GravCircleFormative *[52 marks]*

1. An object of mass m at the end of a string of length r moves in a vertical circle at a constant angular speed ω. *[1 mark]*

What is the tension in the string when the object is at the bottom of the circle?

A. $m(\omega^2 r + g)$

B. $m(\omega^2 r - g)$

C. $mg(\omega^2 r + 1)$

D. $mg(\omega^2 r - 1)$

Markscheme

A

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2. Newton's law of gravitation *[1 mark]*

A. is equivalent to Newton's second law of motion.

B. explains the origin of gravitation.

C. is used to make predictions.

D. is not valid in a vacuum.

Markscheme

C

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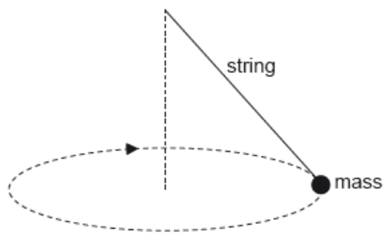
3. A mass at the end of a string is swung in a horizontal circle at increasing speed until the string breaks. *[1 mark]*



The subsequent path taken by the mass is a

A. line along a radius of the circle.

B. horizontal circle.

C. curve in a horizontal plane.

D. curve in a vertical plane.

Markscheme

D

4. An object of mass *m* moves in a horizontal circle of radius *r* with a constant speed *v*. What is the rate at which work is done by the centripetal force? *[1 mark]*

A. $\frac{mv^3}{r}$

B. $\frac{mv^3}{2\pi r}$

C. $\frac{mv^3}{4\pi r}$

D. zero

Markscheme

D

A planet has radius *R*. At a distance *h* above the surface of the planet the gravitational field strength is *g* and the gravitational potential is *V*.

5a. State what is meant by gravitational field strength. *[1 mark]*

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Markscheme

the «gravitational» force per unit mass exerted on a point/small/test mass

[1 mark]

5b. Show that $V = -g(R + h)$. *[2 marks]*

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Markscheme

at height h potential is $V = -\frac{GM}{(R+h)}$

field is $g = \frac{GM}{(R+h)^2}$

«dividing gives answer»

Do not allow an answer that starts with $g = -\frac{\Delta V}{\Delta r}$ and then cancels the deltas and substitutes $R + h$

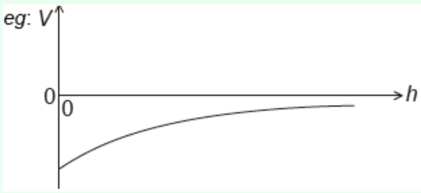
[2 marks]

5c. Draw a graph, on the axes, to show the variation of the gravitational potential V of the planet with height h above the surface of the planet. *[2 marks]*

Markscheme

correct shape and sign

non-zero negative vertical intercept



[2 marks]

5d. A planet has a radius of 3.1×10^6 m. At a point P a distance 2.4×10^7 m above the surface of the planet the gravitational field strength is 2.2 N kg^{-1}. Calculate the gravitational potential at point P, include an appropriate unit for your answer. *[1 mark]*

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Markscheme

V = «–2.2 × ($3.1 \times 10^6 + 2.4 \times 10^7$) =» «–» 6.0×10^7 J kg^{-1}

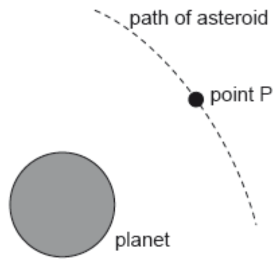
Unit is essential

Allow eg MJ kg^{-1} if power of 10 is correct

Allow other correct SI units eg m^2s^{-2}, N m kg^{-1}

[1 mark]

5e. The diagram shows the path of an asteroid as it moves past the planet. *[3 marks]*



When the asteroid was far away from the planet it had negligible speed. Estimate the speed of the asteroid at point P as defined in (b).

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Markscheme

total energy at P = 0 / KE gained = GPE lost

« $\frac{1}{2}mv^2 + mV = 0 \Rightarrow$» $v = \sqrt{-2V}$

$v =$ « $\sqrt{2 \times 6.0 \times 10^7}$ =» 1.1×10^4 «ms^{-1}»

*Award **[3]** for a bald correct answer*

Ignore negative sign errors in the workings

Allow ECF from 6(b)

[3 marks]

5f. The mass of the asteroid is 6.2×10^{12} kg. Calculate the gravitational force experienced by the **planet** when the asteroid is at point P. *[2 marks]*

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Markscheme

ALTERNATIVE 1

force on asteroid is «$6.2 \times 10^{12} \times 2.2 =$» 1.4×10^{13} «N»

«by Newton's third law» this is also the force on the planet

ALTERNATIVE 2

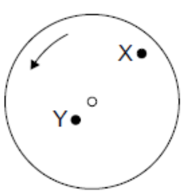
mass of planet = 2.4×10^{25} «kg» «from $V = -\frac{GM}{(R+h)}$»

force on planet «$\frac{GMm}{(R+h)^2}$» = 1.4×10^{13} «N»

MP2 must be explicit

[2 marks]

6. A horizontal disc rotates uniformly at a constant angular velocity about a central axis normal to the plane of the disc. *[1 mark]*



Point X is a distance $2L$ from the centre of the disc. Point Y is a distance L from the centre of the disc. Point Y has a linear speed v and a centripetal acceleration a.

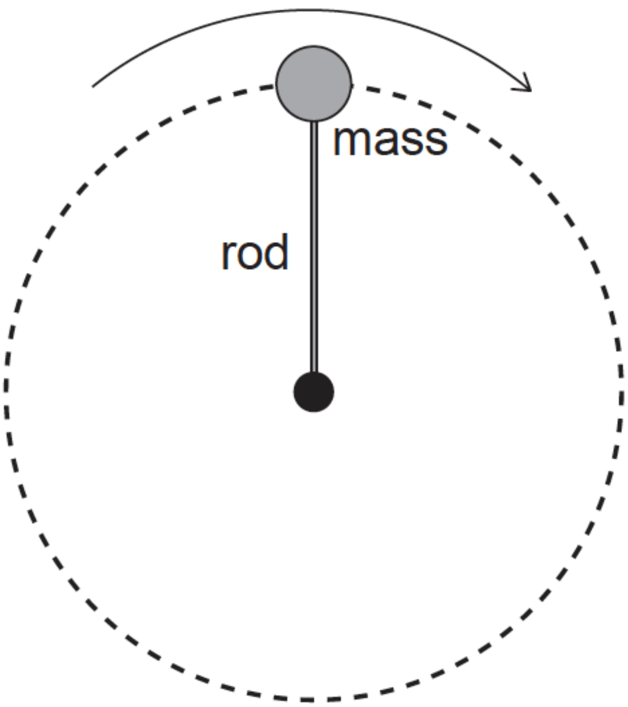
What is the linear speed and centripetal acceleration of point X?

	Linear speed of X	Centripetal acceleration of X
A.	v	a
B.	$2v$	$2a$
C.	v	$2a$
D.	$2v$	$4a$

Markscheme

B

7. A mass connected to one end of a rigid rod rotates at constant speed in a vertical plane about the other end of the rod. *[1 mark]*



The force exerted by the rod on the mass is

A. zero everywhere.

B. constant in magnitude.

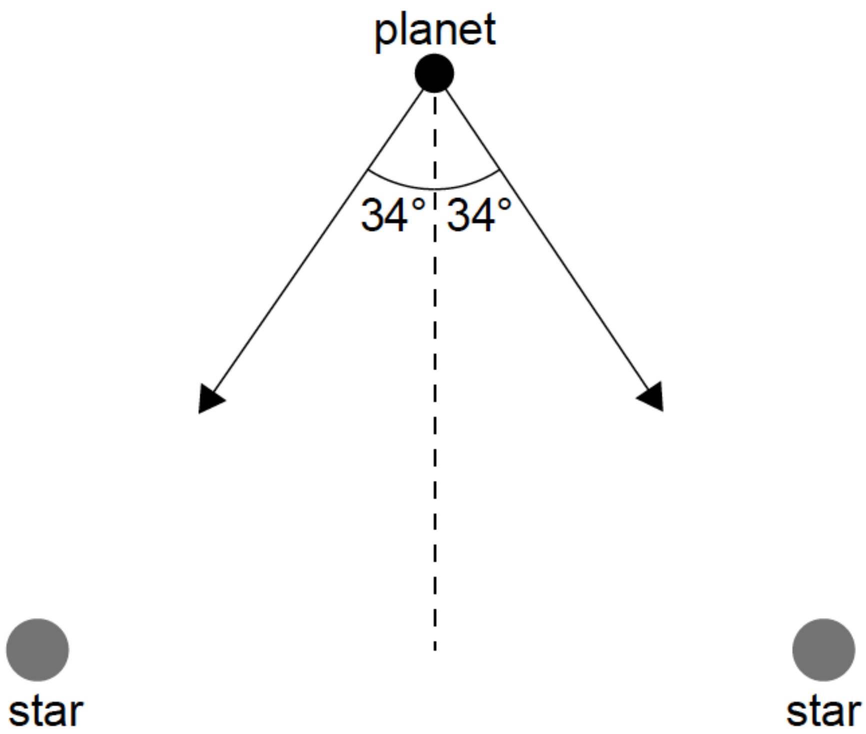
C. always directed towards the centre.

D. a minimum at the top of the circular path.

Markscheme

D

The two arrows in the diagram show the gravitational field strength vectors at the position of a planet due to each of two stars of equal mass *M*.



Each star has mass $M = 2.0 \times 10^{30}$ kg. The planet is at a distance of 6.0×10^{11} m from each star.

8a. Show that the gravitational field strength at the position of the planet due to **one** of the stars is $g = 3.7 \times 10^{-4}$ N kg^{-1}. *[1 mark]*

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Markscheme

$$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{-11} \times 2.0 \times 10^{30}}{(6.0 \times 10^{11})^2}$$

OR

3.71×10^{-4} N kg^{-1}

8b. Calculate the magnitude of the resultant gravitational field strength at the position of the planet. *[2 marks]*

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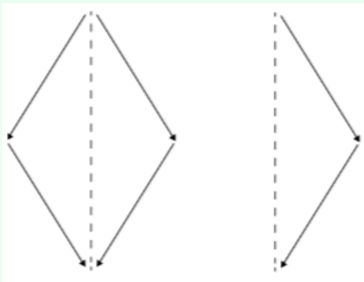
Markscheme

«g_{net} = 2cos34» 2g ***OR*** $g$cos34 ***OR*** $g$sin56 ***OR*** vector addition diagram shown



«g_{net} =«$2 \times 3.7 \times 10^{-4} \times \cos 34^{o}$ =» 6.1×10^{-4} Nkg^{-1}

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9. A car travels in a horizontal circle at constant speed. At any instant the resultant horizontal force acting on the car is *[1 mark]*

A. zero.
B. in the direction of travel of the car.
C. directed out from the centre of the circle.
D. directed towards the centre of the circle.

Markscheme

D

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10. A spacecraft travels away from Earth in a straight line with its motors shut down. At one instant the speed of the spacecraft is 5.4 km s^{-1}. After a time of 600 s, the speed is 5.1 km s^{-1}. The average gravitational field strength acting on the spacecraft during this time interval is *[1 mark]*

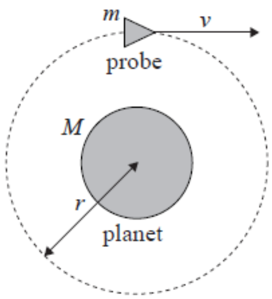
1. 5.0×10^{-4} N kg^{-1}
2. 3.0×10^{-2} N kg^{-1}
3. 5.0×10^{-1} N kg^{-1}
4. 30 N kg^{-1}

Markscheme

C

This question is about a probe in orbit.

A probe of mass *m* is in a circular orbit of radius *r* around a spherical planet of mass *M*.



(diagram not to scale)

11a. State why the work done by the gravitational force during one full revolution of the probe is zero. *[1 mark]*

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Markscheme

because the force is always at right angles to the velocity / motion/orbit is an equipotential surface;

Do not accept answers based on the displacement being zero for a full revolution.

11b. Deduce for the probe in orbit that its *[4 marks]*

(i) speed is $v = \sqrt{\frac{GM}{r}}$.

(ii) total energy is $E = -\frac{GMm}{2r}$.

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Markscheme

(i) equating gravitational force $\frac{GMm}{r^2}$;
to centripetal force $\frac{mv^2}{r}$ to get result;

(ii) kinetic energy is $\frac{GMm}{2r}$;
addition to potential energy $-\frac{GMm}{r}$ to get result;

11c. It is now required to place the probe in another circular orbit further away from the planet. To do this, the probe's engines will be fired for a very short time. *[2 marks]*

State and explain whether the work done on the probe by the engines is positive, negative **or** zero.

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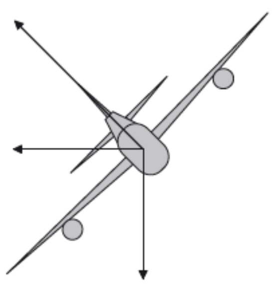
Markscheme

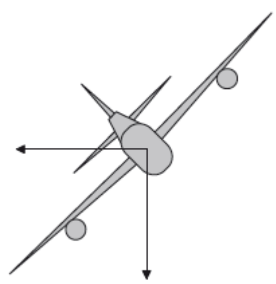
the total energy (at the new orbit) will be greater than before/is less negative;
hence probe engines must be fired to produce force in the direction of motion / positive work must be done (on the probe);
*Award **[1]** for mention of only potential energy increasing.*

12. An aircraft is flying at constant speed in a horizontal circle. Which of the following diagrams best illustrates the forces acting on the aircraft in the vertical plane? *[1 mark]*

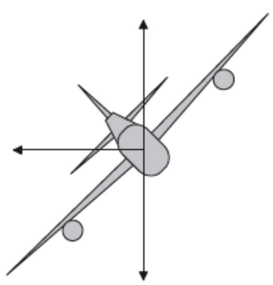
A.



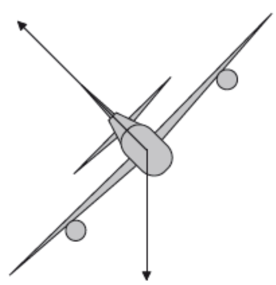
B.



C.



D.



Markscheme

D

13. The mass of Earth is M_{E}, its radius is R_{E} and the magnitude of the gravitational field strength at the surface of Earth is g. The universal gravitational constant is G. The ratio $\frac{g}{G}$ is equal to *[1 mark]*

A. $\frac{M_{\mathrm{E}}}{R_{\mathrm{E}}^2}$

B. $\frac{R_{\mathrm{E}}^2}{M_{\mathrm{E}}}$

C. $M_{\mathrm{E}}R_{\mathrm{E}}$

D. 1

Markscheme

A

14. A communications satellite is moving at a constant speed in a circular orbit around Earth. At any given instant in time, the resultant force on the satellite is *[1 mark]*

A. zero.

B. equal to the gravitational force on the satellite.

C. equal to the vector sum of the gravitational force on the satellite and the centripetal force.

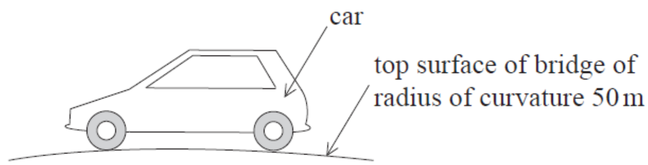
D. equal to the force exerted by the satellite's rockets.

Markscheme

B

This question is about circular motion.

The diagram shows a car moving at a constant speed over a curved bridge. At the position shown, the top surface of the bridge has a radius of curvature of 50 m.



15a. Explain why the car is accelerating even though it is moving with a constant speed. *[2 marks]*

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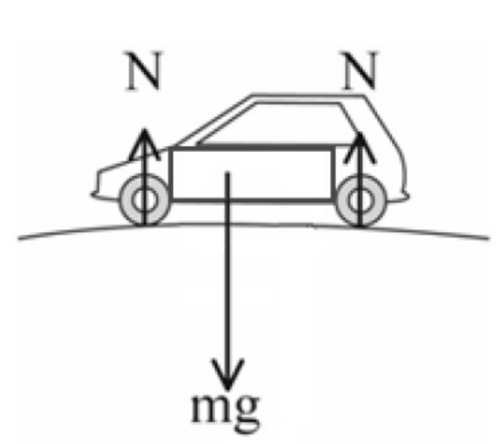
Markscheme

direction changing;

velocity changing so accelerating;

15b. On the diagram, draw and label the vertical forces acting on the car in the position shown. *[2 marks]*

Markscheme



weight/gravitational force/mg/w/F_w/F_g and reaction/normal reaction/perpendicular contact force/N/R/F_N/F_R both labelled; *(do not allow "gravity" for "weight".)*

weight between wheels (in box) from centre of mass and reactions at both wheels / single reaction acting along same line of action as the weight;

Judge by eye. Look for reasonably vertical lines with weight force longer than (sum of) reaction(s). Extra forces (eg centripetal force) loses the second mark.

15c. Calculate the maximum speed at which the car will stay in contact with the bridge. *[3 marks]*

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Markscheme

$g = \frac{v^2}{r}$;
$v = \sqrt{50 \times 9.8}$;

22(ms^{-1});

*Allow **[3]** for a bald correct answer.*

This question is in **two** parts. **Part 1** is about gravitational force fields. **Part 2** is about properties of a gas.

Part 1 Gravitational force fields

16a. State Newton's universal law of gravitation. *[2 marks]*

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Markscheme

the (attractive) force between two (point) masses is directly proportional to the product of the masses;
and inversely proportional to the square of the distance (between their centres of mass);
Use of equation is acceptable:
*Award **[2]** if all five quantities defined. Award **[1]** if four quantities defined.*

16b. A satellite of mass *m* orbits a planet of mass *M*. Derive the following relationship between the period of the satellite *T* and the radius of its orbit *R* (Kepler's third law). *[3 marks]*

$T^2 = \frac{4\pi^2 R^3}{GM}$

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Markscheme

$G\frac{Mm}{R^2} = \frac{mv^2}{R}$ so $v^2 = \frac{Gm}{R}$;
$v = \frac{2\pi R}{T}$;
$v^2 = \frac{4\pi^2 R^2}{T^2} = \frac{Gm}{R}$;

or

$G\frac{Mm}{R^2} = m\omega^2 R$;
$\omega^2 = \frac{4\pi^2}{T^2}$;
$\frac{4\pi^2}{T^2} = \frac{GM}{R^3}$;
*Award **[3]** to a clear response with a missing step.*

16c. A polar orbiting satellite has an orbit which passes above both of the Earth's poles. One polar orbiting satellite used for Earth observation has an orbital period of 6.00×10^3 s. *[8 marks]*

Mass of Earth = 5.97×10^{24} kg
Average radius of Earth = 6.37×10^{6} m

(i) Using the relationship in (b), show that the average height above the surface of the Earth for this satellite is about 800 km.

(ii) The satellite moves from an orbit of radius 1200 km above the Earth to one of radius 2500 km. The mass of the satellite is 45 kg.

Calculate the change in the gravitational potential energy of the satellite.

(iii) Explain whether the gravitational potential energy has increased, decreased or stayed the same when the orbit changes, as in (c)(ii).

Markscheme

(i) $R^3 = \frac{6.67\times10^{-11}\times5.97\times10^{24}\times6000^2}{4\times\pi^2}$;
R=7.13x10^6(m);
h=(7.13x10^6-6.37x10^6)=760(km);
*Award **[3]** for an answer of 740 with π taken as 3.14.*

(ii) clear use of $\Delta V = \frac{\Delta E}{m}$ and $V = -\frac{Gm}{r}$ **or** $\Delta E = GMm\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$;
one value of potential energy calculated (2.37×10^9 ***or*** 2.02×10^9);
3.5×10^8 (J);
*Award **[3]** for a bald correct answer.*
*Award **[2]** for 7.7x10^9. Award **[1]** for 7.7x10^{12}.*
*Award **[0]** for answers using mgΔh.*

(iii) increased;
further from Earth / closer to infinity / smaller negative value;
*Award **[0]** for a bald correct answer.*