Gravitational and electric fields

Q1.

(a) Define the electric field strength at a point in an electric field.

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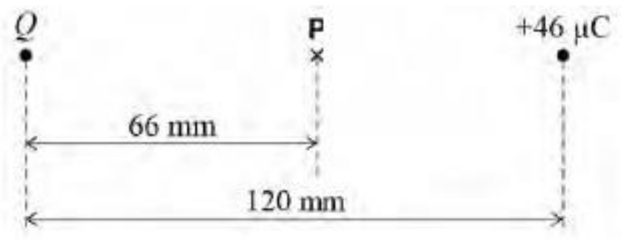
(2)

(b) **Figure 1** shows a point charge of +46 μC placed 120 mm from a point charge Q.

Figure 1



Position **P** is on the line joining the charges at a distance 66 mm from charge Q. The resultant electric field strength at position **P** is zero.

Calculate the charge Q.

Q = ____________________ C

(3)

(c) Explain, without calculation, whether net work must be done in moving a proton from infinity to position **P** in **Figure 1**.

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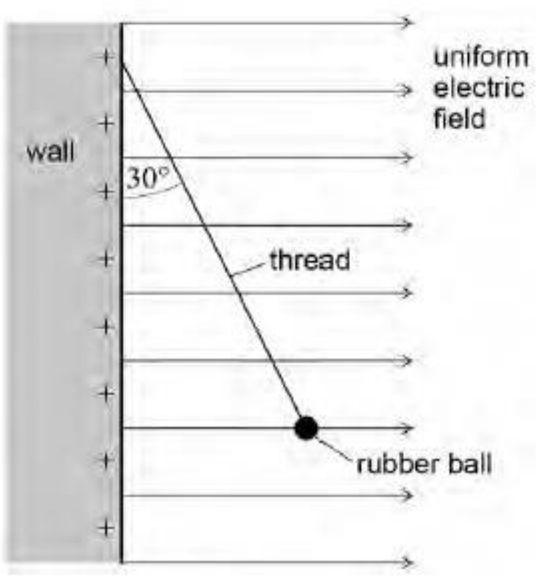
(2)

(d) A small rubber ball coated with a conducting paint carries a positive charge. The ball is suspended in equilibrium from a vertical wall by an uncharged non-conducting thread of negligible mass. The wall is positively charged and produces a horizontal uniform electric field perpendicular to the wall along the whole of its length.
Figure 2 shows that the thread makes an angle of 30° to the wall.

Figure 2



The thread breaks.

Explain the motion of the ball.

(2)
(Total 9 marks)

Q2.

The distance between the Sun and the Earth is 1.5×10^{11} m

What is the gravitational force exerted on the Sun by the Earth?

A 3.5×10^{22} N ○

B 1.7×10^{26} N ○

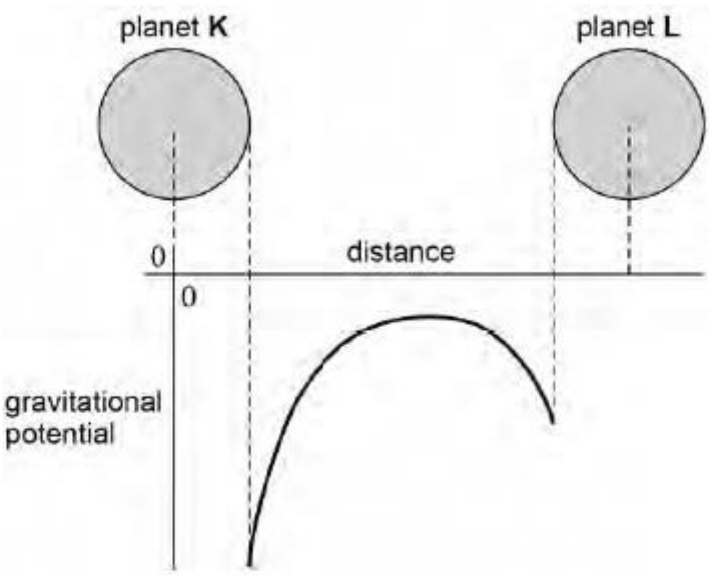
C 5.3×10^{33} N ○

D 8.9×10^{50} N ○

(Total 1 mark)

Q3.

The graph shows how the gravitational potential varies with distance between two planets, **K** and **L**, that have the same radius.



Which statement is correct?

A The mass of **L** is greater than the mass of **K**. ○

B The gravitational field strength at the surface of **L** is greater than that at the surface of **K**. ○

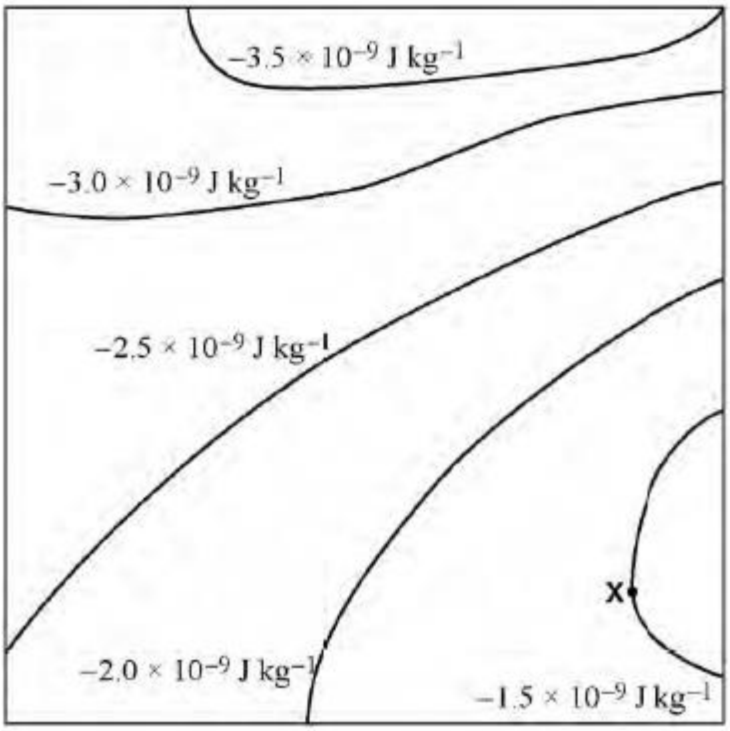
C The escape velocity from planet **L** is greater than that from planet **K**. ○

D More work must be done to move a mass of 1 kg from the surface of **K** to a distant point, than 1 kg from the surface of **L**. ○

(Total 1 mark)

Q4.

The diagram shows equipotential lines near a group of asteroids.



Which arrow shows the direction of the gravitational field at **X**?

A ↑ ⬭

B ↓ ⬭

C ← ⬭

D → ⬭

(Total 1 mark)

Q5.

Planet **N** has a gravitational potential $-V$ at its surface. Planet **M** has double the density and double the radius of planet **N**. Both planets are spherical and have uniform density.

What is the gravitational potential at the surface of planet **M**?

A $-16V$ ⬭

B $-8V$ ⬭

C $-4V$ ⬭

D $-0.2V$ ⬭

(Total 1 mark)

Q6.

A spacecraft of mass 1.0×10^6 kg is in orbit around the Sun at a radius of 1.1×10^{11} m

The spacecraft moves into a new orbit of radius 2.5 × 10^{11} m around the Sun.

What is the total change in gravitational potential energy of the spacecraft?

A –6.76 × 10^{14} J ⬭

B –3.38 × 10^{14} J ⬭

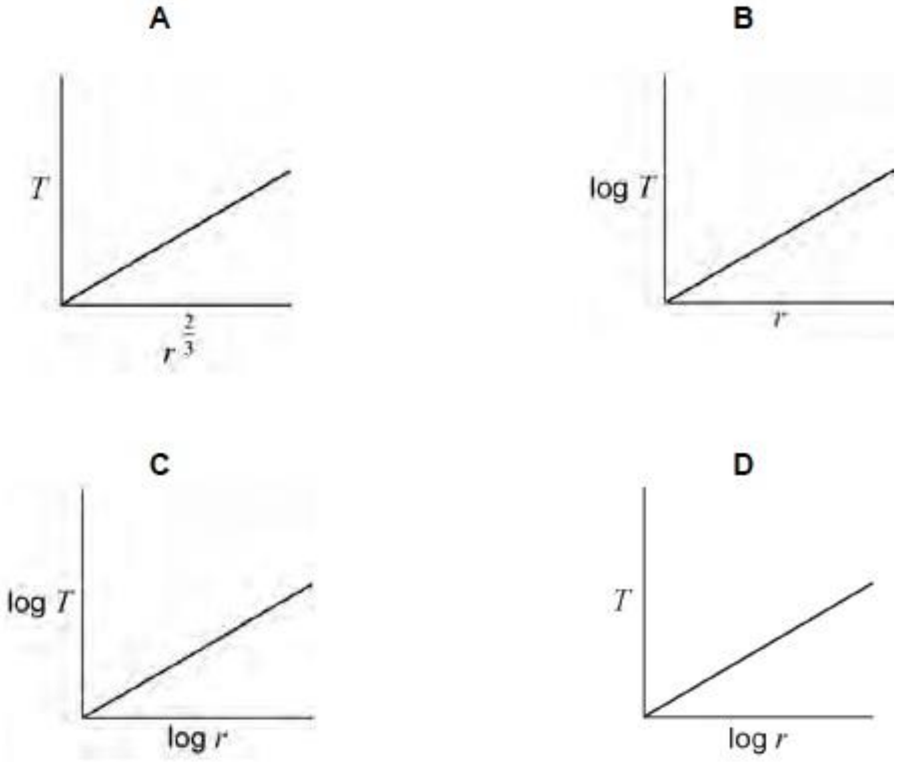
C 3.38 × 10^{14} J ⬭

D 6.76 × 10^{14} J ⬭

(Total 1 mark)

Q7.

Which graph shows the relationship between the time period T and the orbital radius r of a planet in orbit around the Sun?



A ⬭

B ⬭

C ⬭

D ⬭

(Total 1 mark)

Q8.

The Earth can be assumed to be a uniform sphere of radius R.

What is the mean density of the Earth?

A $\dfrac{3g}{4\pi RG}$ ☐

B $\dfrac{3RG}{4\pi g}$ ☐

C $\dfrac{3G}{4\pi Rg}$ ☐

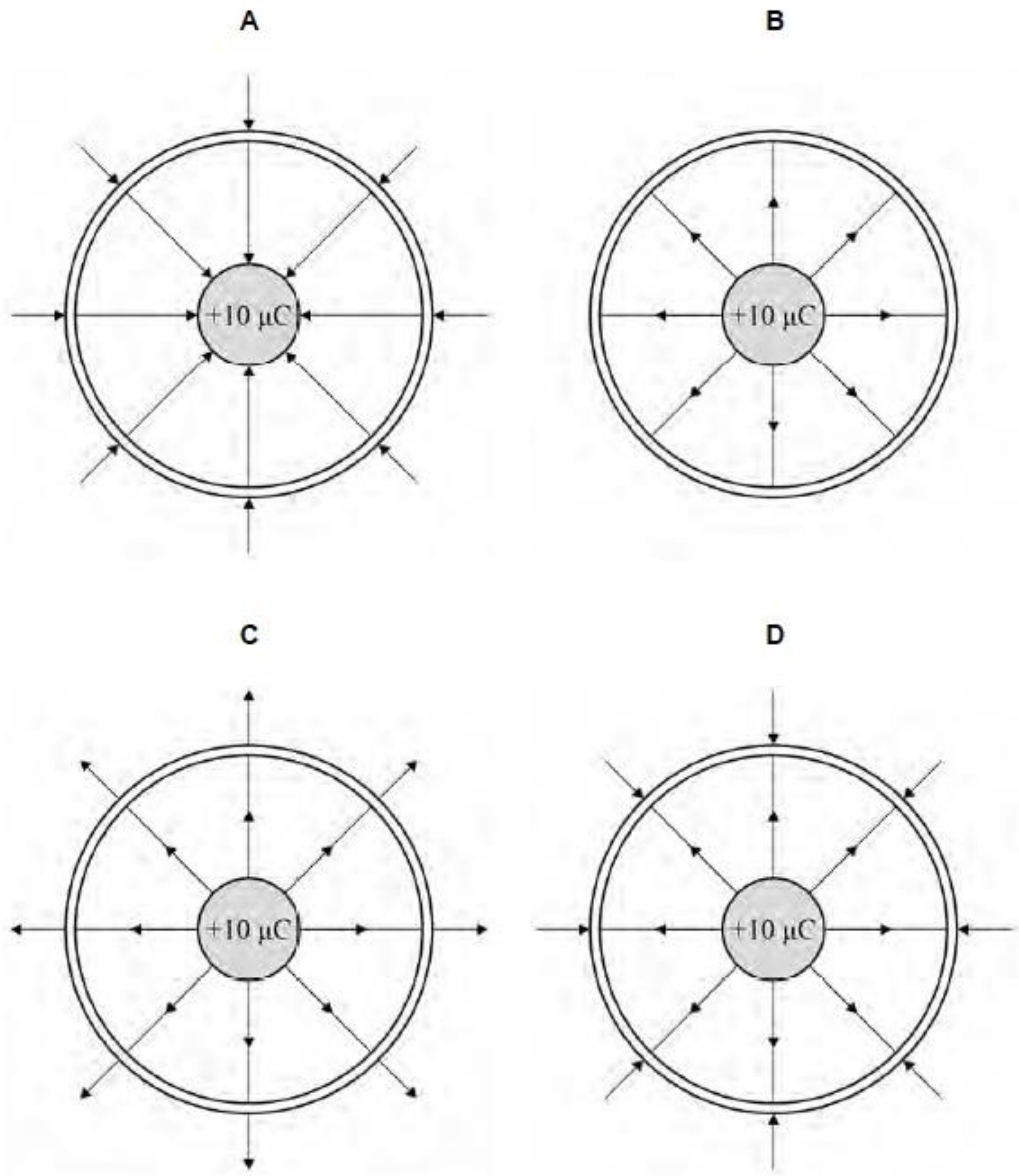
D $\dfrac{3Rg}{4\pi G}$ ☐

(Total 1 mark)

Q9.

A conducting sphere holding a charge of +10 μC is placed centrally inside a second uncharged conducting sphere.

Which diagram shows the electric field lines for the system?



A ○

B ○

C ○

D ○

(Total 1 mark)

Q10.

A charged spherical conductor has a radius r. An electric field of strength E exists at the surface due to the charge.

What is the potential of the spherical conductor?

A $r^2 E$

B $r E^2$

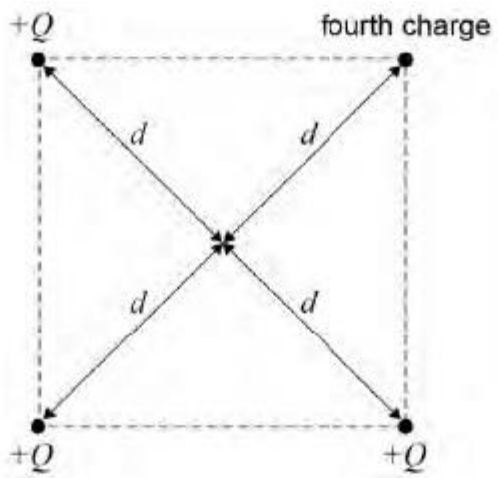
C $\frac{E}{r}$

D $r E$

(Total 1 mark)

Q11.

Four positive charges are fixed at the corners of a square as shown.



The total potential at the centre of the square, a distance d from each charge, is $\frac{5Q}{4\pi\varepsilon_0 d}$

Three of the charges have a charge of +Q

What is the magnitude of the fourth charge?

A $-\frac{7Q}{4}$

B Q

C $\sqrt{2}Q$

D $2Q$

(Total 1 mark)

Q12.

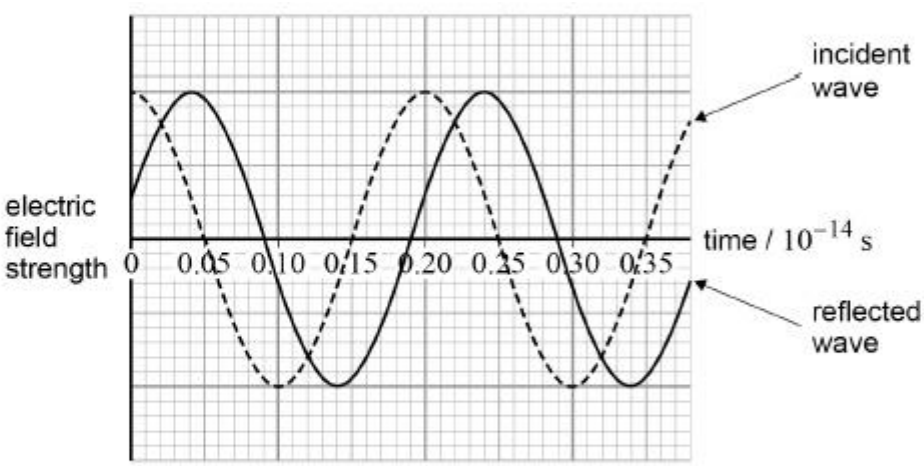
A gravimeter is an instrument used to measure the acceleration due to gravity. The gravimeter measures the distance fallen by a free-falling mirror in a known time.

To do this, monochromatic light is reflected normally off the mirror, creating interference between the incident and reflected waves. The mirror is released from rest and falls, causing a change in the phase difference between the incident and reflected waves at a detector.

At the point of release of the mirror, the waves are in phase, resulting in a maximum intensity at the detector. The next maximum is produced at the detector when the mirror has fallen through a distance equal to half a wavelength of the light. The gravimeter records the number of maxima detected in a known time as the mirror falls. These data are used by the gravimeter to compute the acceleration of the free-falling mirror.

Figure 1 illustrates the phase relationship between the incident and reflected waves at the detector for one position of the mirror.

Figure 1



(a) Show that the wavelength of the light is 600 nm.

(3)

(b) Determine the phase difference, in rad, between the incident and reflected waves shown in **Figure 1**.

phase difference = ______________________________ rad

(2)

(c) A maximum is detected each time the mirror travels a distance equal to half a wavelength of the light.

In one measurement 2.37×10^5 maxima are recorded as the mirror is released from rest and falls for 0.120 s.

Using an appropriate equation of motion, calculate the acceleration due to gravity that the gravimeter computes from these data.

State your answer to 3 significant figures.

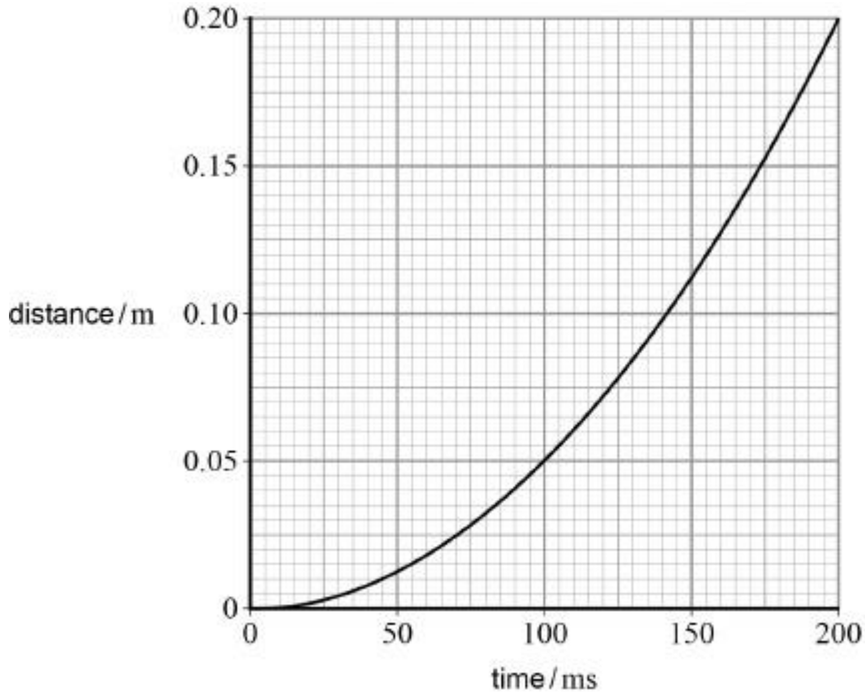
wavelength of the light = 600 nm

acceleration due to gravity = ______________________________ m s^{-2}

(3)

(d) **Figure 2** is a graph that the gravimeter could produce to show how the distance travelled by the mirror varies with time as it falls.

Figure 2



Determine the gradient of the line when the time is 0.12 s.

gradient = ______________________________

(2)

(e) State what this gradient represents.

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(1)

(Total 11 marks)

Q13.

(a) State what is represented by gravitational field lines.

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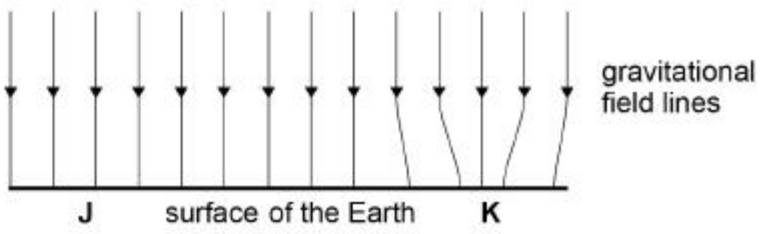
(1)

(b) **Figure 1** shows the gravitational field above a small horizontal region on the surface of the Earth.

Figure 1



Suggest why the field lines converge over a small area at **K**.

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(2)

(c) A ball travelling at constant speed passes position **J** moving towards position **K** in **Figure 1**.

Assume friction is negligible.

Explain any change in the speed of the ball as it approaches **K**.

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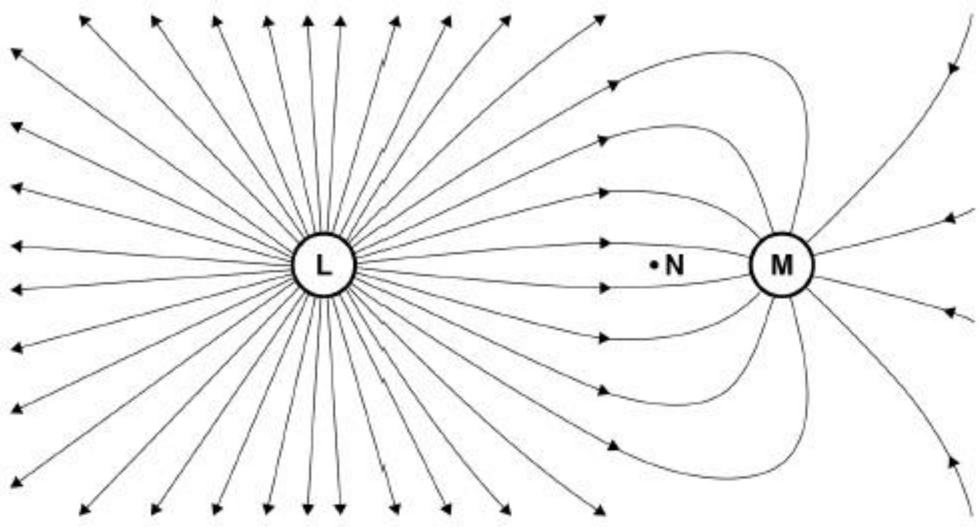
(2)

(d) **Figure 2** shows lines of force for the electric field surrounding two charged objects **L** and **M**.

Figure 2



Explain why the lines of force shown in **Figure 2** cannot represent a gravitational field.

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(1)

(e) State which object **L** or **M** has a charge with the greater magnitude.

object ____________________

State which object **L** or **M** has a positive charge.

object ____________________

(1)

(f) Draw, on **Figure 2**, an equipotential line that passes through point **N**.
Do **not** extend your line beyond the given field lines.

(2)

(Total 9 marks)

Q14.

(a) Derive an expression to show that for satellites in a circular orbit

$$T^2 \propto r^3$$

where T is the period of orbit and r is the radius of the orbit.

(2)

(b) Pluto is a dwarf planet. The mean orbital radius of Pluto around the Sun is 5.91×10^9 km compared to a mean orbital radius of 1.50×10^8 km for the Earth.

Calculate in years the orbital period of Pluto.

orbital period of Pluto = ____________________ yr

(2)

(c) A small mass released from rest just above the surface of Pluto has an acceleration of 0.617 m s^{-2}.

Assume Pluto has no atmosphere that could provide any resistance to motion.

Calculate the mass of Pluto.

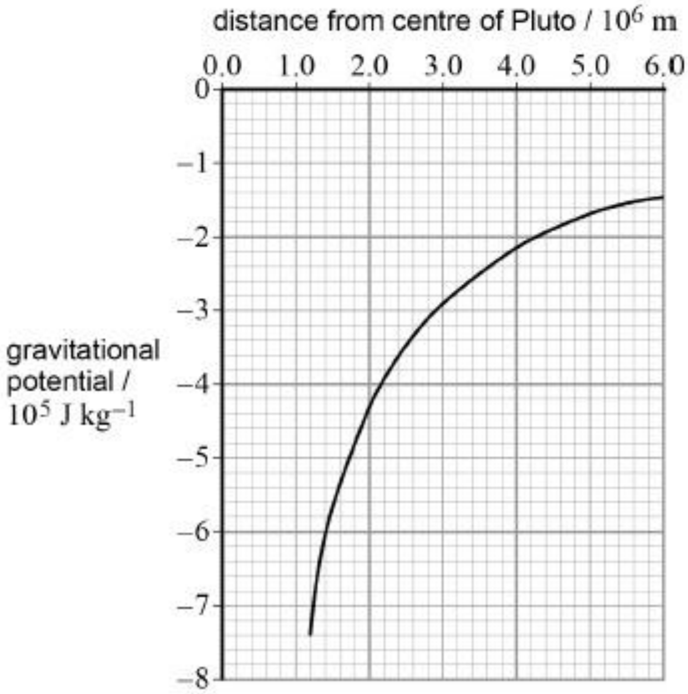
Give your answer to an appropriate number of significant figures.

radius of Pluto = 1.19×10^6 m

mass of Pluto = ____________________ kg

(3)

(d) The graph shows the variation in gravitational potential with distance from the centre of Pluto for points at and above its surface.



A meteorite hits Pluto and ejects a lump of ice from the surface that travels vertically at an initial speed of 1400 m s^{-1}.

Determine whether this lump of ice can escape from Pluto.

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(3)

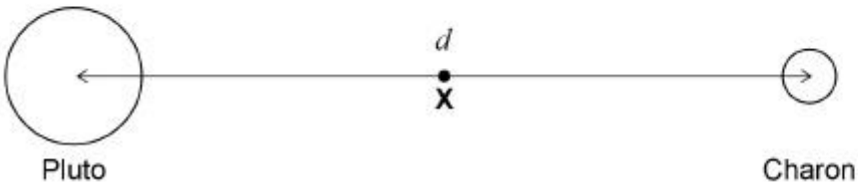
(Total 10 marks)

Q15.

Charon is a moon of Pluto that has a mass equal to $\frac{1}{9}$ that of Pluto.

The distance between the centre of Pluto and the centre of Charon is *d*.

X is the point at which the resultant gravitational field due to Pluto and Charon is zero.



What is the distance of **X** from the centre of Pluto?

A $\frac{2}{9}d$

B $\frac{2}{3}d$

C $\frac{3}{4}d$

D $\frac{8}{9}d$

(Total 1 mark)

Q16.

The distance between the Sun and Mars varies from 2.1×10^{11} m to 2.5×10^{11} m.
When Mars is closest to the Sun, the force of gravitational attraction between them is F.

What is the force of gravitational attraction between them when they are furthest apart?

A $0.71F$

B $0.84F$

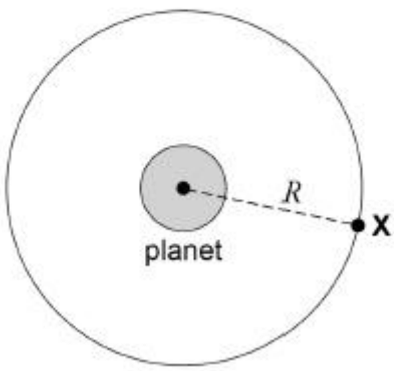
C $1.2F$

D $1.4F$

(Total 1 mark)

Q17.

A satellite **X** of mass m is in a concentric circular orbit of radius R about a planet of mass M.



What is the kinetic energy of **X**?

A $\frac{GMm}{2R}$ ☐

B $\frac{GMm}{R}$ ☐

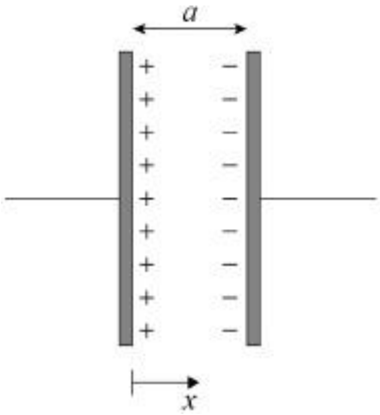
C $\frac{2GMm}{R}$ ☐

D $\frac{4GMm}{R}$ ☐

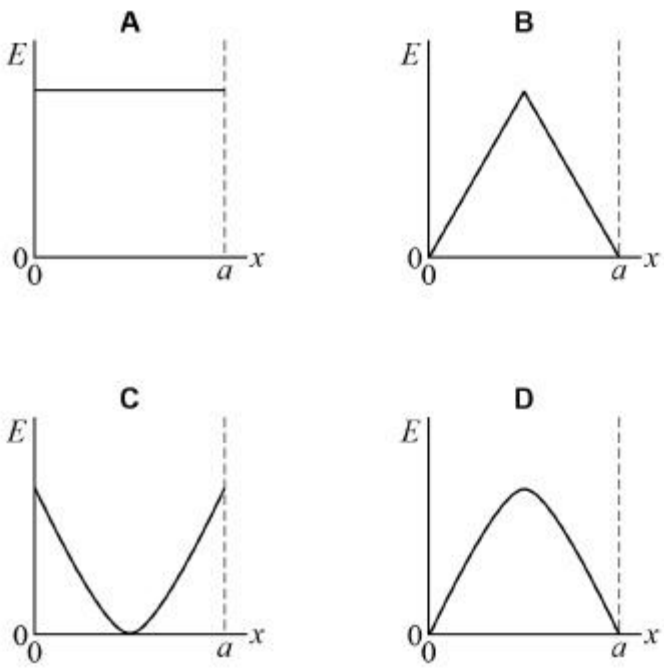
(Total 1 mark)

Q18.

Two parallel metal plates of separation a carry equal and opposite charges.



Which graph best represents how the electric field strength E varies with the distance x in the space between the two plates?



A ☐

B ☐

C ☐

D ☐

(Total 1 mark)

Q19.

A particle of mass m and charge q is accelerated through a potential difference V over a distance d.

What is the average acceleration of the particle?

A $\frac{qV}{md}$ ☐

B $\frac{mV}{qd}$ ☐

C $\frac{V}{mqd}$ ☐

D $\frac{dV}{mq}$ ☐

(Total 1 mark)

Q20.

An electron moves through a distance of 0.10 m parallel to the field lines of a uniform electric field of strength 2.0 kN C^{-1}.

What is the work done on the electron?

A zero ☐

B 1.6×10^{-17} J ☐

C 3.2×10^{-17} J ☐

D 1.6×10^{-21} J ☐

(Total 1 mark)

Q21.

A parallel-plate capacitor is fully charged and then disconnected from the power supply. A dielectric is then inserted between the plates.

Which row correctly identifies the charge on the plates and the electric field strength between the plates?

	Charge	Electric field strength	
A	Stays the same	Increases	⬭
B	Increases	Decreases	⬭
C	Increases	Increases	⬭
D	Stays the same	Decreases	⬭

(Total 1 mark)

Q22.

Read the following passage and answer the questions that follow.

A mass spectrometer is an instrument for measuring the masses of isotopes. The main working parts of the instrument are shown in **Figure 1**.

Figure 1

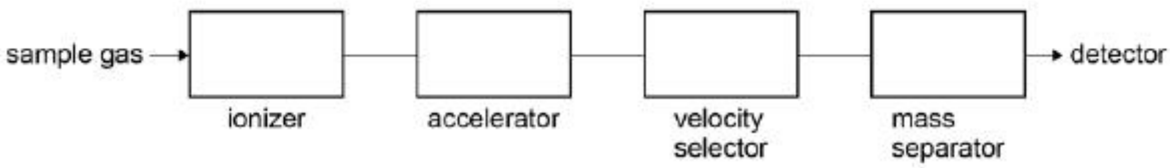
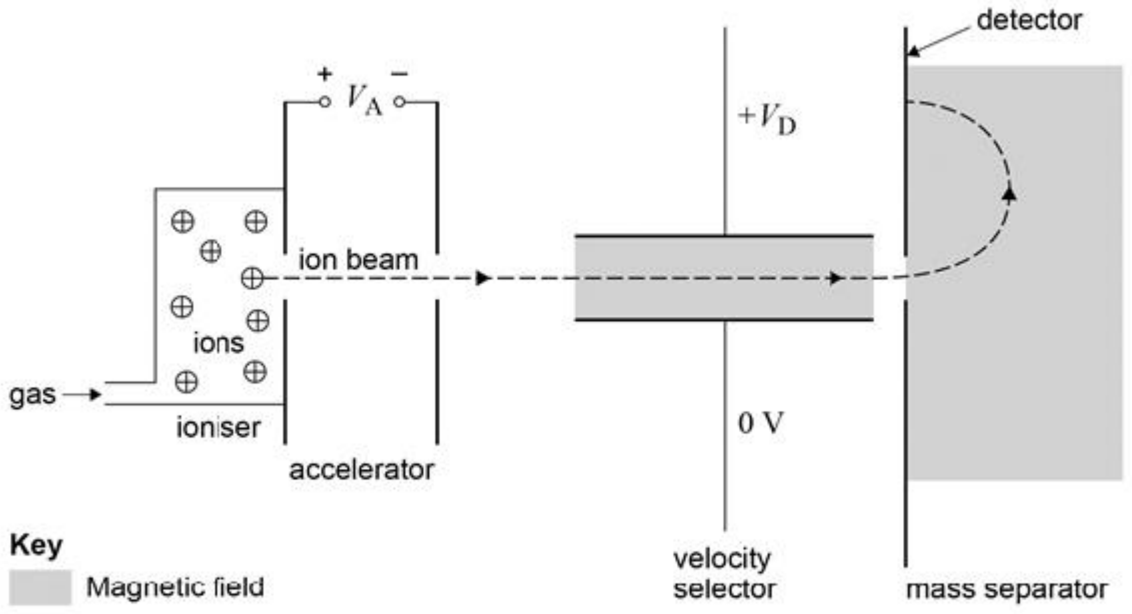


Figure 2 shows the components in more detail. Positive ions are created in the ionizer. Some of these ions enter the accelerator where they are accelerated by a potential difference V_A. The ions emerge from the accelerator with different speeds and enter the velocity selector.

The velocity selector contains a region where there is a uniform magnetic field at right angles to an electric field. This electric field is formed between two parallel plates held at a potential difference V_D. This combination of fields only allows ions of a particular velocity to enter the mass separator. Here ions of different mass are separated by a uniform magnetic field. Finally the ions are detected.

Figure 2



(a) Explain what is meant by ionisation.

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(1)

(b) Discuss the energy transfers that take place in the accelerator as the ion passes through it. Assume the ions are in a perfect vacuum.

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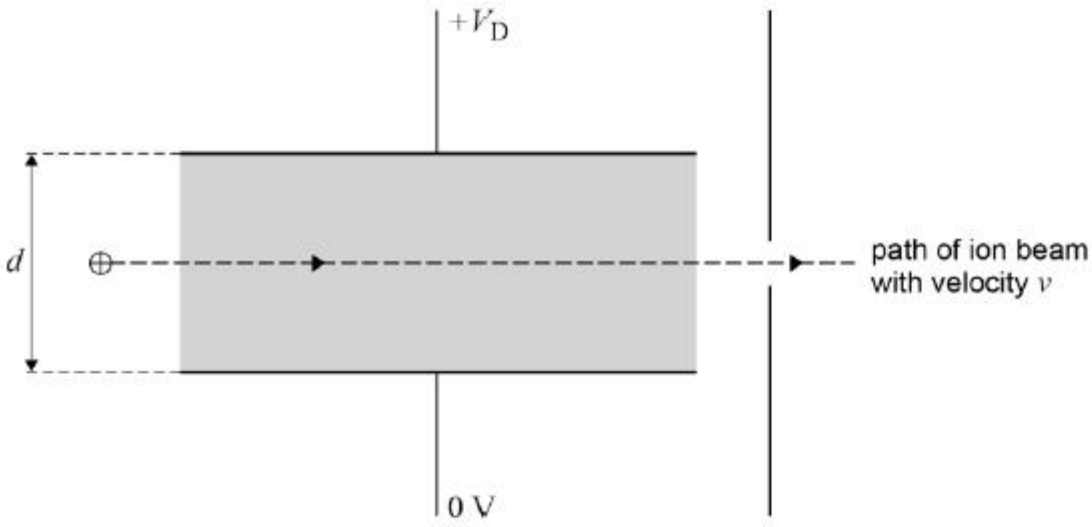
(3)

(c) **Figure 3** shows the path taken by an ion that moves through the velocity selector at a velocity v.

Figure 3



Discuss how the path changes when an ion enters the velocity selector with a velocity greater than v.

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(3)

(d) Draw, on **Figure 3**, the path of the ion that is suggested by your answer to part **(c)**.

(1)

(e) Ions created in the ioniser may have the same charge but a different number of nucleons.

Discuss how the path of an ion in the mass separator is affected when it has more nucleons.

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(2)

(f) Some ions are created with the same mass but a double charge. The path of the ions shown in **Figure 2** is that of a singly charged ion.

Compare, with justification, the path of a doubly charged ion through the mass spectrometer with that of a singly charged ion of the same mass.

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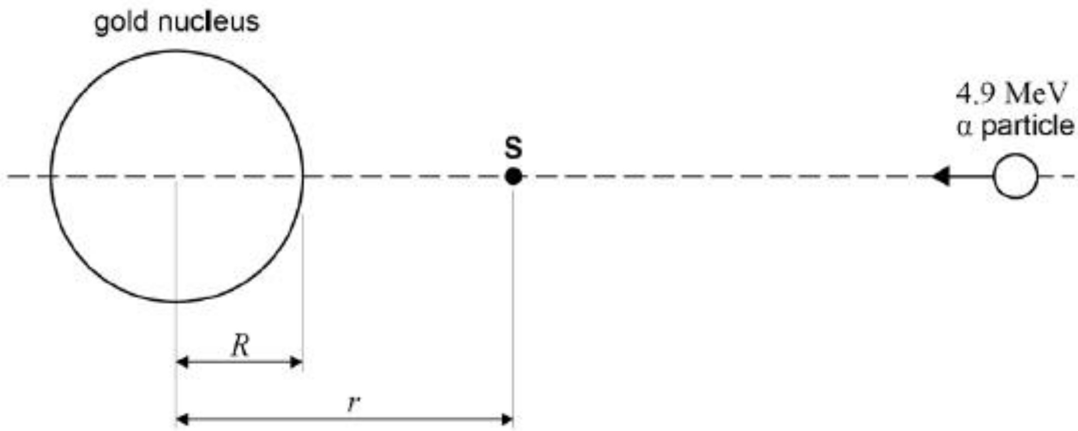
(3)

(Total 13 marks)

Q23.

An α particle with an initial kinetic energy of 4.9 MeV is directed towards the centre of a gold nucleus of radius R which contains 79 protons. The α particle is brought to rest at point **S**, a distance r from the centre of the nucleus as shown in the diagram below.



(a) Calculate the electric potential energy, in J, of the α particle at point **S**.

electric potential energy = ____________________ J

(2)

(b) Calculate r, the distance of closest approach of the α particle to the nucleus.

r = ____________________ m

(3)

(c) Determine the number of nucleons in the gold nucleus.

R, radius of the gold nucleus = 7.16×10^{-15} m
$R_0 = 1.23 \times 10^{-15}$ m

number of nucleons = ________________

(3)

(d) The target nucleus is changed to one that has fewer protons. The α particle is given the same initial kinetic energy.

Explain, without further calculation, any changes that occur to the distance r. Ignore any recoil effects.

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(2)

(Total 10 marks)

Q24.

(a) Define the gravitational potential at a point.

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(2)

(b) Explain why gravitational potential is always negative.

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(2)

(c) Show that the magnitude of the gravitational potential at the Earth's surface due to the mass of the Earth is about 6.3×10^7 J kg^{-1}.

(2)

(d) A satellite is launched into a geostationary orbit.

Describe and explain **two** features of a geostationary orbit.

1. ____

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2. ____

____

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(2)

(e) The satellite has a mass of 1200 kg and the radius of its orbit is 4.23×10^7 m.

Calculate the gain in gravitational potential energy of the satellite when it is placed into orbit from the Earth's surface.

gain in potential energy = ____________________ J

(3)

(f) Impulse engines are used to place the satellite into an orbit with a longer period.

Discuss any changes this makes to the orbital motion of the satellite.

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(4)

(Total 15 marks)

Q25.

The distance between the centres of the Earth and the Moon is 3.8×10^8 m. The mass of the Earth is 6.0×10^{24} kg and the mass of the Moon is 7.4×10^{22} kg.

A spacecraft of mass 10×10^3 kg is moving along a line joining their centres.

At what distance from the centre of the Earth would the spacecraft experience no resultant force due to the Earth and the Moon?

A 3.8×10^7 m ○

B 4.8×10^7 m ○

C 3.4×10^8 m ○

D 3.8×10^8 m ○

(Total 1 mark)

Q26.

An electron on the surface of the Earth is placed in an electric field of strength 5000 N C^{-1}.

What is $\left(\frac{\text{electric force}}{\text{gravitational force}}\right)$ for the electron?

A 1.1×10^{-14} ○

B 2.9×10^{-10} ○

C 3.4×10^{9} ○

D 9.0×10^{13} ○

(Total 1 mark)

Q27.

The radius of a planet is R. The gravitational potential at the surface of the planet due to its mass is −4000 J kg^{-1}.

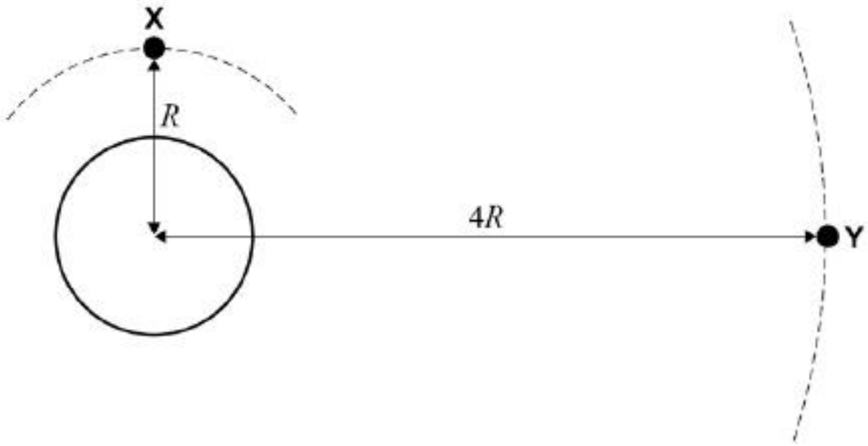
What is the gravitational potential at a distance $2R$ from the centre of the planet?

A	-1000 J kg^{-1}	☐	
B	-2000 J kg^{-1}	☐	
C	-4000 J kg^{-1}	☐	
D	-8000 J kg^{-1}	☐	

(Total 1 mark)

Q28.

Satellites **X** and **Y** orbit the Earth at distances R and $4R$ respectively, as shown in the diagram.



Which statement is **incorrect**?

A	The speed of **Y** is greater than the speed of **X**	☐
B	The time period of **Y** is greater than the time period of **X**.	☐
C	The potential energy of **Y** is greater than the potential energy of **X**.	☐
D	The gravitational force acting on **Y** is less than the gravitational force acting on **X**.	☐

(Total 1 mark)

Q29.

An α particle makes a head−on collision with a gold nucleus containing 79 protons. The distance of closest approach of the α particle to the nucleus is 4.0×10^{-14} m.

What electrostatic force acts on the gold nucleus when at this separation?

A	9.1×10^{-11} N	☐

B	23 N	○
C	290 N	○
D	1.4×10^{20} N	○

(Total 1 mark)

Q30.

An electron moving with constant speed enters a uniform electric field at right angles to the direction of the field.

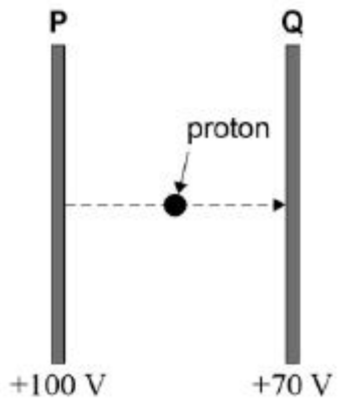
What is true about the force acting on the electron?

A	It is at right angles to the direction of the field.	○
B	It is in the opposite direction to the direction of the field.	○
C	It causes the electron to continue in the same direction with its speed increasing steadily.	○
D	It causes the electron to continue in the same direction with its speed decreasing steadily.	○

(Total 1 mark)

Q31.

Two fixed parallel metal plates **P** and **Q** are at constant electrical potentials of +100 V and +70 V respectively. A proton travelling from **P** to **Q** experiences a force F due to the electric field between **P** and **Q**, and a change of potential energy of ΔE_p.



Which line, **A** to **B**, in the table gives the direction of F and the value of ΔE_p?

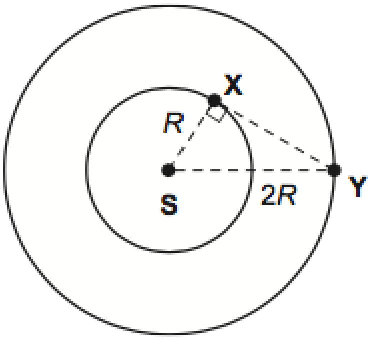
	Direction of F	ΔE_p	
A	towards **P**	+30 eV	○
B	towards **Q**	+30 eV	○

C	towards **Q**	−30 eV	○
D	towards **P**	−30 eV	○

(Total 1 mark)

Q41.

Two planets **X** and **Y** are in concentric circular orbits about a star **S**. The radius of the orbit of **X** is R and the radius of orbit of **Y** is $2R$.



The gravitational force between **X** and **Y** is F when angle **SXY** is 90°, as shown in the diagram.

What is the gravitational force between **X** and **Y** when they are nearest to each other?

A $2F$

B $3F$

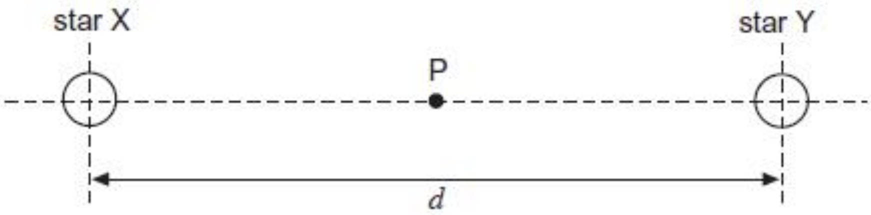
C $4F$

D $5F$

(Total 1 mark)

Q42.

X and Y are two stars of equal mass M. The distance between their centres is d.



What is the gravitational potential at the mid-point P between them?

A $\frac{GM}{2d}$

B $-\frac{GM}{d}$

C $-\frac{4GM}{d}$

D $-\frac{8GM}{d}$

(Total 1 mark)

Q43.

A geosynchronous satellite is in a constant radius orbit around the Earth. The Earth has a mass of 6.0×10^{24} kg and a radius of 6.4×10^{6} m.

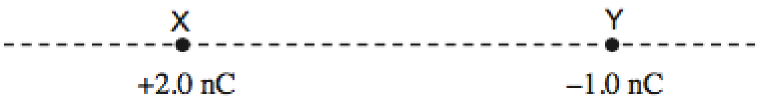
What is the height of the satellite above the Earth's surface?

A 1.3×10^{7} m
B 3.6×10^{7} m
C 4.2×10^{7} m
D 4.8×10^{7} m

(Total 1 mark)

Q44.

A +2.0 nC point charge X is at a fixed distance from a –1.0 nC point charge Y. The force between the two charges is F.



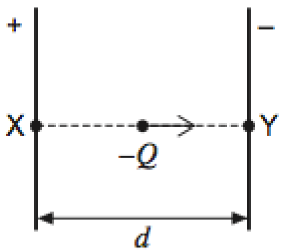
If an **additional** charge of +2.0 nC is supplied to both X and Y, which line, **A** to **D**, in the table gives the magnitude and direction of the force on X?

	Magnitude	Direction
A	2 F	from X to Y
B	4 F	from X to Y
C	2 F	from Y to X
D	4 F	from Y to X

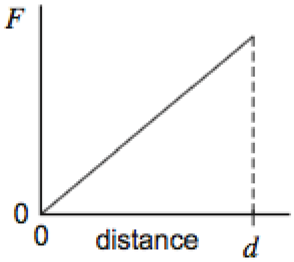
(Total 1 mark)

Q45.

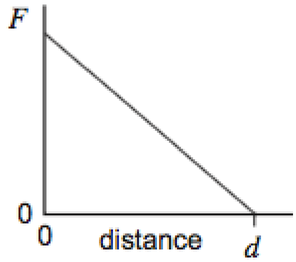
The diagram shows a charge $-Q$ being moved from point X to point Y between two charged parallel plates separated by a distance d.



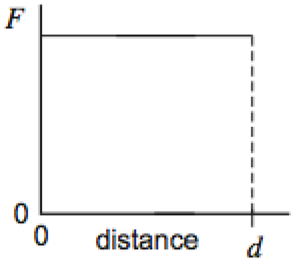
Which one of the following graphs best illustrates how the magnitude of force F on the charge varies with distance as it moves towards Y?



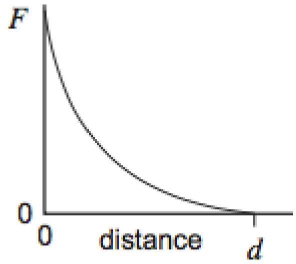
A



B



C

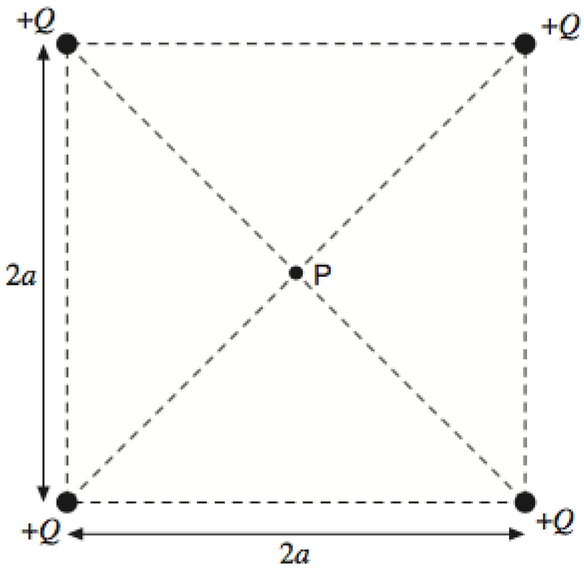


D

(Total 1 mark)

Q46.

The diagram shows four point charges, each $+Q$, at the corners of a square of side $2a$.



What is the electric field strength at P, the centre of the square?

A zero

B $\frac{Q}{4\pi\varepsilon_0 a^2}$

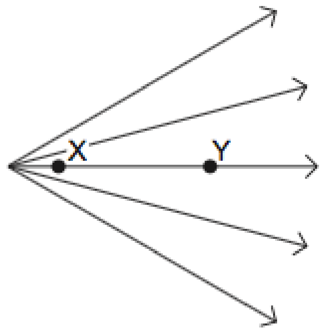
C $\frac{Q}{2\pi\varepsilon_0 a^2}$

D $\frac{Q}{\pi\varepsilon_0 a^2}$

(Total 1 mark)

Q47.

The diagram shows the field lines in a region of an electric field created by a positive charge.



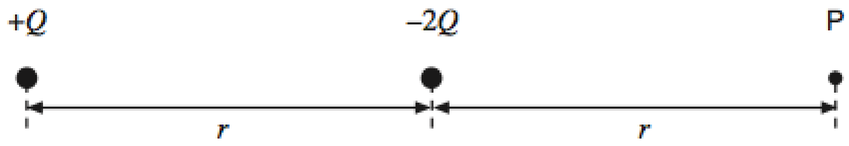
Which one of the following statements is correct?
When moving from X to Y

A the electric potential is constant.
B the electric potential increases.
C the electric potential decreases.
D the electric potential changes from positive to negative.

(Total 1 mark)

Q48.

The diagram shows two point charges of magnitude $+Q$ and $-2Q$ placed a distance r apart.



What is the electric potential at point P, a distance r to the right of the $-2Q$ charge?

A $-\frac{3Q}{8\pi\varepsilon_0 r}$

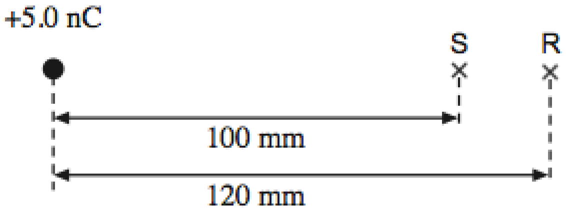
B $-\frac{Q}{2\pi\varepsilon_0 r}$

C $+\frac{Q}{8\pi\varepsilon_0 r}$

D $+\frac{5Q}{8\pi\varepsilon_0 r}$

(Total 1 mark)

Q49.



The potentials at points R and S due to the +5.0 nC charge are 375 V and 450 V respectively.

How much work is done when a +2.0 nC charge is moved from R to S?

A 0.12 μJ
B 0.15 μJ
C 0.19 μJ
D 0.38 μJ

(Total 1 mark)

Q50.

The gravitational constant, G, is a constant of proportionality in Newton's law of gravitation. The permittivity of free space, ε_0, is a constant of proportionality in Coulomb's law.

When comparing the electrostatic force acting on a pair of charged particles to the gravitational force between them, the product $\varepsilon_0 G$ can appear in the calculation.

Which is a unit for $\varepsilon_0 G$?

A $C^2\ kg^{-2}$
B $C^2\ m^{-2}$
C $F\ kg^2\ N^{-1}\ m^{-2}$
D it has no unit

(Total 1 mark)

Q51.

The planet Venus may be considered to be a sphere of uniform density 5.24×10^3 kg m^{-3}. The gravitational field strength at the surface of Venus is 8.87 N kg^{-1}.

(a) (i) Show that the gravitational field strength g_s at the surface of a planet is related to the the density ρ and the radius R of the planet by the expression

$$g_s = \frac{4}{3}\pi G R \rho$$

where G is the gravitational constant.

(2)

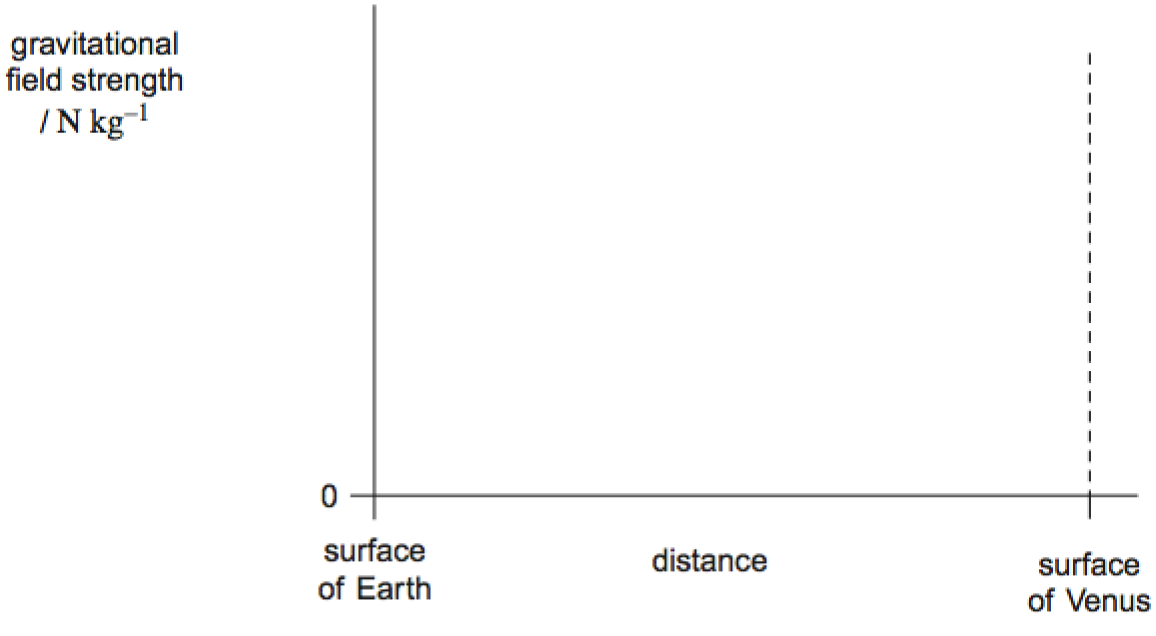
(ii) Calculate the radius of Venus.

Give your answer to an appropriate number of significant figures.

radius = ____________________ m

(3)

(b) At a certain time, the positions of Earth and Venus are aligned so that the distance between them is a minimum.
Sketch a graph on the axes below to show how the magnitude of the gravitational field strength *g* varies with distance along the shortest straight line between their surfaces.
Consider only the contributions to the field produced by Earth and Venus.
Mark values on the vertical axis of your graph.



(3)
(Total 8 marks)

Q52.

The Rosetta space mission placed a robotic probe on Comet 67P in 2014.

(a) The total mass of the Rosetta spacecraft was 3050 kg. This included the robotic probe of mass 108 kg and 1720 kg of propellant. The propellant was used for changing velocity while travelling in deep space where the gravitational field strength is negligible.

Calculate the change in gravitational potential energy of the Rosetta spacecraft from launch until it was in deep space.
Give your answer to an appropriate number of significant figures.

Mass of the Earth = 6.0×10^{24} kg
Radius of the Earth = 6400 km

change in gravitational potential energy ____________________ J

(4)

(b) As it approached the comet, the speed of the Rosetta spacecraft was reduced to match that of the comet. This was done in stages using four 'thrusters'. These were fired simultaneously in the same direction.

Explain how the propellant produces the thrust.

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(3)

(c) Each thruster provided a constant thrust of 11 N.

Calculate the deceleration of the Rosetta spacecraft produced by the four thrusters when its mass was 1400 kg.

deceleration ____________________ m s^{-2}

(1)

(d) Calculate the maximum change in speed that could be produced using the 1720 kg of propellants.

Assume that the speed of the exhaust gases produced by the propellant was 1200 m s^{-1}

maximum change in speed ____________________ m s^{-1}

(3)

(e) When the robotic probe landed, it had to be anchored to the comet due to the low gravitational force. Comet 67P has a mass of about 1.1×10^{13} kg. A possible landing site was about 2.0 km from the centre of mass.

(i) Calculate the gravitational force acting on the robotic probe when at a distance of 2.0 km from the centre of mass of the comet.

gravitational force ____________________ N

(3)

(ii) Calculate the escape velocity for an object 2.0 km from the centre of mass of the comet.

escape velocity ____________________ m s^{-1}

(3)

(iii) A scientist suggests using a drill to make a vertical hole in a rock on the surface of the comet. The anchoring would be removed from the robotic probe before the drill was used. The drill would exert a force of 25 N for 4.8 s.

Explain, with the aid of a calculation, whether this process would cause the robotic probe to escape from the comet.

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(3)

(Total 20 marks)

Q53.

Two identical uniform spheres each of radius R are placed in contact. The gravitational force between them is F.

The spheres are now separated until the force of attraction is $\frac{F}{9}$.

What is the distance between the **surfaces** of the spheres after they have been separated?

A $2R$

B $4R$

C $8R$

D $12R$

(Total 1 mark)

Q54.

A satellite of mass m is in a circular orbit at height R above the surface of a uniform spherical planet of radius R and density ρ.

What is the force of gravitational attraction between the satellite and the planet?

A $\frac{\pi\rho GmR}{3}$

B $\frac{2\pi\rho GmR}{3}$

C $\frac{\pi\rho GmR^2}{3}$

D $\frac{2\pi\rho GmR^2}{3}$

(Total 1 mark)

Q55.

The following data refers to two planets, P and Q.

	Radius / km	Density / kg m^{-3}
planet P	8000	6000
planet Q	16 000	3000

The gravitational field strength at the surface of P is 13.4 N kg^{-1}.
What is the gravitational field strength at the surface of Q?

A 3.4 N kg^{-1}

B 13.4 N kg^{-1}

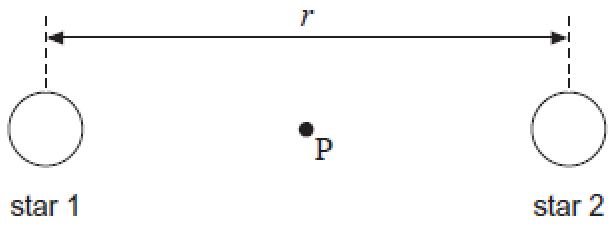
C 53.6 N kg^{-1}

D 80.4 N kg^{-1}

(Total 1 mark)

Q56.

The diagram shows an isolated binary star system. The two stars have equal masses, M, and the distance between their centres is r.



The point P is half-way between the two stars.
What is the gravitational field strength at P?

A zero

B $-\frac{GM}{r^2}$

C $-\frac{2GM}{r^2}$

D $-\frac{4GM}{r^2}$

(Total 1 mark)

Q57.

Which one of the following statements about gravitational potential is **incorrect**?

A It is analogous to the electric potential at a point in an electric field.

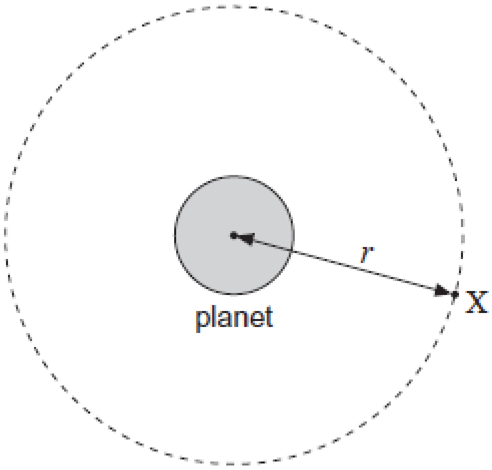
B It is equal to the gravitational potential energy of a mass of 1 kg.

C It is a vector quantity.

D The difference in gravitational potential between two points at different heights above the Earth depends on the position of the points.

Q58.

A satellite X is in a circular orbit of radius r about the centre of a spherical planet of mass M.



Which line, **A** to **D**, in the table gives correct expressions for the centripetal acceleration a and the speed v of the satellite?

	Centripetal acceleration a	Speed v
A	$\frac{GM}{2r}$	$\sqrt{\frac{GM}{2r}}$
B	$\frac{GM}{2r}$	$\sqrt{\frac{GM}{r}}$
C	$\frac{GM}{r^2}$	$\sqrt{\frac{GM}{2r}}$
D	$\frac{GM}{r^2}$	$\sqrt{\frac{GM}{r}}$

(Total 1 mark)

Q59.

A satellite orbiting the Earth moves to an orbit which is closer to the Earth.

Which line, **A** to **D**, in the table shows correctly what happens to the speed of the satellite and to the time it takes for one orbit of the Earth?

	Speed of satellite	Time For One Orbit Of Earth
A	decreases	decreases
B	decreases	increases
C	increases	decreases

D	increases	increases

(Total 1 mark)

Q60.

A positive ion has a charge−to−mass ratio of 2.40×10^{7} C kg^{-1}. It is held stationary in a vertical electric field.
Which line, **A** to **D**, in the table shows correctly both the strength and the direction of the electric field?

	Electric field strength / V m^{-1}	**Direction**
A	4.09×10^{-7}	upwards
B	4.09×10^{-7}	downwards
C	2.45×10^{6}	upwards
D	2.45×10^{6}	downwards

(Total 1 mark)

Q61.

In the equation $X = \frac{ab}{r^n}$, X represents a physical variable in an electric or a gravitational field, a is a constant, b is either mass or charge and n is a number.

Which line, **A** to **D**, in the table provides a consistent representation of X, a and b according to the value of n?

The symbols E, g, V and r have their usual meanings.

	n	X	a	b
A	1	E	$\frac{1}{4\pi\varepsilon_0}$	charge
B	1	V	$\frac{1}{4\pi\varepsilon_0}$	mass
C	2	g	G	mass
D	2	V	G	charge

(Total 1 mark)

Q62.

Which one of the following statements is correct?

An electron follows a circular path when it is moving at right angles to

A a uniform magnetic field.

B a uniform electric field.

C uniform electric and magnetic fields which are perpendicular.

D uniform electric and magnetic fields which are in opposite directions.

(Total 1 mark)

Q63.

(a) State, in words, Coulomb's law.

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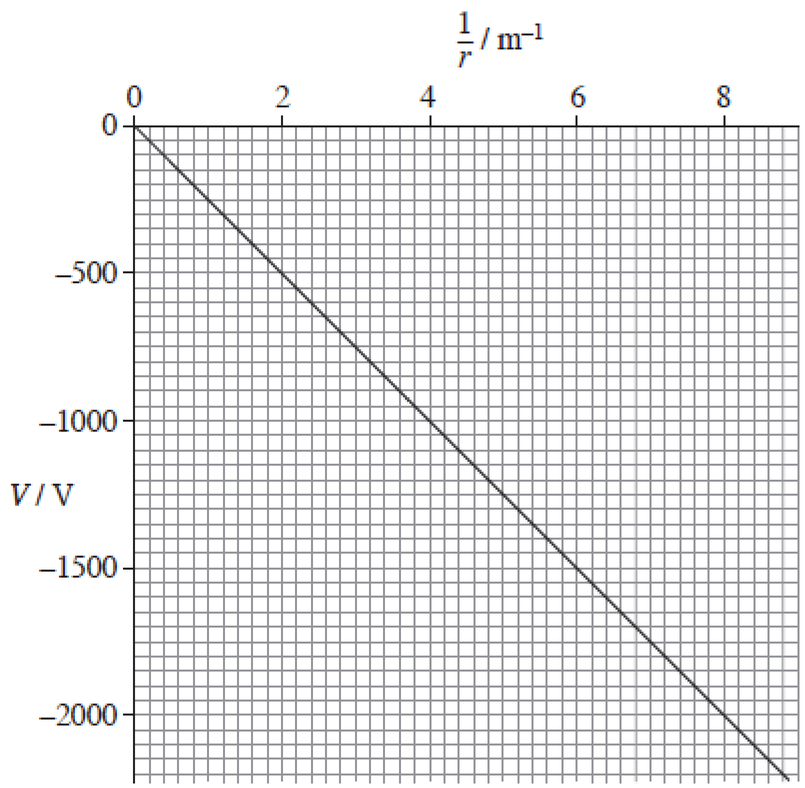
(2)

(b) The graph shows how the electric potential, V, varies with $\frac{1}{r}$, where r is the distance from a point charge Q.



State what can be deduced from the graph about how V depends on r and explain why all the values of V on the graph are negative.

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(2)

(c) (i) Use data from the graph to show that the magnitude of Q is about 30 nC.

(2)

(ii) A +60 nC charge is moved from a point where r = 0.20 m to a point where r = 0.50 m. Calculate the work done.

(2)

work done ____________________ J

(iii) Calculate the electric field strength at the point where r = 0.40 m.

electric field strength ____________________ V m^{-1}

(2)

(Total 10 marks)

Q64.

(a) (i) State what is meant by the term **escape velocity**.

____

____

(1)

(ii) Show that the escape velocity, v, at the Earth's surface is given by $v = \sqrt{\frac{2GM}{R}}$

where M is the mass of the Earth
and R is the radius of the Earth.

(2)

(iii) The escape velocity at the Moon's surface is 2.37×10^3 m s^{-1} and the radius of the Moon is 1.74×10^6 m.

Determine the mean density of the Moon.

mean density ____________________ kg m^{-3}

(2)

(b) State **two** reasons why rockets launched from the Earth's surface do **not** need to achieve escape velocity to reach their orbit.

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(2)
(Total 7 marks)

Q65.

(a) Explain why astronauts in an orbiting space vehicle experience the sensation of weightlessness.

____

(2)

(b) A space vehicle has a mass of 16 800 kg and is in orbit 900 km above the surface of the Earth.

mass of the Earth = 5.97×10^{24} kg
radius of the Earth = 6.38×10^{6} m

(i) Show that the orbital speed of the vehicle is approximately 7400 m s^{-1}.

(4)

(ii) The space vehicle moves from the orbit 900 km above the Earth's surface to an orbit 400 km above the Earth's surface where the orbital speed is 7700 m s^{-1}.

Calculate the total change that occurs in the energy of the space vehicle.
Assume that the vehicle remains outside the atmosphere after the change of orbit.
Use the value of 7400 m s^{-1} for the speed in the initial orbit.

change in energy ____________________ J

(4)

(Total 10 marks)

Q1.

(a) (The electric field strength at a point) is the force per unit charge ✓

On a (small) positive charge (at that point) ✓
(only given if an attempt is made at the first mark)

An equation is not sufficient unless the symbols are defined. Unit charge can be replaced by coulomb.

(Reference to a point is not needed as it is in the question but a reference to moving between points or other points can cancel a mark.)

If "mass" appears in the answer, it must be a synonym for "object".

2

(b) (At B) the (magnitude) of the electric field strength due to Q = the magnitude of the electric field strength due to the 46 µC charge ✓

$$\frac{46\times10^{-6}}{4\pi\varepsilon_0(0.054)^2}=\frac{Q}{4\pi\varepsilon_0(0.066)^2}$$ ✓

$$\left(Q = 46\times10^{-6}\left(\frac{0.066}{0.054}\right)^2\right)$$

$Q = 6.9\times10^{-5}$ (C) ✓ (68.7 µC rounding must be correct)

This first mark may be inferred from the equation but must refer to an electric field.

(Note: the answer 5.6×10^{-5} shows that an inverse square has not been used).

A correct answer gains full marks.

Allow first and second marks even with arithmetic errors ie 10^{-6} missing, distances in mm and the constant $4\pi\varepsilon_0$ not present.

Award one mark if they use the inverse square coulomb law equation to correctly calculate one side of the equation $\left(\frac{46\times10^{-6}}{4\pi\varepsilon_0(0.054)^2} = \right)$ *1.4×10^{8}.*

3

(c) Work must be done on the positive proton because P is at a positive potential

OR

Work must be done (on the positive proton) due to the repulsive forces / because like charges repel OWTTE ✓

The potential at infinity is zero ✓

2

(d) (As the ball falls) it experiences both vertical and horizontal forces/accelerations ✓

The ball is given a constant acceleration

OR

The motion is in a straight line

OR

The motion is at 30° to the vertical (away from the wall) ✓

In this 2nd mark a wrong answer will gain zero marks even if accompanied by a correct answer

'Horizontal' needs to be accompanied by some implication that it is away from the wall. This may be by some reference to repulsion from the wall.

Moves diagonally can imply straight.

"Moving away and downwards" does not imply straight.

Do not credit "horizontal straight line" or "vertical straight line."

'Gravity ' on its own is not a force whereas weight is.

2

[9]

Q2.

A

[1]

Q3.

D

[1]

Q4.

C

[1]

Q5.

B

[1]

Q6.

D

[1]

Q7.

C

[1]

Q8.

A

[1]

Q9.

C

[1]

Q10.

D

[1]

Q11.

D

[1]

Q12.

(a) Period = 0.2×10^{-14} (s) read off

OR

Recognisable T substituted into $T = 1 / f$ ✓

An acceptable subject (period, time for one cycle, one cycle, T, etc.)

Allow non-standard symbol with unit seen on time.

Allow this subtraction of two times seen in $f = 1/T$

Use of $T = 1 / f$ and $c = f\lambda$ ✓

OR

Use of $\lambda = cT$

Use of here is:

Subject must be seen with substitutions or rearranged equations with $f = 1/T$ and $\lambda = c/f$

Condone power 10 error here

Condone lack of subject in vertical working where rearranged equation with appropriate subject seen at heading of column

6(.0) × 10^{-7} (m) ✓

Number must be expressed as 6×10^{-7} or 600×10^{-9}

or equivalent not enough to see only nano prefix.

3

(b) (Determines a fraction of cycle)

$\frac{0.04}{0.2}$ or $\frac{2}{10}$ or $\frac{1}{5}$ or 0.2 or $\frac{1.2(\times 10^{-7})}{6(\times 10^{-7})}$ or 0.2λ seen ✓

Condone their fraction × 2π or their decimal × 2π
For 1st mark

2π/5 OR 0.4 π

OR

1.26 or 1.3 ✓

Allow 8π/5 OR 1.6 π
OR
5.03 or 5.0

2

(c) (Distance =) $3 \times 10^{-7} \times 2.37 \times 10^{5}$ seen

OR

(Distance =) 0.07(11) (m) seen ✓

Subs into $s = \frac{1}{2}at^2$ ✓

Condone error in sub for s where formula has been otherwise correctly manipulated with a (or g) as subject

9.88 (3 sf only) ✓

Alternative:

1st mark average speed = $\frac{3 \times 10 - 7 \times 2.37 \times 105}{0.12}$

2nd mark $a = \frac{2 \times \text{their average speed}}{0.12}$

3rd mark 9.88

3

(d) Draws a tangent to the curve at approximately

t = 120 ms and attempts a gradient calculation ✓

Tangent must be a straight line that touches curve and divergent from curve before 90 ms and after 150 ms

(Gradient =) 1.2 (range 1.1 to 1.3) ✓

Allow 1.2×10^{-3} (range 1.1×10^{-3} to 1.3×10^{-3}) ✓
Ignore units on answer line
2nd mark is dependent on 1st mark
Max 1 mark for correct answer in range where tangent satisfies above conditions but doesn't quite touch curve (half-square tolerance)
First alternative:
1st mark
*Use of v = u +at with sub for a = 9.88 or 9.875 **and** t=0.12*

2nd mark

1.2 or 1.19 or 1.185 ***only***

Second alternative:

1st mark

Use of s = 1/2at² and ds/dt = at with sub for a = 9.88 or 9.875 ***and*** *t = 0.12*

2nd mark

1.2 or 1.19 or 1.185 ***only***

4

(e) (instantaneous) Velocity (of the mirror) or (instantaneous) speed (of the mirror) ✓

Ignore any units quoted

Do not allow:

Average speed / constant speed

4

[8]

Q13.

(a) Gravitational field lines show the direction (and relative magnitude) of force on a mass (placed in the force field) ✓
Or
The direction a stationary/placed mass would (initially) move.

1

(b) (Lines are closer together so) the field is stronger ✓
(Material forming the Earth) at **K** has a high(er) density (than the surrounding material) ✓

For second mark allow more mass at ***K****.*

'Force is stronger' does not gain first mark.

2

(c) The ball will speed up/accelerate (when moving towards **K**) ✓
(because) the potential is lower at **K** ✓
Or
the angled field lines between **J** and **K** have a component towards the right ie towards **K**) ✓

2

(d) A gravitational field should only show attraction to a body / lines of force should only be going to an object / arrow heads (on the left) should point towards **L**. ✓ (owtte)

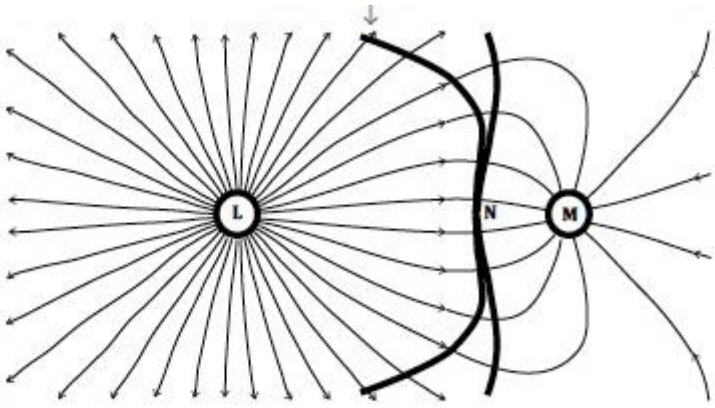
Reference to positive or negative almost always will lose the mark.

1

(e) object = L
object = L ✓

1

(f) The drawn line should approximately cross the field lines at right angles ✓



A mark is given if the line is symmetrical top to bottom and it bends to the left. ✓

First mark:

Only look at the <u>*4 lines*</u> *of force close to N. Essentially the range is from a vertical line to one that curves only slightly in order to cross the 4 field lines close to N at right angles. This mark can also be given if a right angle symbol appears on the diagram at any field crossing of the drawn line.*

Second mark:

There must be some bending of the line to the left (beyond the 4 lines close to N) but no more than that indicated by the arrow above the diagram (For reference the range extends to the position of the second field line that is truncated)

So a very large circle centred on L and leaving the diagram might get 2nd mark but not the 1st.

A vertical line might get the 1st but not the 2nd.

A small circle around M will not score.

If multiple lines are drawn only mark the line that passes through N.

2

[9]

Q14.

(a) (centripetal) force = $m\,r\,(2\,\pi\,/\,T\,)^2$ Or m r $(\omega)^2$

(is given by the gravitational) force = $G\,m\,M\,/\,r^2$ ✓ (mark for both equations)

(equating both expressions and substituting for ω if required)

$T^2 = (4\pi^2\,/\,GM)\,r^3$ ✓ ($4\pi^2\,/\,GM$ is constant, the constants may be on either side of equation but *T* and *r* must be numerators)

First mark is for two equations (gravitational and centripetal)

The second mark is for combining.

2

(b) (use of $T^2 \propto r^3$ so $(T_P\,/\,T_E)^2 = (r_P\,/\,r_E)^3$)

$(T_P\,/1.00)^2 = (5.91 \times 10^9\,/1.50 \times 10^8)^3$ ✓ (mark is for substitution of given data into any equation that corresponds

to the proportional equation given above)
($T_P^2 = 61163$)
$T_P = 250$ (yr) ✓ (247 yr)

Answer only gains both marks

The calculation may be performed using data for the Sun in $T^2 = (4\pi^2 / GM)\, r^3$ easily spotted from $M_s = 1.99 \times 10^{30}$ kg giving a similar answer 247 – 252 yr.

2

(c) using M (= $g\, r^2 / G$) = $0.617 \times (1.19 \times 10^6)^2 / 6.67 \times 10^{-11}$ ✓
M = 1.31×10^{22} kg ✓
answer to 3 sig fig ✓ (this mark stands alone)

The last mark may be given from an incorrect calculation but not lone wrong answer.

3

(d) Initial KE = ½ (m) $1400^2 = 9.8 \times 10^5$ (m) J✓
Energy needed to escape = 7.4×10^5 (m) J ✓
So sufficient energy to escape. ✓

OR For object on surface escape speed given by $7.4 \times 10^5 = \frac{1}{2} v^2$ ✓
escape speed = 1200 m s^{-1} ✓ (if correct equation is shown the previous mark is awarded without substitution)
So sufficient (initial) speed to escape. ✓

OR escape velocity = $\sqrt{\frac{2GM}{R}}$ substituting M from part (c) ✓
escape speed = 1200 m s^{-1} ✓ (1210 m s^{-1})
So sufficient (initial) speed to escape. ✓

OR escape velocity = $\sqrt{2Rg}$ substituting from data in (c) ✓

Third alternative may come from a CE from (c)

(1.06 × 10^{-8} × $(1.06 \times 10^{-8} \times \sqrt{\text{answer(c)}})$*)*

Conclusion must be explicit for third mark and cannot be awarded from a CE

3

[10]

Q15.

C

[1]

Q16.

A

[1]

Q17.

A

[1]

Q18.

A

[1]

Q19.

A

[1]

Q20.

C

[1]

Q21.

D

[1]

Q22.

(a) Ionisation is when an atom / molecule loses (or gains) one (or more) electrons ✓

1

(b) Potential energy of ion is transferred to kinetic energy of ion✓

Power supply transfers energy to the ion✓

Decrease in energy stored in supply = increase in (kinetic) energy stored by the ion✓

3

(c) electric force is constant✓

magnetic force increases with speed✓

(magnetic force dominates) direction of force predicted by any consistent named force rule✓

3

(d) Path curves upwards between the plates✓

1

(e) The magnetic force is the same (Bqv) ✓

So *r* increases / less curvature✓

OR

$Bqv = \frac{mv^2}{r}$ so $r = \frac{mv}{Bq}$ ✓

v, B, q constant so $r \propto m$ and r increases✓

2

(f) Same path in velocity separator ✓

since Bqv=Eq so v independent of q ✓

In mass selector radius is decreased ✓

since $r = \frac{mv}{Bq}$ so $r \propto \frac{1}{q}$ ✓

Both correct with one correct justification would get 3 marks

MAX 3

[13]

Q23.

(a) 1eV = 1.6×10^{-19} J

kinetic energy = $1.6 \times 10^{-19} \times 4.9 \times 10^{6} = 7.8(4) \times 10^{-13}$ J ✓

ke lost = pe gained = $7.8(4) \times 10^{-13}$ J ✓

2

(b) using $V = Q / 4\pi\varepsilon_0 r$ and $E_p = qV$

$r = qQ/4\pi\varepsilon_0 E_p$✓

$= (2 \times 1.6 \times 10^{-19})(79 \times 1.6 \times 10^{-19})/4\pi \times 8.85 \times 10^{-12} \times 7.84 \times 10^{-13}$✓

$r = 4.67(4.64) \times 10^{-14}$ m ✓

3

(c) $A = (R/R_0)^3$ ✓

$= (7.16 \times 10^{-15} / 1.23 \times 10^{-15}\text{ m})^3$ ✓

= 197 placed on the dotted line ✓

3

(d) r gets smaller ✓

less force so needs to travel further to lose same initial ke ✓

Fewer protons means that r will be smaller when alpha particle has the same electrostatic potential energy (as initial kinetic energy)

2

[10]

Q24.

(a) the work done per unit mass ✓

in moving from infinity to the point ✓

2

(b) Gravitational potential is defined as zero at ∞ ✓

(Forces attractive) so work must be done (on a mass) to reach ∞ (hence negative) ✓

2

(c) $V = - GM / r = 6.67 \times 10^{-11} \times 5.97\ 10^{24} / 6.37 \times 10^{6}$ ✓

$= - 6.25 \times 10^{7}$ J kg^{-1} ✓

2

(d) in the plane of the equator

always above the same location on the earth

having the same period as the earth / 24 hours

✓✓any two lines

2

(e) $V = - GM / r = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} / 4.23 \times 10^{7} = - 9.41 \times 10^{6}$ J kg^{-1} ✓

$E_p = \Delta V \times m = = (6.26 - 0.94) \times 10^{7} \times 1200$ ✓

$= 6.38 \times 10^{10}$ J ✓

3

(f) radius must increase ✓

velocity gets smaller ✓

reference to R^3 is proportional to T^2 ✓

reference (from circular motion) v^2 is proportional to $1/r$ ✓

4

[15]

Q25.

C

[1]

Q26.

D

[1]

Q27.

B

[1]

Q28.

A

[1]

Q29.

B

[1]

Q30.

B

[1]

Q31.

C

[1]

Q41.

B

[1]

Q42.

C

[1]

Q43.

B

[1]

Q44.

C

[1]

Q45.

C

[1]

Q46.

A

[1]

Q47.

C

[1]

Q48.

A

[1]

Q49.

B

[1]

Q50.

A

[1]

Q51.

(a) (i) $M = \frac{4}{3}\pi R^3 \rho$ ✓

combined with $g_s = \frac{GM}{R^2}$ (gives $g_s = \frac{4}{3}\pi G R \rho$) ✓

Do not allow r instead of R in final answer but condone in early stages of working.

Evidence of combination, eg cancelling R^2 required for second mark.

2

(ii) $R = \left(\frac{3g_s}{4\pi G\rho}\right) = \frac{3 \times 8.87}{4\pi 6.67 \times 10^{-11} \times 5.24 \times 10^3}$ ✓

gives $R = 6.06 \times 10^6$ (m) ✓

answer to **3SF** ✓

SF mark is independent but may only be awarded after some working is presented.

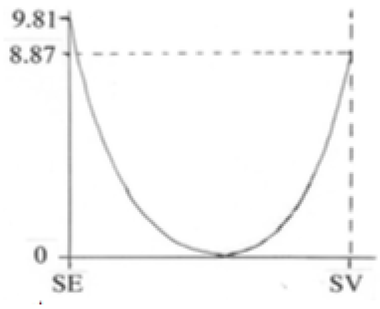
3

(b) line starts at 9.81 and ends at 8.87 ✓

correct shape curve which falls and rises ✓

falls to zeo value near centre of and to right of centre of distance scale ✓

[*Minimum of graph in 3rd point to be >0.5 and <0.75 SE-SV distance]*



For 3rd mark accept flatter curve than the above in central region.

3

[8]

Q52.

(a) Total mass of spacecraft = 3050 kg

Change in PE = $\dfrac{6.67 \times 10^{-11} \times 6 \times 10^{24} \times 3050}{6400 \times 10^{3}}$

1.9×10^{11}(J)

2 sf

condone errors in powers of 10 and incorrect mass for payload

Allow if some sensible working

4

(b) Chemical combustion of propellant / fuel or gases produced at high pressure

Gas is expelled / expands through nozzle

Change in momentum of gases escaping

equal and opposite change in momentum of the spacecraft

Thrust = rate of change of change in momentum

Max 3

N3 in terms of forces worth 1

3

(c) 0.031(4) (m s^{-2})

1

(d) Use of rocket equation

$v = 1200 \ln \dfrac{3050}{1330}$

996 (m s^{-1})

Condone 1000 (m s^{-1})

3

(e) (i) Use of correct mass 108 kg

$F = \dfrac{6.67 \times 10^{-11} \times 1.1 \times 10^{13} \times 108}{(2 \times 10^{3})^{2}}$

0.0198 N

Allow incorrect powers of 10 and mass

3

(ii) Use of $v = \sqrt{\frac{2GM}{r}}$

Correct substitution $v = \frac{2 \times 6.67 \times 10^{-11} \times 1.1 \times 10^{18}}{2 \times 10^{8}}$

0.86 (m s^{-1})

Recognisable mass – condone incorrect power of 10

3

(iii) Impulse = 25 N × 4.8 = 120 N s

(120 = 108 *v* so) Velocity = 1.1 m s^{-1}

Clear conclusion

ie explanation/comparison of calculated velocity with escape velocity from **(e)(ii)**

May use F = ma approach

3

[20]

Q53.

B

[1]

Q54.

A

[1]

Q55.

B

[1]

Q56.

A

[1]

Q57.

C

[1]

Q58.

D

[1]

Q59.

C

[1]

Q60.

A

[1]

Q61.

C

[1]

Q62.

A

[1]

Q63.

(a) force between two (point) charges is

proportional to product of charges ✓

inversely proportional to square of distance between the charges ✓

Mention of force is essential, otherwise no marks.

Condone "proportional to charges".

Do not allow "square of radius" when radius is undefined.

Award full credit for equation with all terms defined.

2

(b) *V* is inversely proportional to *r* [**or** $V \propto (-)1 / r$] ✓

(*V* has negative values) because charge is negative

[**or** because force is attractive on + charge placed near it

or because electric potential is + for + charge and − for − charge] ✓

potential is defined to be zero at infinity ✓

Allow $V \times r$ = constant for 1st mark.

max 2

(c) (i) $Q(= 4\pi\varepsilon_0 rV) = 4\pi\varepsilon_0 \times 0.125 \times 2000$

OR *gradient* $= Q / 4\pi\varepsilon_0 = 2000 / 8$ ✓

(for example, using any pair of values from graph) ✓

= 28 (27.8) (± 1) (nC) ✓

(gives Q = 28 (27.8) ±1 (nC) ✓

2

(ii) at $r = 0.20$m $V = -1250$V and at $r = 0.50$m $V = -500$V

so pd $\Delta V = -500 - (-1250) = 750$ (V) ✓

work done $\Delta W (= Q\Delta V) = 60 \times 10^{-9} \times 750$

$= 4.5(0) \times 10^{-5}$ (J) (45 μJ) ✓

(final answer could be between 3.9 and 5.1 × 10^{-5})

Allow tolerance of ± 50V on graph readings.

[Alternative for 1st mark:

*$\Delta V = \frac{27.8\times10^{-9}}{4\pi\varepsilon_0}\times\left(\frac{1}{0.2}-\frac{1}{0.5}\right)$ (**or** similar substitution using 60 nC*

instead of 27.8 nC:
use of 60 nC gives ΔV = 1620V)]

2

(iii) $E\left(=\frac{Q}{4\pi\varepsilon_0 r^2}\right) = \frac{27.8\times10^{-9}}{4\pi\varepsilon_0\times0.40^2}$ ✓ = 1600 (1560) (V m^{-1}) ✓

[or deduce $E = \frac{V}{r}$ by combining $E = \frac{Q}{4\pi\varepsilon_0 r^2}$ with $V = \frac{Q}{4\pi\varepsilon_0 r}$ ✓

from graph $E = \frac{625\pm50}{0.40}$ = 1600 (1560 ± 130) (V m^{-1}) ✓]

Use of Q = 30 nC gives 1690 (V m^{-1}).
Allow ecf from Q value in (i).
If Q = 60 nC is used here, no marks to be awarded.

2

[10]

Q64.

(a) (i) (Minimum) Speed (given at the Earth's surface) that will allow an object to leave / escape the (Earth's) gravitational field (with no further energy input)

Not gravity
Condone gravitational pull / attraction

B1
1

(ii) ½ $mv^2 = \frac{GMm}{r}$

B1

Evidence of correct manipulation

At least one other step before answer

B1
2

(iii) Substitutes data and obtains $M = 7.33\times10^{22}$(kg)
or
Volume = (1.33 × 3.14 × (1.74 × 10^6)^3 or 2.2 × 10^{19}

or $\rho = \frac{3v^2}{8\pi G r^2}$

C1

3300 (kg m^{-3})

A1
2

(b) (Not given all their KE at Earth's surface) energy continually added in flight / continuous thrust provided / can use fuel (continuously)

B1

Less energy needed to achieve orbit than to escape from Earth's gravitational field / it is not leaving the gravitational field

B1
2

[7]

Q65.

(a) Idea that both astronaut and vehicle are travelling at same (orbital) speed or have the same (centripetal) acceleration / are in freefall

Not falling at the same speed

B1

No (normal) reaction (between astronaut and vehicle)

B1
2

(b) (i) Equates centripetal force with gravitational force using appropriate formulae

E.g. $\frac{GMm}{r^2} = \frac{mv^2}{r}$ or $mr\omega^2$

B1

Correct substitution seen e.g. $v^2 = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{\text{any value of radius}}$

B1

(Radius of) 7.28×10^6 seen or $6.38 \times 10^6 + 0.9 \times 10^6$

B1

7396 (m s^{-1}) to at least 4 sf

Or $v^2 = 5.47 \times 10^7$ seen

B1
4

(ii) $\Delta PE = 6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^4$ (1 / (7.28

$\times 10^6) - 1 / (6.78 \times 10^6)$)

C1

-6.8×10^{10} J

C1

$\Delta KE = 0.5 \times 1.68 \times 10^4 \times (7700^2 - 7400^2) = 3.81 \times 10^{10}$ J

C1

$\Delta KE - \Delta PE = (-)\ 2.99 \times 10^{10}$ (J)

A1

OR

Total energy in original orbit shown to be $(-)GMm / 2r$ or $mv^2 / 2 - GMm / r$

C1

Initial energy
$= -6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^4 / (2 \times 7.28 \times 10^6) = 4.59 \times 10^{11}$

C1

Final energy
$= -6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 1.68 \times 10^4 / (2 \times 6.78 \times 10^6) = 4.93 \times 10^{11}$

3.4×10^{10}(J)

Condone power of 10 error for C marks

A1

4

[10]

Q1.

(a) As was the case in 2017, many students had not learnt definitions thoroughly. So, the actual unit of charge was absent from many scripts as was a reference to a positive charge. Weaker students mixed the definition of electric field strength with electric potential. 44.4% of students did not gain any credit here.

(b) This was a very discriminating question and just over half of the students performed well and gained at least two marks. The hurdle to overcome was to use an inverse-square force equation rather than an inverse equation that relates to potential. Once the correct equation had been established, most found no difficulty in the re-arrangements involved. It is worth pointing out that students who explained their work with a couple of words were much more likely to obtain marks even if their calculations were wrong.

(c) Most students showed a weakness in their understanding in this topic. The fact that the resultant electric field was zero at P, and they rightly concluded that the field was zero at infinity, made it too tempting to conclude the line between P and infinity must be an equipotential, which was obviously wrong. Only about a third of the students thought about the work that must be done in moving a proton to a region close to two positive charges. Also very few referred to the potential being zero at infinity. 60.7% of students scored zero.

(d) This was another question done badly, with 61.1% failing to score. The common answers fell into two groups. The first just regarded the ball being released as if it were thrown and therefore following a parabolic path. The second group ignored gravity all together and wrote about the ball travelling away horizontally. Very few students analysed the situation by considering the forces and then the resulting accelerations in the horizontal and vertical directions. In fact, many students did not mention force or acceleration but kept to generalities such as “it moves away from the wall and falls”.

Q2.

81.4% correct

Q3.

80.5% correct

Q4.

27.1% correct

Q5.

47.6% correct

Q6.

36.6% correct

Q7.

30.8% correct

Q8.

58.5% correct

Q9.

49.2% correct

Q10.

63.3% correct

Q11.

57.5% correct

Q12.

(a) A question asking a student to “Show that” is asking the student to demonstrate clearly their logic in arriving at the provided answer. The marks are awarded for clear communication of the steps taken in the working. Where lapses occur, such as no ‘subject’, no formula, or no rearrangement of terms, then the student is not demonstrating that logic with sufficient detail. Students should be encouraged to pay attention to the way their working is laid out in this type of question. Many students were awarded 3 marks by having unambiguous, explicit working.

(b) Typically, high performing students demonstrated clear understanding through the working presented in the determination of the phase difference. However, other students were very unsure of how to use **Figure 1** to find the phase difference. Some of these students determined the time difference to be 0.05×10^{-14} instead of 0.04×10^{-14} . Students need to take care when reading off data from graphs to ensure that such readings are sufficiently accurate.

(c) Some students ignored the direction to use the data provided to compute the value for g arrived at by the gravimeter and simply quoted $g = 9.81\ ms^{-2}$. Other students attempted to use the data to obtain a value close to 9.8 and in this case errant doubling and halving was seen. Able students typically approached this question in a structured way, producing working that was clearly presented and easy to follow. A significant number of students failed to quote the final answer to 3 sf, instead leaving it as 4 sig figs or rounding to 2 sig figs.

(d) A very large number of students read a single point of the curve and divided the distance by the time. Another common mistake was the use of d = 0.12 rather than t = 120 ms. This read-off error led to tangents being drawn at the wrong point on the curve. Students who drew a tangent generally arrived at an accurate answer that was inside the allowed range. Power of ten errors were tolerated where students kept their time in milliseconds rather than converting to seconds. Tangents drawn were of variable quality; it was difficult to ascertain the unique point on the curve that the drawn line touched.

(e) A common incorrect answer was acceleration, while a significant number of students thought that it was the average speed of the mirror. Good quality responses identified the gradient at 120 ms as the instantaneous speed.

Q13.

(a) A majority of answers simply reinterpreted the words of the question and made no reference to force or mass. So there was a proliferation of answers such as, “They show the direction of the field acts in”. Only a minority of students gave a complete answer. A common misunderstanding that was frequently stated was the idea that a mass will follow the field line when free to move. This may be true for an initial movement, but subsequently, because of the build-up of momentum, it is not generally true.

(b) Many students appreciated that the gravitational field was stronger at K but then did not give a good reason for it. They often referred to the earth not being flat, or stated that K is up a mountain or down a hole. Other students did state that there was a mass at K or it was an area where the Earth’s density is greater, but they did not refer to the field being stronger. Also a few students referred to gravitational force when they were really referring to gravitational field.

(c) Only a small number of students deduced that the field had a component horizontally near K. Therefore very few scored 2 marks. A majority did appreciate that the ball would accelerate, even if their reasoning was sometimes false. Several students misinterpreted the question and thought that the ball was falling, but this would not have excluded the student from scoring both marks. If no direction was stated, the motion was treated as horizontal by examiners. If the students thought the ball was falling, and separated the horizontal and vertical motion, both marks are obtainable. The vertical was ignored and both points in the mark scheme are still true for the horizontal motion.

(d) The idea behind the question was well understood by the vast majority of students. It was only the least able who missed out on the mark.

(e) Most students, 70%, could do this easily.

(f) A majority of students seemed to be unaware how equipotential lines relate to field lines. Very few scored full marks. Common shapes drawn were a line joining L to M, a straight vertical line, and a tight circle around M.

Q14.

(a) Most scripts showed a clear connection between the centripetal force and the force of gravity on the satellite, to arrive at the correct proportional relationship between T^2 and r^3. Less able students failed to get the two starting equations and only toyed with the centripetal equation unsuccessfully. The most common algebraic mistake was to miss that the π term was squared when $(2\pi)^2$ was expanded.

(b) Marks for this calculation were quite low because students could not cope with the quite complicated proportional relationship. Some students avoided the proportional calculation by using the Kepler’s equation derived earlier. Quite a number of these students then got into difficulty because the distances were given in km and not m.

(c) This question was tackled well by most students. Equating the Universal gravitational force to mg was a well understood task. Only the least able students failed to rearrange the equation or made calculation errors. A significant number that were correct failed to answer using 3 significant figures, but by the same token some making calculation errors did give an answer to 3 significant figures, and thereby gained a mark.

(d) The students who took the very straightforward approach and calculated the escape velocity were very successful in this question. However, a majority of students made errors. Many did not know the escape velocity equation or could not get to it from the conservation of energy. Other students referred to the top of the graph, Figure 8, at a potential of -1.4 × 105 J kg^{-1} as being the point at which the ice escapes, which is a physics error.

Q41.

This question tested the gravitational inverse square law in the context of two planets orbiting a star. Application of Pythagoras' theorem shows that $(XY)^2 = 3R^2$. When the planets are closest, their separation is reduced to *R*; thus the force increases from *F* to 3*F*. The facility of the question was 58%, with one in five of the responses being for distractor C (4*F*).

Q42.

This question turned to gravitational potential. At the mid-point P between the two identical stars, the gravitational potential due to one of the stars must be $-GM/0.5d$, which is $-2GM/d$. The total gravitational potential due to both stars must therefore be $-4GM/d$. This was realised by 62% of the students. Faulty algebraic work probably caused 28% of the students to choose distractor B ($-GM/d$).

Q43.

If calculated from first principles from the data given in the question, about the height of a geosynchronous satellite, it is a demanding question for the time available in an objective test. Nevertheless 53% of the responses were correct; perhaps some students had rehearsed the calculation and committed the result to memory. The question asked for the height of the satellite *above the Earth's surface,* and it is not surprising that the most common incorrect response was distractor C (the radius of the satellite's orbit). 24% of the students made this mistake.

Q44.

This question, with a facility of 34.6%, was the most demanding in this test. Actually 68.5% of the students realised that, once the charge on each of X and Y had been increased by +2.0 nC, the force on X would become 2*F*. But practically half of them failed to spot that both charges would now be positive, and the force on X would now be one of repulsion i.e. from Y to X.

Q45.

This question question concerned *E* between two charged parallel plates, where the field strength is constant throughout the region between them. Hence the magnitude of the force on a charge does not vary with the distance across the gap. Just over half of the students chose the correct answer, but almost a quarter of them were tempted by distractor A, showing the force to increase linearly with the distance.

Q46.

The vector nature of *E* was the essential point in deciding the answer. At the centre of the square, equidistant from each of the four equal point charges, *E* is bound to be zero. This question had been used previously, and its facility improved from 53% then to 66% in 2016. A significant number of students chose distractors B and C.

Q47.

This question concerned the relationship between field strength and potential in a region of a radial electric field created by a point positive charge. 71% correctly realised that the electric potential would decrease as the distance from the point charge was increased, but almost a quarter thought it would increase (distractor B).

Q48.

This question, about the magnitude of the electric potential in a region close to two charges, was the most discriminating question in the test. Its facility was 58%. It appears that algebraic weakness caused 26% of the students to opt for distractor B.

Q49.

This question was rather easy, with a facility of 71%. It was a direct test of $\Delta W = Q\Delta V$. The correct answer follows from $2.0 \times 10^{-9} \times (450 - 375)$. The most common incorrect choice was distractor D (0.38 μJ). This follows from $5.0 \times 10^{-9} \times (450 - 375)$, showing that those involved had not read the question properly: they thought that the charge being moved was +5.0 nC rather than +2.0 nC.

Q50.

This was an unusual question on combinations of electrical units. 54% of the responses were correct, whilst 18% selected distractor C and 20% distractor D (no unit). The latter must have been tempting because both $\boldsymbol{\varepsilon_0}$ and **G** are constants.

Q51.

Combining $g = GM/R^2$ with $M = 4/3\ \pi R^3\rho$ caused very few problems in part (a)(i) and the marks were high. The main failing was the indiscriminate use of *r* for *R* in the working. In part (a)(ii) the correct substitution of the given values into the equation from (a)(i) readily produced the expected answer, which was usually given correctly to three significant figures. A minority of the students chose to ignore the equation from part (a)(i) and made hard work for themselves by working out a result from first principles.

In part (b) the graph of *g* against the distance between Earth and Venus was rewarding for most. A graph of a correct general shape was usually presented, with the majority appreciating that there would be a minimum value to the right of centre. This minimum was not always shown to be zero, which was expected. Some answers did not heed the instruction to mark values on the vertical axis of the graph.

Q52.

(a) Most students gave the answer to 3 significant figures, although 2 sf was what was required. The correct mass (3050 kg) was chosen by those who used the correct formula, but some students used no mass in calculating the potential only.

(b) Many stated that the propellant/fuel was ejected through the nozzle. The statements about the momentum of the exhaust gases were often confused. The most popular way of deriving thrust was by attempting to use Newton's 3rd law but the statements were often incomplete.

(c) The simple use of F = ma was easily achieved by most students.

(d) Although some students attempted to use conservation of momentum, most realised that the rocket equations was needed. There is the same confusion over the meaning of the symbols v_f and m_f. Some used $m_f = 1720$ kg instead of 1330 kg, and others, after correctly calculating $v_f = 996$ m s^{-1}, went on to subtract this from the exhaust gas speed, thus sacrificing a mark.

(e) (i) Most students chose the correct formula, but many forgot to square the radius, and others chose the wrong mass. The original mass of the spacecraft (3050 kg) was the most popular erroneous value, although even the mass of the Earth was seen occasionally.

(ii) Nearly everyone started with the correct formula but two common errors ensued. Some forgot to take the square root and others did not convert 2.0 km to meters. Also some gave the answer to 1 sf (0.9 m s^{-1}) thus losing a mark.

(iii) Those who calculated that the velocity change of the probe was 1.1 m s^{-1} followed with the right conclusion. Some students used the wrong mass but could still gain the third mark with a correct comparison.

Q53.

This question was on Newton's law, in particular the realisation that it is an inverse square relationship. Reduction in the force of attraction from F (when in contact at separation 2R) to F / 9 implies that the separation of centres has increased by a factor of 3, from 2R to 6R. Hence the distance between the surfaces of the spheres would be 4R. 58% of the students gave this, with 21% choosing distractor A (which was 2R).

Q54.

This question was an algebraic test of Newton's law involving the use of density and the volume of a sphere to determine mass. Slightly more than one half of the students succeeded with this, although more than a quarter of them selected distractor B, where the force would be twice the expected value.

Q55.

This question turned to gravitational field strength. This question had been used in a previous examination, when slightly less than half of the responses were correct. This time 65% were correct and the discrimination was also much improved. The basis of the calculation of g at the surface of the second planet ultimately depended on the ratio of the relative $R \times$ values (which happened to be 1.0).

Q56.

This question distracted only 13% of the students away from the correct answer. When the question was pre-tested only 68% of the responses were correct. Yet it should not have been too demanding for students to appreciate that the field strength would be zero at the mid-point between two identical stars.

Q57.

Features of gravitational potential were tested by this question, in which students had to choose an *incorrect* statement. Questions in this format always present a challenge to students, since they would normally expect to select *correct* statements. Consequently this question, with a facility of 44%, was one of the most difficult questions in this test. Students ought to be familiar with the fact that, whilst field strength is a vector quantity, potential is a scalar. Therefore statement C (potential is a vector) cannot be correct and is the required answer.

Q58.

This question was about satellites. The former required correct algebraic expressions for the centripetal acceleration and speed of a satellite in circular orbit around a planet. Just over four-fifths of the responses were correct.

Q59.

This question tested students' understanding of the effect of the descent towards a planet on the speed and orbit time. 74% of them knew that the speed would increase and the orbit time would decrease, because $v \propto r^{-1/2}$ whilst $T \propto r^{3/2}$.

Q60.

This question concerned the strength and direction of an electric field in which a positive ion of given charge-to-mass ratio was held at rest. Application of $mg = EQ$ was the key to finding the field strength. This question was re-used from an earlier year and its facility improved only slightly, from 46% to 53%. The most popular wrong answers were distractor B (wrong direction), which was chosen by 18%, and distractor C (wrong strength), chosen by 19%.

Q61.

This question proved to be somewhat easier, despite the rather abstract phrasing of the stem. 85% of the students knew that only alternative C gave a consistent expression i.e. $g = GM / r^2$.

Q62.

This question required students to understand the trajectory of an electron moving in electric and / or magnetic fields. 73% gave a correct response.

Q63.

Statements of Coulomb's law were generally satisfactory in part (a) and marks were high. Occasionally there was confusion with the law of gravitation (distance between *masses* rather than *charges*) and reference to *indirect* proportion (which was not acceptable) rather than *inverse* proportion.

In part (b), inverse proportion was generally recognised as the relationship between V and r shown on the graph. Many students knew that the negative values of potential were caused by the charge Q being negative. Alternative arguments that approached an answer via the definition of potential usually failed because the positive nature of the charge being moved was not stated. No doubt it was confusion with gravitational potential, which is always attractive, that caused a significant number of students to conclude that electric potential is always negative.

There was a good spread of marks across the three calculations in part (c). Part (c)(i) was usually answered correctly, either by substitution of a data point from the graph or by use of the gradient. Part (c)(ii) was most easily approached by reading the potentials corresponding to $r = 0.20$ m and $r = 0.50$ m from the graph, leading to $\Delta V = 750$V, and then applying $\Delta W = Q\Delta V$. The principal failing in the answers that started from first principles, by calculating the two potentials from the Q value in part (i), was to use 60 nC as both the source of the potentials and as the charge being moved. Direct substitution of the charge from part (i) into $E = Q / 4\pi\varepsilon_0 r^2$ gave the most straightforward answer in part (iii). Although the use of $E = V / d$ gave the correct numerical answer here, it should be recognised that this equation is only valid in a uniform field whereas the field in this question is radial. Both marks were therefore awarded for this approach only when the use of $E = V / r$ had been justified.

Q64.

(a) (i) Well done.

(ii) Candidates scored 2 or zero. The latter invariably used centripetal force = gravitational force.

(iii) Many promising calculation were ruined by failure to cube the radius when finding the volume.

(b) Most candidates did not realise that escape velocity was not needed because the rocket was not escaping!

Q65.

(a) Most candidates mentioned the lack of reaction force but some answers were spoilt by claiming that there was no resultant force or even no gravity.

(b) (i) Each step needed to be clearly shown, starting with the statement that gravitational force = centripetal force.

There were several cases of the use of 900 km for the radius.

(ii) Common errors were treating potential energy as positive, the use of the wrong radii and the use of mgh.