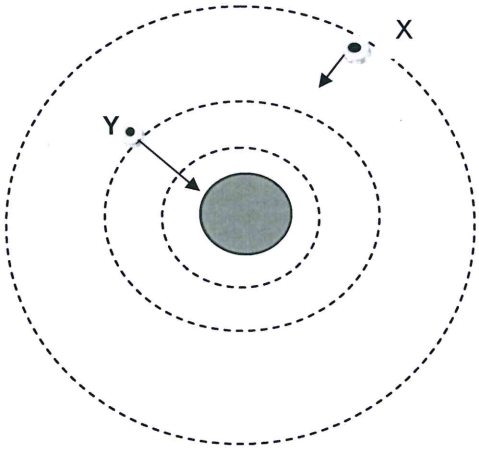
(5 marks)

This question is about the gravitational field around an asteroid. The asteroid is spherical and of uniform density. The diagram below shows lines of equal gravitational field strength as dashed lines. There is a constant difference in the value of the field strength between each line.

(a) Describe what the diagram shows about the gravitational field strength as the distance from the asteroid increases. (1 mark)

Description	Marks
the field strength is inversely proportional to the distance apart $g \propto \frac{1}{r^2}$ Allow the field strength is decreasing or decreasing at a decreasing rate	1
	Total 1

(b) Draw the gravitational field at points X and Y. (2 marks)



Description	Marks
arrows point to centre of asteroid	1
arrow length X < length Y	1
	Total 2

(c) The asteroid has a radius of 1.25×10^5 m. If the gravitational field strength on its surface is 0.194 N kg^{-1}, calculate the mass of the asteroid. (2 marks)

Description	Marks
$g = G\frac{m}{r^2}$ $\therefore m = \frac{gr^2}{G}$ $m = \frac{0.194 \times (1.25 \times 10^5)^2}{6.67 \times 10^{-11}}$ $m = 4.54 \times 10^{19}$ kg	1–2
	Total 2

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Answer 2 2011:1:5

(4 marks)

Bathroom scales measure weight (a force) but give the reading in kilograms (mass). A particular scale shows a person's mass as being 70 kg at the Earth's equator. The spinning of the Earth contributes to the scale's reading. What would the scale read at the South Pole, with the same person standing on it? (Circle the correct answer.)

the same   less than 70 kg   more than 70 kg

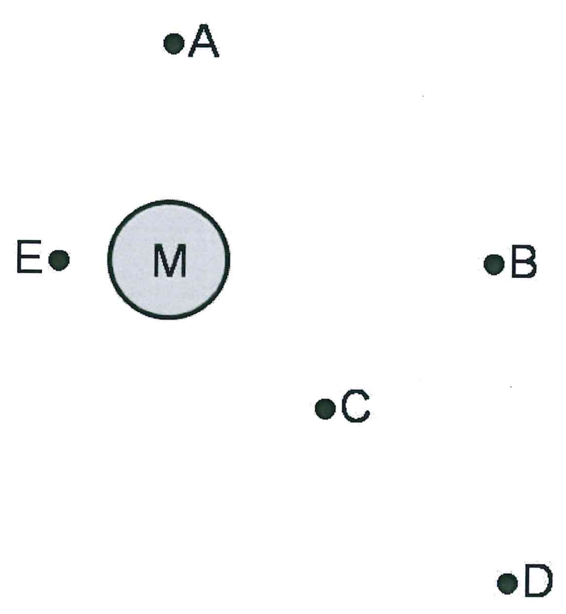
Explain your reasoning:

Description	Marks
'More than 70 kg' circled	1
Part of the gravitational force is used to provide centripetal force at the equator $F_g=F_w+F_c$ The centripetal force is zero at the poles so the weight force is correspondingly larger	1–3
OR The Earth is not spherical. You are slightly closer to the Earth's centre at the poles so the gravitational force is slightly larger at the poles, hence weight is larger at the poles.	1–2
	Total 4

Answer 3 2011:1:2

(4 marks)

The diagram below shows five points, labelled 'A' to 'E', in free space around a large mass M. You may wish to use a ruler to help you answer this question.



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Answer 3: continued

Which two points have the same magnitude of gravitational field strength due to M?

Point		Point
A	and	**C**

Which two points experience the same direction of gravitational field due to M (as viewed in this diagram)?

Point		Point
C	and	**D**

What is the ratio of the gravitational field strength at E to the gravitational field strength at B?

Point E		Point B
9	:	**1**

Description	**Marks**
A and C	1
C and D	1
9 : 1 (only 1 mark if distance measured to surface, 36 : 1 OR ratio reversed, 1: 9)	1–2
	Total 4

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Answer 4 2013:1:12

(7 marks)

A satellite orbits 4.22×10^7 m above the Earth's centre. At a certain point in its orbit around the Earth, the satellite and the Moon line up as shown in the diagram below. Show that in this position the influence of the Moon on the satellite is negligible, compared with the influence of the Earth.

Description	Marks
The satellite will feel a force of attraction from both the Earth and the Moon $\overleftarrow{F_E = GM_EM_s / r^2}$ and $\overrightarrow{F_m = GM_mM_s / r^2}$	1
Attraction by the Earth: $F = 6.67\times10^{-11}\times5.97\times10^{24} \times m_s / (4.22\times10^7)^2$ $F = 0.2236\times m_s$ N	1–2
Satellite moon distance $3.84\times10^8-4.22\times10^7=3.418\times10^8$ Attraction by the Moon: $F = 6.67\times10^{-11} \times7.35\times10^{22} \times1\ m_s / (3.418\times10^8)^2$ $F = 4.20\times10^{-5} \times m_s$ N	1–3
Therefore the force of attraction of the Earth is significantly larger by a factor of 5330 (or Moon's attraction is less by a factor of 0.00019), so the satellite will remain in a stable orbit not significantly affected by the gravitational pull of the Moon.	1
Total	7

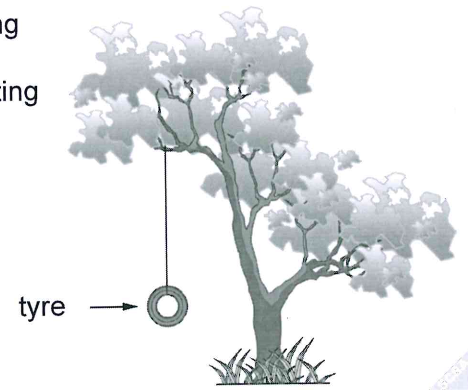
(NB: other methods of determining ratios are possible for full marks)

Answer 5 2013:2:15

(18 marks)

Andrew and Sarah were at the park and noticed a tyre-swing hanging in a tree. They realised that it would behave as a pendulum and would complete one swing (return to its starting point for one complete cycle) with a period (T) in seconds. They had previously discussed pendulums in class and been given the equation:

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



[Where ℓ = length in metres]

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Answer 5: continued

(18 marks)

(a) The tyre swung with a period of 3.84 s. Determine the length of the rope in metres. (2 marks)

Description	Marks
$L = \frac{T^2 g}{4\pi^2} = \frac{3.84^2 \times 9.8}{4\pi^2}$	1
L=3.66 m	1
Total	**2**

(b) Andrew and Sarah decided to conduct an investigation to determine the relationship between the length of a pendulum and its period.

A table of results for this investigation is shown below:

Length of pendulum ℓ (m)	Time for ten swings (s)	Time for one swing T (s)	Period squared T^2 (s^2)
0.10	5.5	**0.55**	**0.30**
0.20	6.9	**0.69**	**0.48**
0.30	10.9	**1.09**	**1.19**
0.40	12.5	**1.25**	**1.56**
0.50	15.0	**1.50**	**2.25**
0.60	18.5	**1.85**	**3.42**

(i) Complete the above table. (2 marks)

Description	Marks
One mark for each column (significant figures are not assessed here)	1–2
Total	**2**

(ii) Use the data from the table to plot a straight line graph on the grid provided to demonstrate the relationship between the length of the pendulum and the square of the period (plot ℓ on the x-axis). (4 marks)

Description	Marks
Correct axes, labelled with units	1
Points correct	1
Line of best fit	1
Not through the origin	1
Total	**4**

(iii) Use your graph to determine the pendulum length that gives a period of 1.0 s. (3 marks)

Description	Marks
Shows evidence of using graph	1
0.2 – 0.3 metres (determined by graph)	1
1-2 significant figures	1
Total	**3**

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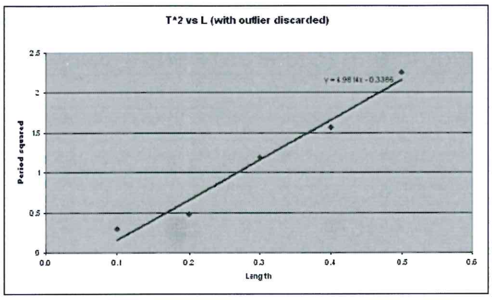
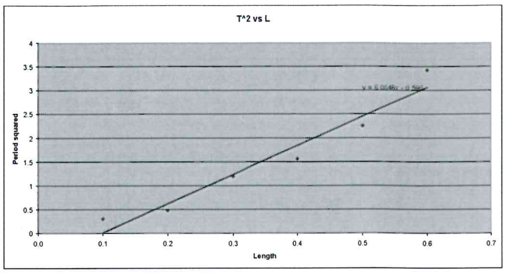
Answer 5: continued

(iv) Determine the gradient of your graph using a line of best fit. (4 marks)





Description	Marks
Gradient = $\dfrac{\text{rise}}{\text{run}}$	1
Value = 4–6	1
Units = $\dfrac{s^2}{m}$	1
Uses line of best fit and not data points	1
Total	**4**

(v) Use your gradient to determine the experimental value of g. (3 marks)

Description	Marks
$T^2 = \dfrac{4\pi^2}{g} L$ so gradient $= \dfrac{4\pi^2}{g}$	1
G = $4\pi^2/4.6$	1
= 8.6 (range 6.6 – 9.9) m s^{-2} (units not important)	1
Total	**3**

Answer 6 2014:3:21

(18 marks)

It is generally accepted that around 65 million years ago the Earth was struck by a fast-moving object approximately 10 km in diameter. This impact is believed to have left a scar on the Earth in the form of the Chicxulub Crater and to have been responsible for the extinction of the dinosaurs.

In 2013 the 'Chelyabinsk meteor' entered the Earth's atmosphere over Russia. This meteor had a mass of approximately 12 kilotonnes, measured about 20 metres in diameter and released about 1.8 × 10^{15} J, causing extensive damage, though mostly to arable land and not populated cities.

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Chapter 2·1 & 2·2 – Gravitational Fields & Forces
Answer 6: continued

Events such as this have sparked interest in cataloguing such Near Earth Objects (NEOs) and then determining if they have an orbit that might put them on a collision course with the Earth. If a NEO is deemed to have an orbit that puts it on a collision course with the Earth then various possibilities exist for preventing the collision. These methods of prevention fall into two categories, either deflection or destruction of the NEO. With either method, early intervention is desirable. The Earth is orbiting the Sun at 30.0 km s^{-1} and to avoid an impact scientists have to ensure that the NEO and the Earth are not in the same position in space at the same time. The section of the Earth's orbit in which a collision is possible is known as the 'impact window'.

Essentially deflection strategies seek to alter the velocity of the NEO so that it intersects the Earth's orbit before or after the Earth is in that position. It is estimated that a velocity change of a NEO of $\frac{3.5 \times 10^{-2}}{t}$ m s^{-1} is sufficient to avoid a collision where 't' is the time in years to impact.

One possible method of deflecting a NEO is to use a 'gravity tractor'. A gravity tractor is a massive spacecraft that is brought near to the NEO. Gravity will act between the spacecraft and the NEO and both objects will mutually attract each other. In time the NEO will gradually change the direction of its orbit. Once the NEO moves out of its normal path and comes close to the spacecraft, thrusters fire, moving the spacecraft further away from the NEO and allowing the spacecraft to continue to act as a gravity tractor. The gravity tractor method requires the earliest of interventions.

(a) Estimate the velocity of the of the Chelyabinsk meteor. Give your answer to an appropriate number of significant figures. Show **all** workings. (4 marks)

Description	Marks
$E_k = 0.5\ m\ v^2$ 1.8×10^{15} J $= 0.5\ (12 \times 10^6) \times v^2$	1–2
$v^2 = 1.8 \times 10^{15} / 6 \times 10^6$ $v^2 = 3 \times 10^8$ $v = 17\ 320$ m s^{-1}	1
$v = 1.7 \times 10^4$ m s^{-1} (<3 significant figures)	1
Total	**4**

(b) (i) The width, in Earth diameters, of the impact window is (circle your answer): (1 mark)

Description	Marks
One or more than one	1
Total	**1**

(ii) Calculate the length of time that an 'impact window' has for any collision of an object with the Earth, to occur. Ignore the size of the object. Show **all** workings. (3 marks)

Description	Marks
Velocity of Earth = 30.0 km s^{-1} $= 3 \times 10^4$ m s^{-1}	1
Mean radius of the Earth (R_E) = 6.38×10^6 m (from data sheet) Mean diameter of the Earth = $2 \times 6.38 \times 10^6$ m $= 1.276 \times 10^7$ m	1
The Earth will take 1.276×10^7m $/3 \times 10^4$ m s^{-1} = 425 seconds to move out of the way of any incoming object.	1
Total	**3**

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Answer 6: continued

(c) The NEO Apophis is on an orbit that will bring it close to the Earth in 2036. it has an assumed mass of 4.00×10^{10} kg and diameter of 325 m.

(i) Suppose that a spacecraft arrives and begins interacting with Apophis in 2016. Determine the change in velocity required to avoid a collision with the Earth. (3 marks)

Description	Marks
t = 2036 – 2016 = 20	1
Change in velocity = 3.5×10^{-2} / t $\Delta v = 3.5\times10^{-2}$ / 20	1
$\Delta v = 1.75 \times 10^{-3}$ m s^{-1}	1
Total	**3**

(ii) If a gravity tractor type of intervention is decided upon, and does not begin interacting until 2021, then Apophis will require a change in velocity of 2.33×10^{-3} m s^{-1}. Determine the mass of the gravity tractor spacecraft needed, given that the centres of mass will be 175 m apart. (4 marks)

Description		Marks
a=(v-u)/t $=(2.33\times10^{-3}-0)\div(15\times365.25\times24\times60\times60)$ $=4.92\times10^{-12}$ m s^{-2} $F= m_a a= Gm_a m/r^2$ $a= Gm/r^2$	a=(v-u)/t $=(2.33\times10^{-3}-0)\div(15\times365.25\times24\times60\times60)$ $=4.92\times10^{-12}$ m s^{-2} $F=ma= 4\times10^{10}\times4.92\times10^{-12}=0.197$ N	1–2
$m= ar^2/G$ $m=4.92\times10^{-12}\times175^2/6.67\times10^{-11}$ m=2260 kg	$F= Gm_a m/r^2$ $0.197=6.67\times10^{-11}\times4\times10^{10}\times m/175^2$ $m=0.197\times175^2/(6.67\times10^{-11}\times4\times10^{10})$ m=2260 kg	1–2
	Total	**4**

(d) When using a gravity tractor, explain why 'the earliest of interventions' is desirable if an asteroid is to be deflected sufficiently to avoid collision with the Earth. (3 marks)

Description	Marks
Early intervention gives us more time to cause the change in velocity (acceleration)	1
From the equation $\Delta v = 3.5 \times 10^{-2}$ / t we can see that a smaller Δv is required.	1
This allows a smaller force to be exerted (and a less massive spacecraft is required)	1
Total	**3**