GravitationCircle *[183 marks]*

1. 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.

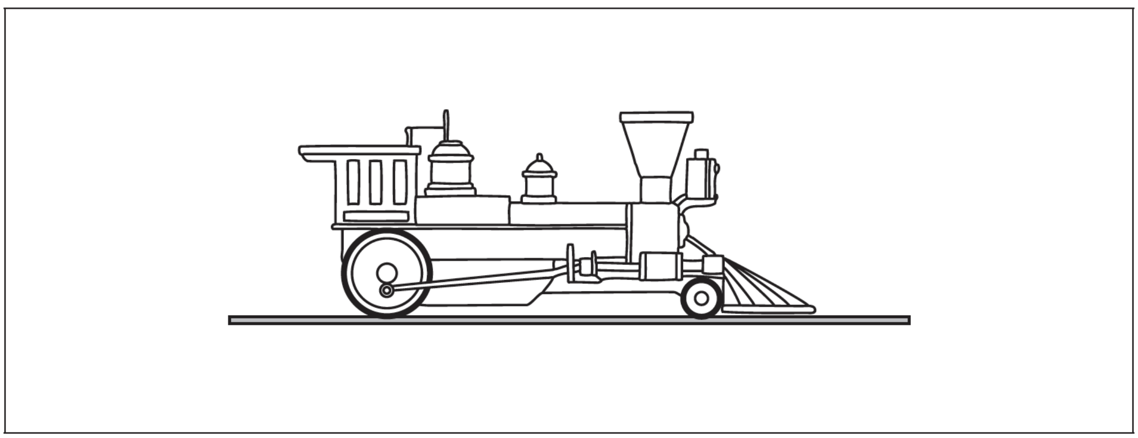
Markscheme

D

This question is in two parts. **Part 1** is about forces. **Part 2** is about internal energy.

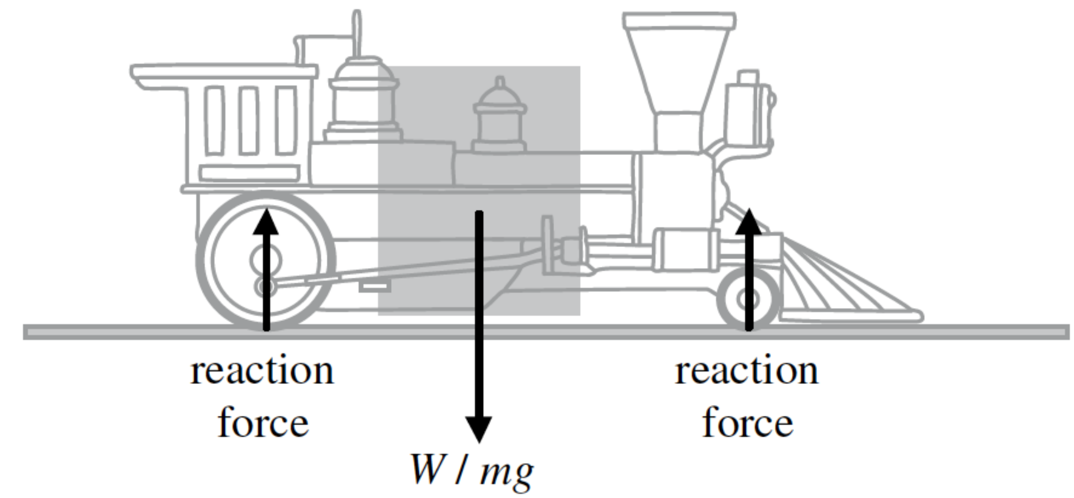
Part 1 Forces

A railway engine is travelling along a horizontal track at a constant velocity.



2a. On the diagram above, draw labelled arrows to represent the vertical forces that act on the railway engine. *[3 marks]*

Markscheme



The shaded box shows the acceptable range of position for W/mg.
single downward arrow labelled *W*/weight ***or*** *mg*/gravity force; *(do not allow gravity)*
two upward arrows labelled reaction/contact forces; *(do not allow for only one arrow seen)*
arrow positions as shown in diagram;

2b. Explain, with reference to Newton's laws of motion, why the velocity of the railway engine is constant. *[2 marks]*

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Markscheme

horizontal forces have resultant of zero; *(must describe or imply horizontal force)*
valid statement linked to theory (*e.g.* Newton 1/Newton 2/conservation of momentum) explaining why zero force results in constant velocity/zero acceleration;

2c. The constant horizontal velocity of the railway engine is 16 ms $^{-1}$. A total horizontal resistive force of 76 kN acts on the railway engine. *[2 marks]*

Calculate the useful power output of the railway engine.

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Markscheme

power $=16 \times 76000$;
1.2 MW;

2d. The power driving the railway engine is switched off. The railway engine stops, from its speed of 16 ms^{-1}, without braking in a distance of 1.1 km. A student hypothesizes that the horizontal resistive force is constant. *[2 marks]*

Based on this hypothesis, calculate the mass of the railway engine.

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Markscheme

acceleration$= \frac{16^2}{2 \times 1100} (= 0.116)$;
$m = \left(\frac{7.6 \times 10^4}{0.116} = \right) 6.5 \times 10^5 \mathrm{kg}$;
*Award **[2]** for a bald correct answer.*

or

use of *Fs*$=\frac{1}{2} m v^2$;
$m = \left(\frac{2 \times 7.6 \times 10^4 \times 1100}{16^2} = \right) 6.5 \times 10^5 \mathrm{kg}$;
*Award **[2]** for a bald correct answer.*

2e. Another hypothesis is that the horizontal force in (c) consists of two components. One component is a constant frictional force of 19 kN. The other component is a resistive force F that varies with speed v where F is proportional to v^3. *[5 marks]*

(i) State the value of the magnitude of F when the railway engine is travelling at 16 ms $^{-1}$.

(ii) Determine the **total** horizontal resistive force when the railway engine is travelling at 8.0 ms $^{-1}$.

Markscheme

(i) 57 kN;

(ii) $F_8 = \frac{F_{16}}{2^3}$;
F_8=7.1(kN);
total force =19+7.1(kN);
=26 kN;
*Award **[4]** for a bald correct answer.*

or

$k = \left(\frac{57 \times 10^3}{16^3}\right) = 13.91$;
F_8=(13.91×8^3)=7.1(kN);
total force=19+7.1(kN);
=26 kN;
*Award **[4]** for a bald correct answer.*

2f. On its journey, the railway engine now travels around a curved track at constant speed. Explain whether or not the railway engine is accelerating. *[3 marks]*

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Markscheme

direction of engine is constantly changing;
velocity is speed + direction / velocity is a vector;
engine is accelerating as velocity is changing;
*Award **[0]** for a bald correct answer.*

or

centripetal force required to maintain circular motion;
quotes Newton 1/Newton 2;
so engine is accelerating as a force acts;
*Award **[0]** for a bald correct answer.*

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3. A spherical planet of uniform density has three times the mass of the Earth and twice the average radius. The magnitude of the gravitational field strength at the surface of the Earth is *g*. What is the gravitational field strength at the surface of the planet? *[1 mark]*

A. 6 g

B. $\frac{2}{3}g$

C. $\frac{3}{4}g$

D. $\frac{3}{2}g$

Markscheme

C

4. A cyclist rides around a circular track at a uniform speed. Which of the following correctly gives the net horizontal force on the cyclist at any given instant of time? *[1 mark]*

	Net horizontal force along direction of motion	Net horizontal force normal to direction of motion
A.	zero	zero
B.	zero	non zero
C.	non zero	zero
D.	non zero	non zero

Markscheme

B

5. 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

6. A particle of mass m is moving with constant speed v in uniform circular motion. What is the total work done by the centripetal force during one revolution? *[1 mark]*

A. Zero

B. $\frac{mv^2}{2}$

C. mv^2

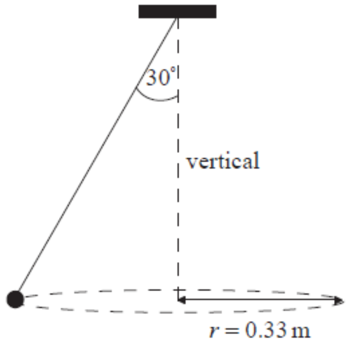
D. $2\pi mv^2$

Markscheme

A

This question is about circular motion.

A ball of mass 0.25 kg is attached to a string and is made to rotate with constant speed *v* along a horizontal circle of radius *r* = 0.33m. The string is attached to the ceiling and makes an angle of 30° with the vertical.



7a. (i) On the diagram above, draw and label arrows to represent the forces on the ball in the position shown. *[4 marks]*

(ii) State and explain whether the ball is in equilibrium.

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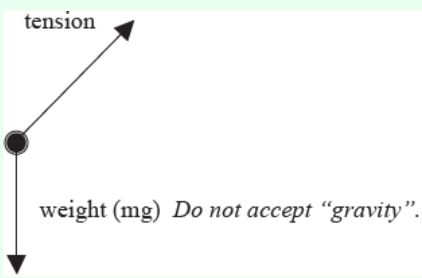
Markscheme

(i) ***[1]*** each for correct arrow and (any reasonable) labelling;



*Award **[1 max]** for arrows in correct direction but not starting at the ball.*

(ii) no;
because the two forces on the ball can never cancel out / there is a net force on the ball / the ball moves in a circle / the ball has acceleration/it is changing direction;
*Award **[0]** for correct answer with no or wrong argument.*

7b. Determine the speed of rotation of the ball. *[3 marks]*

Markscheme

$T\left(=\frac{mg}{\cos 30°}\right) = 2.832\text{N};$

$\frac{mv^2}{r} = T\sin 30°;$

$v = \left(\sqrt{\frac{Tr\sin 30°}{m}} = \sqrt{\frac{2.832\times 0.33\times \sin 30°}{0.25}}\right) = 1.4\text{ms}^{-1};$

or

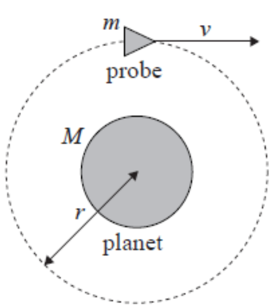
$T\cos 30° = mg;$

$T\sin 30° = \frac{mv^2}{r};$

$v = \left(\sqrt{gr\tan 30°} = \sqrt{9.81\times 0.33\times \tan 30°}\right) = 1.4\text{ms}^{-1};$

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)

8a. State why the work done by the gravitational force during one full revolution of the probe is zero. *[1 mark]*

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.

8b. Deduce for the probe in orbit that its *[4 marks]*

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

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

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;

8c. 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.

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.*

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9. The mass of a planet is twice that of Earth. Its radius is half that of the radius of Earth. The gravitational field strength at the surface of Earth is g. The gravitational field strength at the surface of the planet is *[1 mark]*

A. $\frac{1}{2}g$.

B. g.

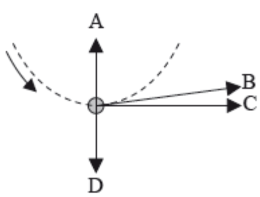
C. $2g$.

D. $8g$.

Markscheme

D

10. A ball is tied to a string and rotated at a uniform speed in a vertical plane. The diagram shows the ball at its lowest position. Which arrow shows the direction of the net force acting on the ball? *[1 mark]*



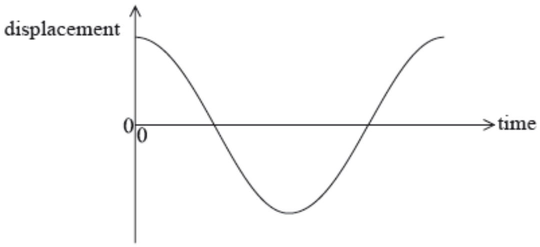
Markscheme

A

This question is in **two** parts. **Part 1** is about a simple pendulum. **Part 2** is about the Rutherford model of the atom.

Part 1 Simple pendulum

A pendulum consists of a bob suspended by a light inextensible string from a rigid support. The pendulum bob is moved to one side and then released. The sketch graph shows how the displacement of the pendulum bob undergoing simple harmonic motion varies with time over one time period.



On the sketch graph above,

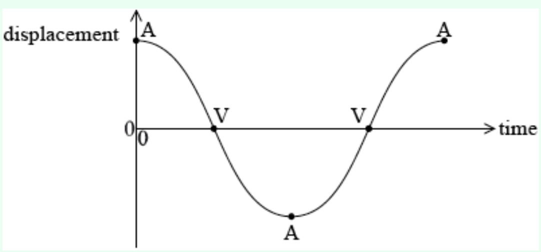
11a. (i) label with the letter A a point at which the acceleration of the pendulum bob is a maximum. *[2 marks]*

(ii) label with the letter V a point at which the speed of the pendulum bob is a maximum.

Markscheme

(i) one A correctly shown;

(ii) one V correctly shown;



11b. Explain why the magnitude of the tension in the string at the midpoint of the oscillation is greater than the weight of the pendulum bob. *[3 marks]*

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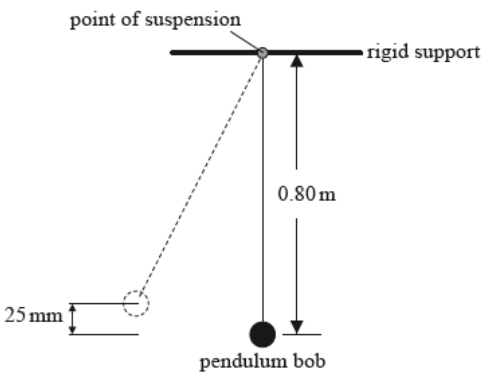
Markscheme

pendulum bob accelerates towards centre of circular path / *OWTTE*;

therefore force upwards;

that adds to tension produced by the weight;

A pendulum bob is moved to one side until its centre is 25 mm above its rest position and then released.



11c. (i) Show that the speed of the pendulum bob at the midpoint of the oscillation is $0.70\ \mathrm{m\,s^{-1}}$. *[5 marks]*

(ii) The mass of the pendulum bob is 0.057 kg. The centre of the pendulum bob is 0.80 m below the support. Calculate the magnitude of the tension in the string when the pendulum bob is vertically below the point of suspension.

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Markscheme

(i) evidence shown of equating kinetic energy and gravitational potential energy;

$v = \sqrt{(2 \times 9.8 \times 0.025)}$;

$= 0.70 \text{ m s}^{-1}$

Allow g = 10 m s^{-2} answer 0.71 m s^{-2}.

(ii) centripetal acceleration $\left(= \frac{v^2}{r}\right) \left[= \frac{0.7^2}{0.8}\right] = 0.61 \left(\text{m s}^{-2}\right)$;

net acceleration $= (9.81 + 0.61 =) \; 10.4 \left(\text{m s}^{-2}\right)$ ***or*** $T - mg = m \times 0.61$;

$\text{tension} = (ma =) \; 0.59 \text{ N}$;

Allow g = 10 m s^{-2} answer 0.60 N.

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

Part 2 Rutherford model of the atom

The isotope gold-197 $\left({}^{197}_{79}Au\right)$ is stable but the isotope gold-199 $\left({}^{199}_{79}Au\right)$ is not.

11d. (i) Outline, in terms of the forces acting between nucleons, why, for large stable nuclei such as gold-197, the number of neutrons exceeds the number of protons. *[4 marks]*

(ii) A nucleus of ${}^{199}_{79}\text{Au}$ decays to a nucleus of ${}^{199}_{80}\text{Hg}$ with the emission of an electron and another particle. State the name of this other particle.

Markscheme

(i) mention of Coulomb repulsion between protons;

mention of strong (nuclear) force (between nucleons);

overall balance must be correct (and more neutrons needed for this);

*Award **[0]** for a statement that neutron is negative.*

(ii) anti neutrino / $\bar{v}$;

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12. The weight of an object of mass 1 kg at the surface of Mars is about 4 N. The radius of Mars is about half the radius of Earth. Which of the following is the best estimate of the ratio below? *[1 mark]*

$$\frac{\text{mass of Mars}}{\text{mass of Earth}}$$

A. 0.1

B. 0.2

C. 5

D. 10

Markscheme

A

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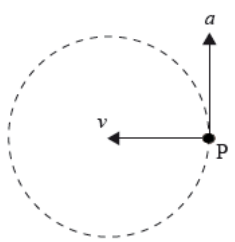
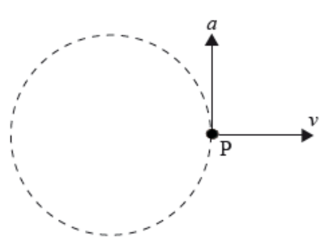
13. A particle P is moving anti-clockwise with constant speed in a horizontal circle. *[1 mark]*

Which diagram correctly shows the direction of the velocity v and acceleration a of the particle P in the position shown?

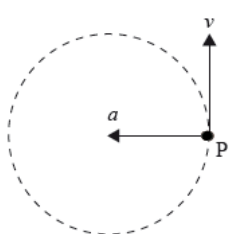
A.



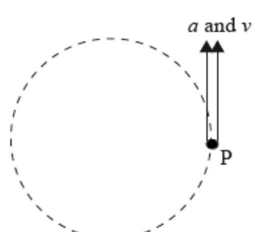
B.



C.



D.



Markscheme

C

14. A small sphere X of mass M is placed a distance d from a point mass. The gravitational force on sphere X is 90 N. Sphere X is removed and a second sphere Y of mass $4M$ is placed a distance $3d$ from the same point mass. The gravitational force on sphere Y is *[1 mark]*

A. 480 N.

B. 160 N.

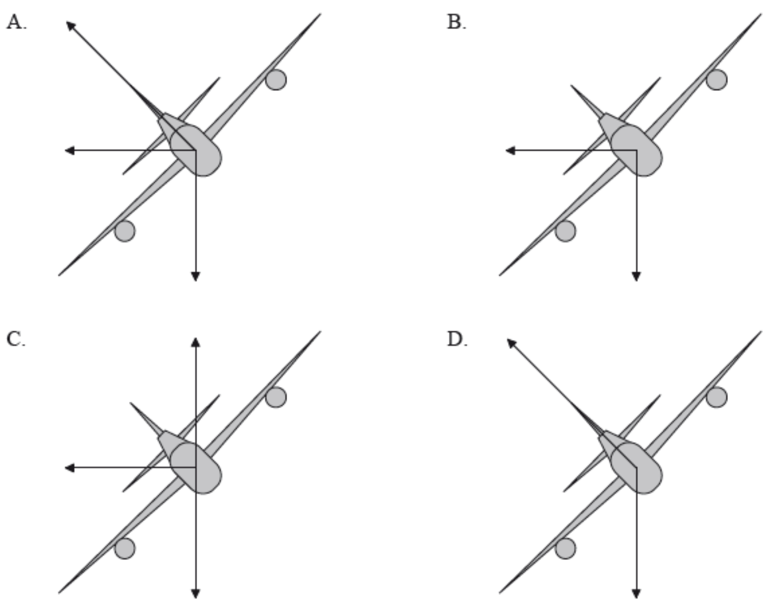
C. 120 N.

D. 40 N.

Markscheme

D

15. 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]*



Markscheme

D

16. For a particle moving at constant speed in a horizontal circle, the work done by the centripetal force is *[1 mark]*

A. zero.

B. directly proportional to the particle mass.

C. directly proportional to the particle speed.

D. directly proportional to the (particle speed) ^{2}.

Markscheme

A

17. 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

18. 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 in **two** parts. **Part 1** is about solar radiation and the greenhouse effect. **Part 2** is about orbital motion.

Part 1 Solar radiation and the greenhouse effect

The following data are available.

Quantity	Symbol	Value
Radius of Sun	R	7.0×10^{8} m
Surface temperature of Sun	T	5.8×10^{3} K
Distance from Sun to Earth	d	1.5×10^{11} m
Stefan-Boltzmann constant	σ	5.7×10^{-8} W m^{-2} K^{-4}

19a. State the Stefan-Boltzmann law for a black body. *[2 marks]*

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Markscheme

power/energy per second emitted is proportional to surface area;
and proportional to fourth power of absolute temperature / temperature in K;
Accept equation with symbols defined.

19b. Deduce that the solar power incident per unit area at distance *d* from the Sun is given by *[2 marks]*

$\frac{\sigma R^2 T^4}{d^2}$.

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Markscheme

solar power given by $4\pi R^2 \sigma T^4$;
spreads out over sphere of surface area $4\pi d^2$;
Hence equation given.

19c. Calculate, using the data given, the solar power incident per unit area at distance *d* from the Sun. *[2 marks]*

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Markscheme

$\left(\frac{\sigma R^2 T^4}{d^2} =\right) \frac{5.7\times10^{-8}\times\left[7.0\times10^{8}\right]^2\times\left[5.8\times10^{3}\right]^4}{\left[1.5\times10^{11}\right]^2}$;

$=1.4\times10^3 (Wm^{-2})$;

*Award **[2]** for a bald correct answer.*

19d. State **two** reasons why the solar power incident per unit area at a point on the surface of the Earth is likely to be different from your answer in (c). *[2 marks]*

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Markscheme

some energy reflected;
some energy absorbed/scattered by atmosphere;
depends on latitude;
depends on time of day;
depends on time of year;
depends on weather (*eg* cloud cover) at location;
power output of Sun varies;
Earth-Sun distance varies;

19e. The average power absorbed per unit area at the Earth's surface is 240Wm $^{-2}$. By treating the Earth's surface as a black body, show that the average surface temperature of the Earth is approximately 250K. *[2 marks]*

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Markscheme

power radiated=power absorbed;
$T = \sqrt[4]{\frac{240}{5.7\times10^{-8}}}\,(= 250\mathrm{K});$

Accept answers given as 260 (K).

19f. Explain why the actual surface temperature of the Earth is greater than the value in (e). *[3 marks]*

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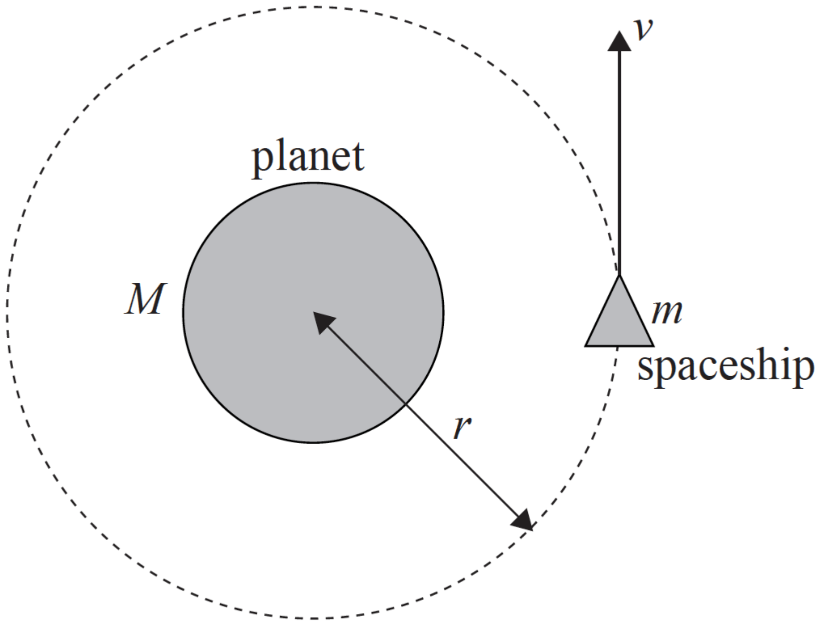
Markscheme

radiation from Sun is re-emitted from Earth at longer wavelengths;
greenhouse gases in the atmosphere absorb some of this energy;
and radiate some of it back to the surface of the Earth;

Part 2 Orbital motion

A spaceship of mass m is moving at speed v in a circular orbit of radius r around a planet of mass M.



(not to scale)

19g. (i) Identify the force that causes the centripetal acceleration of the spaceship. *[4 marks]*

(ii) Explain why astronauts inside the spaceship would feel “weightless”, even though there is a force acting on them.

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Markscheme

(i) gravitational force / gravitational attraction / weight; *(do not accept gravity)*

(ii) astronauts and spaceship have the same acceleration;
acceleration is towards (centre of) planet;
so no reaction force between astronauts and spaceship;

or

astronauts and spaceships are both falling towards the (centre of the) planet;
at the same rate;
so no reaction force between astronauts and spaceship;

19h. Deduce that the speed of the spaceship is $v = \sqrt{\frac{GM}{r}}$. *[2 marks]*

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Markscheme

gravitational force equated with centripetal force / $\frac{GmM}{r^2} = \frac{mv^2}{r}$;

$\Rightarrow v^2 = \frac{GM}{r} \Rightarrow \left(v = \sqrt{\frac{GM}{r}}\right)$;

19i. The table gives equations for the forms of energy of the orbiting spaceship. *[4 marks]*

Form of Energy	Equation
Kinetic	$E_K = \frac{GMm}{2r}$
Gravitational potential	$E_P = -\frac{GMm}{r}$
Total (kinetic + potential)	$E = -\frac{GMm}{2r}$

The spaceship passes through a cloud of gas, so that a small frictional force acts on the spaceship.

(i) State and explain the effect that this force has on the total energy of the spaceship.

(ii) Outline the effect that this force has on the speed of the spaceship.

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Markscheme

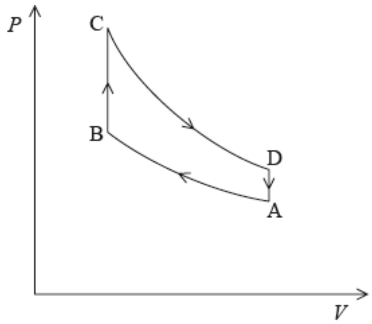
(i) thermal energy is lost;
total energy decreases;

(ii) since E decreases, r also decreases;
as r decreases v increases / E_k increases so v increases;

This question is about the thermodynamics of a car engine and the dynamics of the car.

A car engine consists of four cylinders. In each of the cylinders, a fuel-air mixture explodes to supply power at the appropriate moment in the cycle.

The diagram models the variation of pressure P with volume V for one cycle of the gas, ABCDA, in one of the cylinders of the engine. The gas in the cylinder has a fixed mass and can be assumed to be ideal.



20a. At point A in the cycle, the fuel-air mixture is at 18 °C. During process AB, the gas is compressed to 0.046 of its original volume and the pressure increases by a factor of 40. Calculate the temperature of the gas at point B. *[1 mark]*

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Markscheme

535 (K) / 262 (°C);

20b. State the nature of the change in the gas that takes place during process BC in the cycle. *[1 mark]*

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Markscheme

constant volume change / isochoric / isovolumetric / *OWTTE*;

20c. Process CD is an adiabatic change. Discuss, with reference to the first law of thermodynamics, the change in temperature of the gas in the cylinder during process CD. *[3 marks]*

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Markscheme

Q/thermal energy transfer is zero;

$\Delta U = -W$;

as work is done by gas internal energy falls;

temperature falls as temperature is measure of average kinetic energy;

20d. Explain how the diagram can be used to calculate the net work done during one cycle. *[2 marks]*

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Markscheme

work done is estimated by evaluating area;

inside the loop / *OWTTE*;

The car is travelling at its maximum speed of $56\ \mathrm{m\,s^{-1}}$. At this speed, the energy provided by the fuel injected into one cylinder in each cycle is 9200 J. One litre of fuel provides 56 MJ of energy.

20e. (i) Calculate the volume of fuel injected into one cylinder during one cycle. *[3 marks]*

(ii) Each of the four cylinders completes a cycle 18 times every second. Calculate the distance the car can travel on one litre of fuel at a speed of $56\ \mathrm{m\,s^{-1}}$.

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Markscheme

(i) 1.6×10^{-4} (litre);

(ii) one litre $= \left(\frac{1}{4\times 18\times 1.64\times 10^{-4}} =\right)$ 87 s of travel;

$(87 \times 56) = 4.7$ (km);

Allow rounded 1.6 value to be used, giving 4.9 (km).

20f. A car accelerates uniformly along a straight horizontal road from an initial speed of $12\ \mathrm{m\,s^{-1}}$ to a final speed of $28\ \mathrm{m\,s^{-1}}$ in a distance of 250 m. The mass of the car is 1200 kg. Determine the rate at which the engine is supplying kinetic energy to the car as it accelerates. *[4 marks]*

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Markscheme

use of a kinematic equation to determine motion time $(= 12.5\ \mathrm{s})$;

change in kinetic energy $= \frac{1}{2} \times 1200 \times [28^2 - 12^2]\ (= 384\ \mathrm{kJ})$;

rate of change in kinetic energy $= \frac{384000}{12.5}$; } *(allow ECF of 16^2 from $(28 - 12)^2$ for this mark)*

31 (kW);

or

use of a kinematic equation to determine motion time $(= 12.5\ \mathrm{s})$;

use of a kinematic equation to determine acceleration $(= 1.28\ \mathrm{m\,s^{-2}})$;

work done $\frac{F \times s}{\mathrm{time}} = \frac{1536 \times 250}{12.5}$;

31 (kW);

A driver moves a car in a horizontal circular path of radius 200 m. Each of the four tyres will not grip the road if the frictional force between a tyre and the road becomes less than 1500 N.

20g. (i) Calculate the maximum speed of the car at which it can continue to move in the circular path. Assume that the radius of the path is the same for each tyre. *[6 marks]*

(ii) While the car is travelling around the circle, the people in the car have the sensation that they are being thrown outwards. Outline how Newton's first law of motion accounts for this sensation.

Markscheme

(i) centripetal force must be $< 6000\ (\mathrm{N})$; *(allow force 6000 N)*

$v^2 = F \times \frac{r}{m}$;

$31.6\ (\mathrm{m\,s^{-1}})$;

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

*Allow **[2 max]** if 4× is omitted, giving 15.8 (m s^{-1}).*

(ii) statement of Newton's first law;

(hence) without car wall/restraint/friction at seat, the people in the car would move in a straight line/at a tangent to circle;

(hence) seat/seat belt/door exerts centripetal force;

(in frame of reference of the people) straight ahead movement is interpreted as "outwards";

21. The force F between particles in gravitational and electric fields is related to the separation r of the particles by an equation of the form *[1 mark]*

$F = a\frac{bc}{r^2}$.

Which of the following identifies the units for the quantities a, b and c for a gravitational field?

	a	b and c
A.	$N\,m^2\,C^{-2}$	C
B.	$N\,m^2\,C^{-2}$	kg
C.	$N\,m^2\,kg^{-2}$	C
D.	$N\,m^2\,kg^{-2}$	kg

Markscheme

D

22. A body moves with uniform speed around a circle of radius r. The period of the motion is T. What is the speed of the body? *[1 mark]*

A. $\frac{2\pi r}{T}$

B. $\frac{2\pi T}{r}$

C. Zero

D. $\frac{\pi r^2}{T}$

Markscheme

A

23. The magnitude of the gravitational field strength at the surface of a planet of mass M and radius R is g. What is the magnitude of the gravitational field strength at the surface of a planet of mass $2M$ and radius $2R$? *[1 mark]*

A. $\frac{g}{4}$

B. $\frac{g}{2}$

C. g

D. $2g$

Markscheme

B

24. A car on a road follows a horizontal circular path at constant speed. Which of the following correctly identifies the origin and the direction of the net force on the car? *[1 mark]*

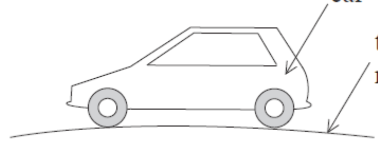
	Origin	Direction
A.	car engine	toward centre of circle
B.	car engine	away from centre of circle
C.	friction between car tyres and road	away from centre of circle
D.	friction between car tyres and road	toward centre of circle

Markscheme

D

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.



25a. Explain why the car is accelerating even though it is moving with a constant speed. *[2 marks]*

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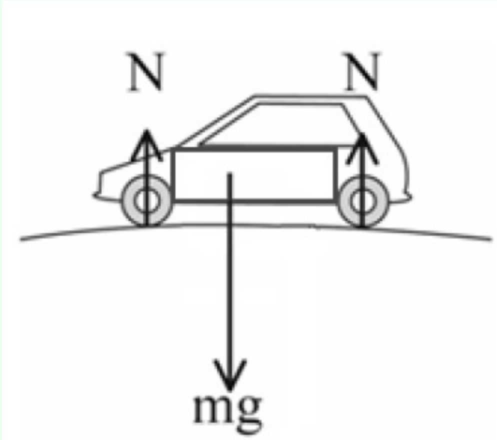
Markscheme

direction changing;

velocity changing so accelerating;

25b. 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.

25c. 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 electric charge and electric circuits. **Part 2** is about momentum.

Part 1 Electric charge and electric circuits

26a. State Coulomb's law. *[2 marks]*

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Markscheme

the force between two (point) charges;
is inversely proportional to the square of their separation and (directly) proportional to (the product of) their magnitudes;

*Allow **[2]** for equation with F, Q and r defined.*

26b. In a simple model of the hydrogen atom, the electron can be regarded as being in a circular orbit about the proton. The radius of the orbit is 2.0×10^{-10} m. *[7 marks]*

(i) Determine the magnitude of the electric force between the proton and the electron.

(ii) Calculate the magnitude of the electric field strength *E* and state the direction of the electric field due to the proton at a distance of 2.0×10^{-10} m from the proton.

(iii) The magnitude of the gravitational field due to the proton at a distance of 2.0×10^{-10} m from the proton is *H*.
Show that the ratio $\frac{H}{E}$ is of the order 10^{-28}C kg^{-1}.

(iv) The orbital electron is transferred from its orbit to a point where the potential is zero. The gain in potential energy of the electron is 5.4×10^{-19}J. Calculate the value of the potential difference through which the electron is moved.

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Markscheme

(i) $F = \left(k\frac{q_1q_2}{r^2} =\right) \frac{9\times10^9\times\left[1.6\times10^{-19}\right]^2}{4\times10^{-20}}$;

$=5.8\times10^{-9}$(N);

*Award **[0]** for use of masses in place of charges.*

(ii) ($\frac{(b)(i)}{1.6\times10^{-19}}$ **or** 3.6×10^{10} (NC^{-1}) **or** (Vm^{-1});

(directed) away from the proton;

Allow ECF from (b)(i).

Do not penalize use of masses in both (b)(i) and (b)(ii) – allow ECF.

(iii) $H = \left(G\frac{m}{r^2} =\right) \frac{6.67\times10^{-11}\times1.673\times10^{-27}}{4\times10^{-20}} = 2.8 \times 10^{-18} \left(\mathrm{Nkg^{-1}}\right)$;

$\frac{H}{E} = \frac{2.8\times10^{-18}}{3.6\times10^{10}}$ **or** 7.8×10^{-29}(Ckg^{-1});

($\approx 10^{28}$ Ckg^{-1})

Allow ECF from (b)(i).

(iv) 3.4(V);

26c. An electric cell is a device that is used to transfer energy to electrons in a circuit. A particular circuit consists of a cell of emf ε and internal resistance r connected in series with a resistor of resistance 5.0 Ω. *[6 marks]*

(i) Define *emf of a cell.*

(ii) The energy supplied by the cell to one electron in transferring it around the circuit is 5.1×10^{-19} J. Show that the emf of the cell is 3.2V.

(iii) Each electron in the circuit transfers an energy of 4.0×10^{-19} J to the 5.0 Ω resistor. Determine the value of the internal resistance *r.*

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Markscheme

(i) power supplied per unit current / energy supplied per unit charge / work done per unit charge;

(ii) energy supplied per coulomb=$\frac{5.1\times10^{-19}}{1.6\times10^{-19}}$ ***or*** 3.19(V);
(≈3.2V)

(iii) pd across 5.0Ω resistor=$\left(\frac{4.0\times10^{-19}}{1.6\times10^{-19}}=\right)2.5\,(\mathrm{V})$;
pd across *r*=(3.2-2.5=)0.70(V);

and

either

current in circuit=$\left(\frac{2.5}{5.0}=\right)0.5\,(\mathrm{A})$;
resistance of *r*=$\left(\frac{0.70}{0.50}=\right)1.4\,(\Omega)$;

or

resistance of *r*=$\frac{0.70}{2.5}\times5.0$;
=1.4(Ω);

or

3.2=0.5(R+*r*);
resistance of *r*=1.4(Ω);
*Award **[4]** for alternative working leading to correct answer.*
*Award **[4]** 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

27a. 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.*

27b. 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.*

27c. 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 6.00×10^3s. *[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).

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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.*

28. What is the acceleration of an object rotating with constant speed *v* in a circle of radius *r*? *[1 mark]*

A. Zero

B. $\frac{v^2}{r}$ towards the centre of the circle

C. $\frac{v^2}{r}$ away from the centre of the circle

D. $\frac{v^2}{r}$ along a tangent to the circle

Markscheme

B

29. The centres of two planets are separated by a distance *R*. The gravitational force between the two planets is *F*. What will be the force between the planets when their separation increases to 3*R*? *[1 mark]*

A. $\frac{F}{9}$

B. $\frac{F}{3}$

C. *F*

D. 3*F*

Markscheme

A

30. The acceleration of free fall of a mass of 2.0 kg close to the surface of Mars is 3.6 ms $^{-2}$. *[1 mark]*
What is the gravitational field strength at the surface of Mars in N kg^{-1}?

A. 1.8
B. 3.6
C. 7.2
D. 9.8

Markscheme

B

Part 2 Satellite

31a. State, in words, Newton's universal law of gravitation. *[2 marks]*

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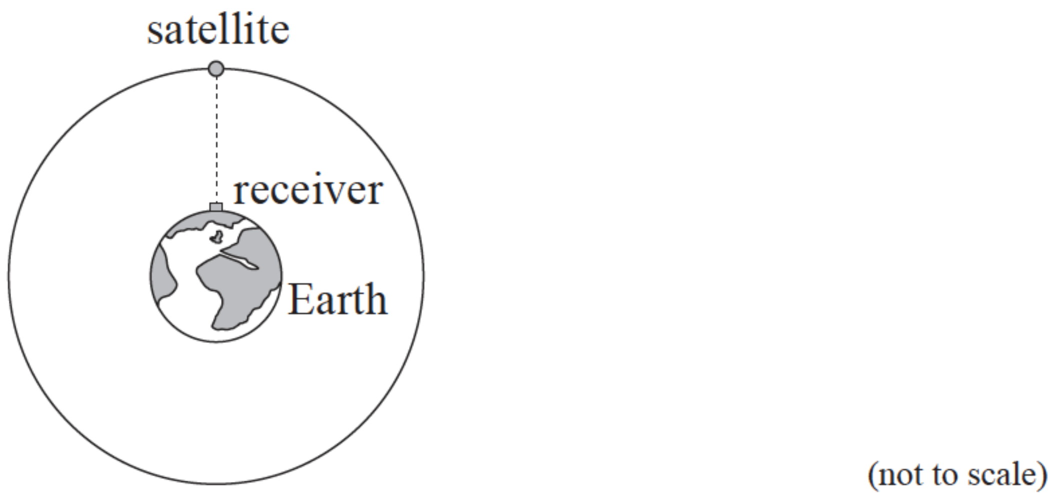
Markscheme

force is proportional to product of masses and inversely proportional to square of distance apart;
reference to point masses;

31b. The diagram shows a satellite orbiting the Earth. The satellite is part of the network of global-positioning satellites (GPS) that transmit radio signals used to locate the position of receivers that are located on the Earth. *[3 marks]*



When the satellite is directly overhead, the microwave signal reaches the receiver 67ms after it leaves the satellite.

(i) State the order of magnitude of the wavelength of microwaves.

(ii) Calculate the height of the satellite above the surface of the Earth

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Markscheme

(i) order of 1 cm;

(ii) $3\times10^{8}\times67\times10^{-3}$;
2.0×10^{7}m;

31c. (i) Explain why the satellite is accelerating towards the centre of the Earth even though its orbital speed is constant. *[8 marks]*

(ii) Calculate the gravitational field strength due to the Earth at the position of the satellite.

Mass of Earth = 6.0×10^{24}kg
Radius of Earth = 6.4×10^{6}m

(iii) Determine the orbital speed of the satellite.

(iv) Determine, in hours, the orbital period of the satellite.

Markscheme

(i) force required towards centre of Earth to maintain orbit;
force means that there is an acceleration / *OWTTE*;

or

direction changes;
a change in velocity therefore acceleration;

(ii) uses=$\frac{GM}{r^2}$ ***or*** $\frac{6.7\times10^{-11}\times6.0\times10^{24}}{\left[2.6\times10^{7}\right]^{2}}$;
0.57Nkg^{-1}; (allow ms^{-2})

(iii) $v=\sqrt{0.57\times\left(2.0\times10^{7}+6.4\times10^{6}\right)}$ by equating $\frac{v^2}{r}$ and g;
3900ms^{-1};

(iv) $T=2\pi\frac{2.6\times10^{7}}{3900}$;
11.9 hours;

32. A mass at point X gives rise to a gravitational field strength g at point P as shown below. *[1 mark]*

An identical mass is placed at point Y as shown below.

The resultant gravitational field strength at P is now

A. greater than $2g$.

B. between $2g$ and g.

C. between g and zero.

D. zero.

Markscheme

C

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33. A car moves at constant speed around a horizontal circular track. The resultant force on the car is always equal to *[1 mark]*

A. the forward force from the engine.

B. the sideways friction between the tires and the track.

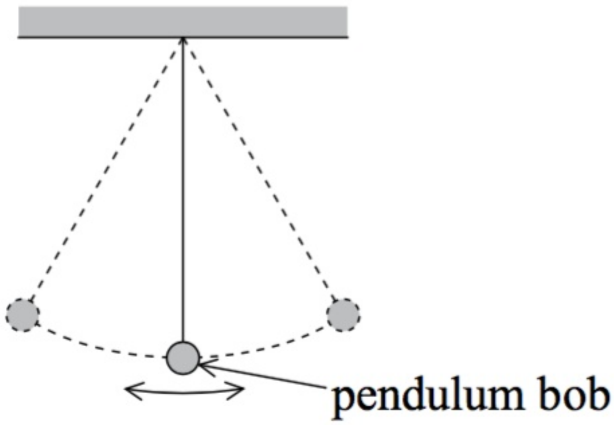
C. the weight of the car.

D. zero.

Markscheme

B

34. A pendulum bob is attached to a light string and is swinging in a vertical plane. *[1 mark]*



At the lowest point of the motion, the magnitude of the tension in the string is

A. less than the weight of the mass of the pendulum bob.
B. zero.
C. greater than the weight of the mass of the pendulum bob.
D. equal to the weight of the mass of the pendulum bob.

Markscheme

C

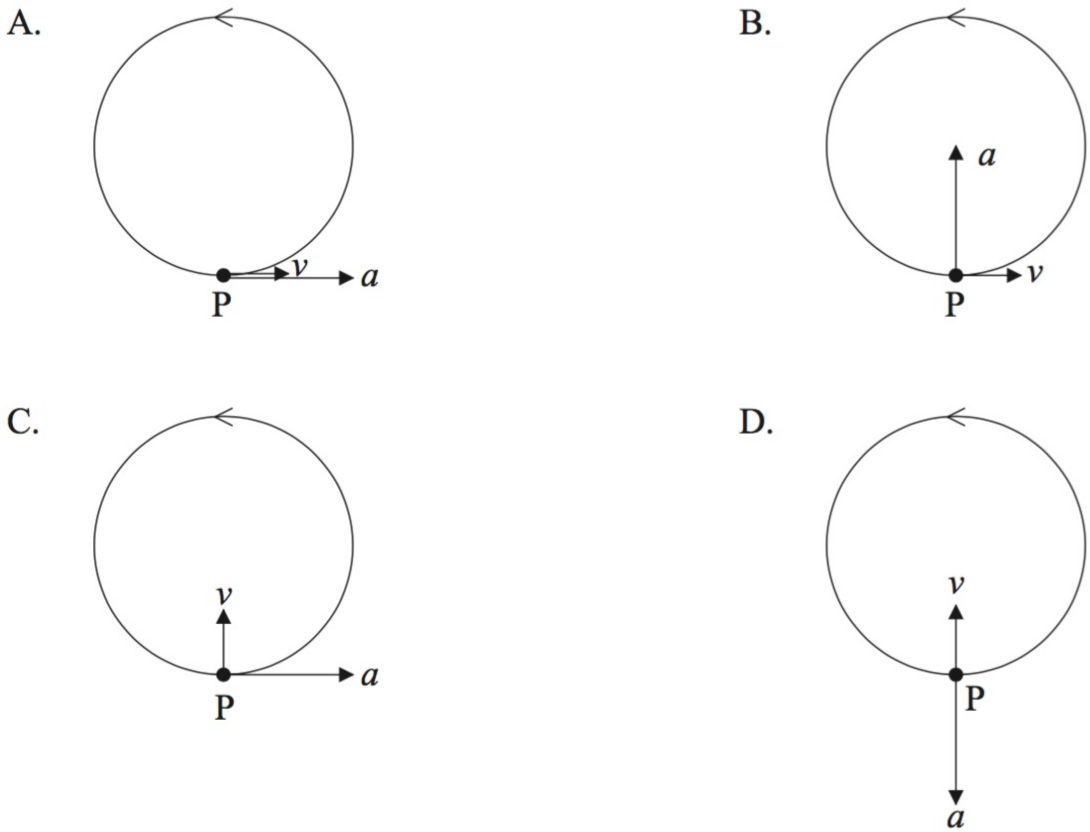
35. An astronaut of mass 60 kg is on board the International Space Station, which is in low orbit around the Earth. The gravitational force of attraction between the Earth and astronaut is approximately *[1 mark]*

A. zero.
B. 6 N.
C. 60 N.
D. 600 N.

Markscheme

D

36. Particle P is moving with uniform speed in a horizontal circle. Which of the following shows the correct directions of the acceleration a and the velocity v of P at the position shown? *[1 mark]*



Markscheme

B

Part 2 Gravitational fields

37a. State Newton's universal law of gravitation. *[3 marks]*

Markscheme

there is an attractive force;
between any two point/small masses;
proportional to the product of their masses;
and inversely proportional to the square of their separation;
Accept formula with all terms defined.

37b. Deduce that the gravitational field strength g at the surface of a spherical planet of uniform density is given by *[2 marks]*

$$g = \frac{GM}{R^2}$$

where M is the mass of the planet, R is its radius and G is the gravitational constant. You can assume that spherical objects of uniform density act as point masses.

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Markscheme

use of $g = \frac{F}{m}$ and $F = \frac{GmM}{R^2}$;
evidence of substitution/manipulation;
to get $g = \frac{GM}{R^2}$

37c. The gravitational field strength at the surface of Mars g_M is related to the gravitational field strength at the surface of the Earth g_E by *[2 marks]*

$g_M = 0.38 \times g_E$.

The radius of Mars R_M is related to the radius of the Earth R_E by

$R_M = 0.53 \times R_E$.

Determine the mass of Mars M_M in terms of the mass of the Earth M_E.

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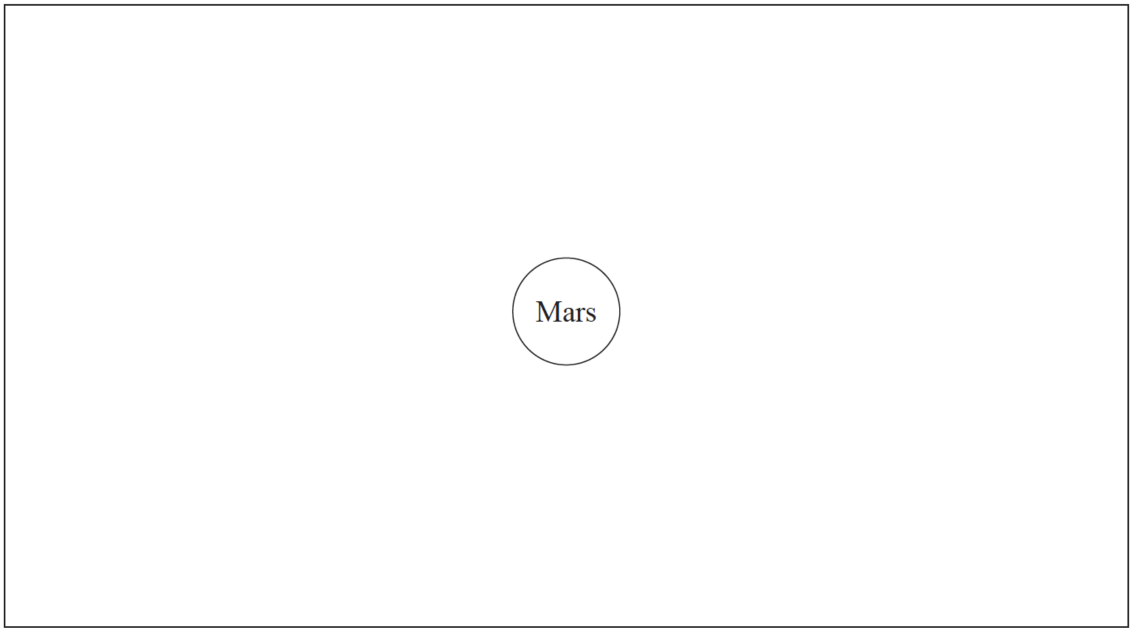
Markscheme

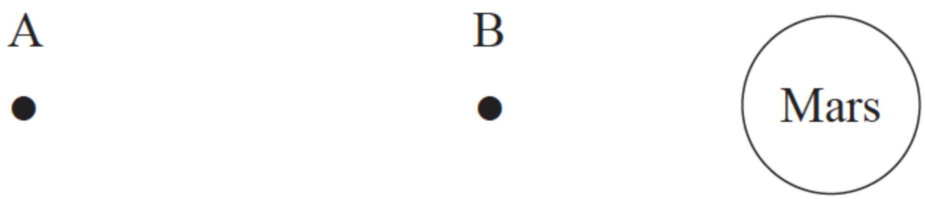
$$\frac{g_M}{g_E} = \frac{\frac{M_M}{R_M^2}}{\frac{M_E}{R_E^2}} \Rightarrow \frac{M_M}{M_E} = \frac{g_M}{g_E} \times \left[\frac{R_M}{R_E}\right]^2;$$

$$M_{\mathrm{M}} \left(= 0.38 \times 0.53^2 M_{\mathrm{E}}\right) = 0.11 M_{\mathrm{E}};$$

37d. (i) On the diagram below, draw lines to represent the gravitational field around the planet Mars. *[3 marks]*



(ii) An object falls freely in a straight line from point A to point B in time t. The speed of the object at A is u and the speed at B is v. A student suggests using the equation $v=u+g_{M}t$ to calculate v. Suggest **two** reasons why it is not appropriate to use this equation.



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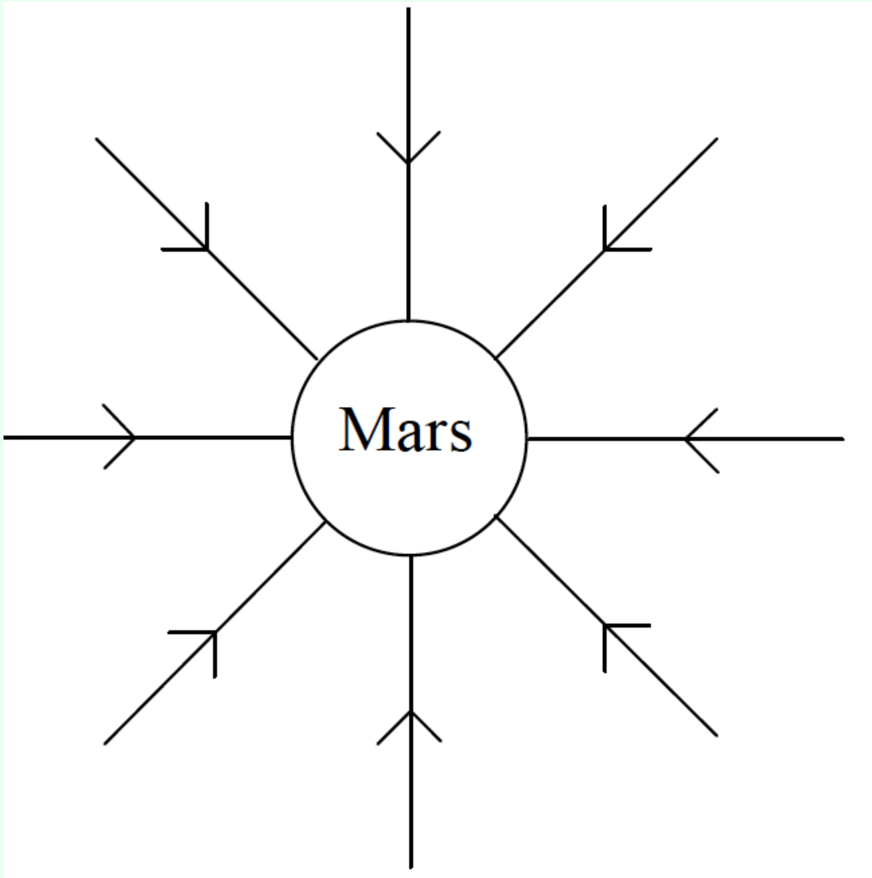
Markscheme

(i) radial field with arrows pointing inwards;



(ii) field between A and B is not equal to field at surface;
acceleration is not constant between these two points;

38. The magnitude of gravitational field strength g is defined from the equation shown below. *[4 marks]*

$$g = \frac{F_g}{m}$$

The magnitude of electric field strength E is defined from the equation shown below.

$$E = \frac{F_E}{q}$$

For each of these defining equations, state the meaning of the symbols

(i) F_g.

(ii) F_E.

(iii) m.

(iv) q.

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Markscheme

(i) the force exerted on a small/test/point mass;
Do not allow bald "gravitational force".

(ii) the force exerted on a small/point/test positive charge;
*To award **[1]** "positive" is required.*
Do not allow bald "electric force".

(iii) the size/magnitude/value of the small/point mass;
Do not accept bald "mass".

(iv) the magnitude/size/value of the small/point/test (positive) charge;
Do not accept bald "charge".

This question is in **two** parts. **Part 1** is about fields, electric potential difference and electric circuits. **Part 2** is about thermodynamic cycles.

Part 1 Fields, electric potential difference and electric circuits

39a. The magnitude of gravitational field strength *g* is defined from the equation shown below. *[4 marks]*

$$g = \frac{F_g}{m}$$

The magnitude of electric field strength *E* is defined from the equation shown below.

$$E = \frac{F_E}{q}$$

For each of these defining equations, state the meaning of the symbols

(i) F_g.

(ii) F_E.

(iii) m.

(iv) q.

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Markscheme

(i) the force exerted on a small/test/point mass;
Do not allow bald "gravitational force".

(ii) the force exerted on a small/point/test positive charge;
*To award **[1]** "positive" is required.*
Do not allow bald "electric force".

(iii) the size/magnitude/value of the small/point mass;
Do not accept bald "mass".

(iv) the magnitude/size/value of the small/point/test (positive) charge;
Do not accept bald "charge".

In part (a) only penalize lack of "small/test/point" once, annotate as ECF.
It must be clear that the mass/charge in (iii) & (iv) refer to the object in (i) and (ii).

39b. In a simple model of the hydrogen atom, the electron is regarded as being in a circular orbit about the proton. The magnitude of the electric field strength at the electron due to the proton is E_p . The magnitude of the gravitational field strength at the electron due to the proton is g_p. *[3 marks]*

Determine the order of magnitude of the ratio shown below.

$$\frac{E_p}{g_p}$$

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Markscheme

$E_p = \frac{e}{4\pi\varepsilon_0 r^2}$ and $g_p = \frac{Gm_p}{r^2}$; *(both needed)*

$\frac{e}{4\pi\varepsilon_0 Gm_p}\left(= \frac{9\times10^9\times1.6\times10^{-19}}{6.7\times10^{-11}\times1.7\times10^{-27}}\right)$;

$\approx 10^{28}$;

*Award **[2 max]** if response calculates ratio of force as this is an ECF from the first marking point (10^{39}) .*
*Award **[3]** for solution that correctly evaluates field strengths separately and then divides.*