3.7 Fields and their Consequences

AQA 7408 · Calculator allowed · about 215 minutes · Write-in edition

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 Mars has mass 6.42 x 10^{23} kg and radius 3.39 x 10^{6} m. Use the Physics Equations Sheet where needed; any equations not on the sheet are given below. Take G = 6.67 x 10^{-11} N m^2 kg^{-2}.

(a) State Newton's law of gravitation for two point masses. **(1)**

(b) Show that the gravitational field strength at the surface of Mars is about 3.7 N/kg. Use $g = GM/r^2$. **(3)**

(c) A small rock is dropped from rest 2.0 m above the Martian surface. Assuming g = 3.7 N/kg is constant over this height, calculate the time taken for the rock to reach the surface. Use $s = (1/2)g\,t^2$. **(3)**

(d) Describe the shape of the gravitational field around Mars as a whole, and state one way this differs from the field close to a small region of the Martian surface (such as the 2.0 m drop in part (c)). **(2)**

(Total for Question 1 is 9 marks)

---

2 A straight wire of length 0.25 m carries a current of 4.5 A. It is placed perpendicular to a uniform magnetic field of flux density 0.18 T.

(a) Calculate the force on the wire due to the magnetic field. Use F = BIL. **(2)**

(b) The current flows from left to right and the magnetic field points into the page. State the direction of the force on the wire and explain how you determined it. **(2)**

(c) The wire is now turned so that it makes an angle of 30 degrees with the magnetic field (rather than being perpendicular to it). Calculate the new force on the wire. Use F = BIL sin(θ). **(3)**

(Total for Question 2 is 7 marks)

3 This question tests core definitions relating to fields.

(a) Define gravitational field strength at a point. **(1)**

(b) Define the electric potential at a point. **(1)**

(c) State Faraday's law of electromagnetic induction. **(1)**

(Total for Question 3 is 3 marks)

4 REQUIRED PRACTICAL. A student uses a current balance to determine the magnetic flux density between two magnadur magnets. A stiff horizontal wire of length 0.060 m passes between the magnets and rests on a top-pan balance support. When a current of 2.0 A is switched on, the balance reading changes by a mass equivalent of 0.24 g. Take g = 9.81 N/kg.

(a) Explain why switching on the current changes the reading on the balance. **(2)**

(b) Calculate the force on the wire corresponding to this change in balance reading. Use F = mg. **(2)**

(c) Calculate the magnetic flux density between the magnets. Use F = BIL. **(3)**

(d) The student repeats the measurement for several different currents and plots a graph of force F (y-axis) against current I (x-axis). Explain how the gradient of this graph is related to B, and why using the gradient gives a more reliable value of B than using a single pair of readings. **(3)**

(Total for Question 4 is 10 marks)

5 Continue to use the Mars data from Question 1 (mass 6.42 x 10^{23} kg, radius 3.39 x 10^{6} m, G = 6.67 x 10^{-11} N m^2 kg^{-2}).

(a) State what is meant by the gravitational potential at a point in a gravitational field. **(1)**

(b) Calculate the gravitational potential at the surface of Mars. Use V = -GM/r. **(2)**

(c) A spacecraft of mass 850 kg leaves the surface of Mars and just escapes its gravitational field. Using $v = \sqrt{2GM/r}$ for the minimum escape velocity, calculate this velocity. **(3)**

(d) Explain, in terms of energy, why $v = \sqrt{2GM/r}$ is called the escape velocity. **(2)**

(Total for Question 5 is 8 marks)

6 Two isolated point charges are fixed 0.15 m apart in air: charge A = +3.2 x 10^{-9} C and charge B = -5.0 x 10^{-9} C. Take k = 1/(4 π epsilon0) = 8.99 x 10^{9} N m^2 C^{-2}.

(a) Calculate the magnitude of the electrostatic force between charges A and B, stating whether the force is attractive or repulsive. Use F = Q1 Q2 / (4 π epsilon0 r^2). **(3)**

(b) Calculate the electric field strength due to charge A alone at the position of charge B. Use E = kQ/r^2. **(2)**

(c) Describe the pattern of the electric field around an isolated positive point charge, including the direction of the field. **(2)**

(d) A proton (charge +1.6 x 10^{-19} C) is placed at the midpoint between A and B, 0.075 m from each charge. Calculate the resultant electrostatic force on the proton, explaining your reasoning about direction. **(4)**

(Total for Question 6 is 11 marks)

7 The moon Ganymede-like body 'Callira' (a fictional body, for calculation purposes) has mass 1.48×10^{23} kg and radius 2.63×10^{6} m. Take $G = 6.67 \times 10^{-11}$ N m^2/kg^2.

(a) Calculate the gravitational field strength at the surface of Callira. **(3)**

(b) Calculate the escape velocity from the surface of Callira, using $v(escape) = \sqrt{2GM/r}$. **(4)**

(Total for Question 7 is 7 marks)

8 Three capacitors are connected in a circuit: C1 = 100 uF and C2 = 220 uF are connected in parallel with each other, and this combination is connected in series with C3 = 150 uF. The network is connected across a 12 V supply.

(a) Calculate the combined capacitance of C1 and C2 in parallel. **(1)**

(b) Calculate the total capacitance of the network. **(3)**

(c) Calculate the total charge supplied by the 12 V source. **(2)**

(d) Calculate the total energy stored in the network. **(3)**

(Total for Question 8 is 9 marks)

9 REQUIRED PRACTICAL. A student measures the magnetic flux density between two magnadur magnets using a current balance method. A straight horizontal wire of length 0.12 m carrying a current of 3.5 A is placed in the field, perpendicular to it. When the current is switched on, the reading on a top-pan balance beneath the magnet assembly changes by an apparent mass of 0.42 g. Take $g = 9.81\ m/s^2$.

(a) Calculate the force on the wire due to the magnetic field. **(2)**

(b) Calculate the magnetic flux density of the field. **(3)**

(c) Using Newton's third law, explain why switching on the current changes the reading on the balance beneath the magnets. **(3)**

(Total for Question 9 is 8 marks)

10 A proton (mass 1.67 x 10^{-27} kg, charge 1.60 x 10^{-19} C) travels at 2.5 x 10^{6} m/s perpendicular to a uniform magnetic field of flux density 0.40 T, which occupies a region of width 5.0 cm. The proton enters the field travelling perpendicular to the boundary of the field region.

(a) Calculate the magnetic force on the proton as it enters the field. Use F = BQv. **(2)**

(b) Explain why this magnetic force causes the proton to move at constant speed along a circular path. **(2)**

(c) By equating the magnetic force BQv to the centripetal force mv^2/r, show that the radius of the circular path is given by r = mv/(BQ). **(2)**

(d) Calculate the radius of the circular path followed by this proton. **(2)**

(e) The magnetic field region has a width of 5.0 cm, measured in the direction the proton was initially travelling. For a particle entering perpendicular to the boundary of a field region, the maximum distance it can penetrate into the field before curving back out of the same boundary is equal to the radius r of its circular path. Using your value of r from part (d), determine, with reasoning, whether this proton crosses completely through the 5.0 cm field region or curves back out of the boundary it entered through. **(3)**

(Total for Question 10 is 11 marks)

11 A Mars communications satellite moves in a circular orbit of radius r about the centre of Mars, held in orbit by the gravitational force. Continue to use GM(Mars) = 4.28×10^{13} N m^2 kg^{-1}.

(a) By equating the gravitational force GMm/r^2 to the centripetal force $m(4\pi^2 r)/T^2$, show that the orbital period T of the satellite is given by $T^2 = (4\pi^2 r^3) / (GM)$. **(3)**

(b) The satellite orbits at a radius of 2.0×10^7 m from the centre of Mars. Calculate its orbital period, giving your answer in hours. **(4)**

(c) Mars rotates on its axis once every 24.6 hours. State what is meant by a synchronous orbit, and use your answer to part (b) to decide, with a reason, whether this satellite is in a synchronous orbit around Mars. **(2)**

(Total for Question 11 is 9 marks)

12 Continue with charge A = +3.2 x 10^{-9} C from Question 6.

(a) State what is meant by the electric potential at a point in an electric field. **(1)**

(b) Calculate the electric potential at a point 0.075 m from charge A. Use V = kQ/r. **(2)**

(c) A proton (charge +1.6 x 10^{-19} C) is brought from a very large distance to this point. Calculate the work done on the proton. Use W = qV. **(2)**

(d) Compare and contrast gravitational fields and electric fields. Your answer should refer to the mathematical form of the force, field strength and potential, and to the nature of the sources that produce each field. **(6)**

(Total for Question 12 is 11 marks)

13 Two parallel plates are separated by 0.020 m, with a potential difference of 500 V between them, creating a uniform electric field. The plates have a length of 0.040 m (measured along the direction of travel of a particle passing between them). An electron (mass 9.11×10^{-31} kg, charge 1.60×10^{-19} C) enters midway between the plates, travelling parallel to them at 2.0×10^{7} m/s.

(a) Calculate the electric field strength between the plates. Use E = V/d. **(2)**

(b) (i) Calculate the electric force on the electron while it is between the plates. Use F = eE. **(2)**

(c) (ii) Calculate the vertical acceleration of the electron while it is between the plates. Use a = F/m. **(2)**

(d) (iii) Calculate the time the electron spends between the plates. Use t = L/v, where L is the plate length. **(2)**

(e) (iv) Calculate the vertical deflection of the electron as it leaves the plates, using $y = (1/2)a\,t^2$. Hence determine, with a reason, whether the electron leaves the plates without striking either one (the maximum possible deflection before hitting a plate is half the plate separation). **(3)**

(Total for Question 13 is 11 marks)

14 A communications satellite of mass 650 kg orbits Callira (mass 1.48 x 10^{23} kg, G = 6.67 x 10^{-11} N m^2/kg^2) in a circular orbit of radius r1 = 3.20 x 10^6 m.

(a) Calculate the orbital speed of the satellite. **(3)**

(b) Calculate the orbital period of the satellite, giving your answer in hours. **(3)**

(c) Using E(orbit) = -GMm/(2r), calculate the total orbital energy of the satellite at r1 = 3.20 x 10^6 m and at a higher orbit r2 = 4.50 x 10^6 m. **(3)**

(d) Hence calculate the minimum energy that must be supplied to move the satellite from the orbit at r1 to the orbit at r2. **(2)**

(Total for Question 14 is 11 marks)

15 Two isolated point charges are held fixed 0.30 m apart in air: Q1 = +5.0 x 10^{-6} C and Q2 = -2.0 x 10^{-6} C. Take k = 8.99 x 10^{9} N m^2/C^2.

(a) Calculate the magnitude of the electrostatic force between the two charges, and state whether it is attractive or repulsive. **(3)**

(b) Calculate the electric field strength at the midpoint between the two charges due to both charges, explaining why the contributions from the two charges add together rather than cancel. **(4)**

(c) Calculate the electric potential at the midpoint due to both charges. **(3)**

(Total for Question 15 is 10 marks)

16 A beam of ions passes undeflected through a velocity selector containing a uniform electric field of strength 2.4×10^4 V/m perpendicular to a uniform magnetic field of flux density 0.060 T, both fields being perpendicular to the ion beam. The selected ions then enter a second region containing only the 0.060 T magnetic field, where they follow a circular path of radius 0.085 m.

(a) Explain why only ions of one particular speed pass through the velocity selector undeflected. **(2)**

(b) Calculate the selected speed of the ions. **(2)**

(c) Calculate the charge-to-mass ratio (q/m) of the ions, using the radius of their circular path in the second region. **(4)**

(Total for Question 16 is 8 marks)

17 Gravitational fields around point masses and electric fields around point charges both obey an inverse-square law, but they also have important differences. Compare and contrast gravitational fields and electric fields, and evaluate why gravitational forces dominate the behaviour of large-scale astronomical systems (such as planets, stars and galaxies) even though the gravitational force is intrinsically far weaker than the electric force at the scale of fundamental particles.

(Total for Question 17 is 6 marks)

Mark scheme · 3.7 Fields and their Consequences

Question 1

(a) the gravitational force between two point masses is directly proportional to the product of the masses and inversely proportional to the square of their separation (oe, e.g. $F = GMm/r^2$ with terms defined) **B1**

(a) Answer: $F = GMm/r^2$, an attractive force along the line joining the masses

(b) correct substitution $g = (6.67 \times 10^{-11} \times 6.42 \times 10^{23}) / (3.39 \times 10^{6})^2$ **M1**

(b) numerator evaluated as awrt 4.28×10^{13} and denominator evaluated as awrt 1.15×10^{13} (oe combined arithmetic) **M1**

(b) g = 3.7 N/kg (cso, to 2 sf, matches given value) **A1**

(b) Answer: g = 3.7 N/kg

(c) rearrangement $t = \sqrt{2s/g}$ **M1**

(c) correct substitution $t = \sqrt{2 \times 2.0 / 3.7}$ **M1**

(c) t = 1.0 s (awrt 1.0 s, cao) **A1**

(c) Answer: t = 1.04 s (awrt 1.0 s)

(d) the field around the whole of Mars is radial, with field lines directed towards the centre of Mars, and field strength decreasing with distance from the centre **B1**

(d) close to the surface over a small region the field is effectively uniform (parallel, equally spaced field lines) because the change in r is negligible (oe) **B1**

(d) Answer: Radial overall; uniform over a small region near the surface

Question 2

(a) correct substitution F = 0.18 x 4.5 x 0.25 **M1**

(a) F = 0.20 N (cao) **A1**

(a) Answer: F = 0.2025 N (awrt 0.20 N)

(b) the force acts vertically upwards (in the plane of the page) **B1**

(b) found using Fleming's left-hand rule: First finger = Field (into page), seCond finger = Current (left to right), thuMb = force/Motion, giving an upward force **B1**

(b) Answer: Force acts vertically upwards, found using Fleming's left-hand rule

(c) correct substitution F = 0.18 x 4.5 x 0.25 x sin(30) **M1**

(c) sin(30) = 0.5 used correctly **M1**

(c) F = 0.10 N (cao) **A1**

(c) Answer: F = 0.101 N (awrt 0.10 N)

Question 3

(a) the gravitational force per unit mass acting on a small test mass placed at that point oe **B1**

(a) Answer: The gravitational force per unit mass on a small test mass placed at that point.

(b) the work done per unit positive charge in bringing a small positive test charge from infinity to that point oe **B1**

(b) Answer: The work done per unit positive charge to bring a small positive test charge from infinity to that point.

(c) the magnitude of the induced EMF is directly proportional to the rate of change of flux linkage oe **B1**

(c) Answer: The magnitude of the induced EMF is proportional to the rate of change of flux linkage.

Question 4

(a) the current-carrying wire in the magnetic field experiences a magnetic force (F = BIL) **B1**

(a) the magnetic force on the supported wire changes the load transmitted to the balance, changing its reading (oe) **B1**

(a) Answer: The wire experiences a magnetic force, changing the load transmitted through its support to the balance and hence the reading

(b) correct substitution $F = 0.24 \times 10^{-3} \times 9.81$ **M1**

(b) $F = 2.4 \times 10^{-3}$ N (awrt 2.4×10^{-3} N, cao) **A1**

(b) Answer: $F = 2.35 \times 10^{-3}$ N (awrt 2.4×10^{-3} N)

(c) correct rearrangement B = F/(IL) **M1**

(c) correct substitution $B = 2.4 \times 10^{-3} / (2.0 \times 0.060)$ (ft from (b)) **M1**

(c) $B = 2.0 \times 10^{-2}$ T (awrt 0.020 T, ft) **A1**

(c) Answer: $B = 1.96 \times 10^{-2}$ T (awrt 0.020 T)

(d) since F = BIL, for constant L the gradient of F against I equals BL **B1**

(d) so B = gradient / L **B1**

(d) using a line of best fit through several points averages out random errors in individual readings, giving a more reliable value than a single measurement (oe) **B1**

(d) Answer: gradient = BL, so B = gradient/L; using several points reduces the effect of random error

Question 5

(a) the work done per unit mass in bringing a small test mass from infinity to that point (oe) **B1**

(a) Answer: Work done per unit mass moving a small mass from infinity to the point

(b) correct substitution $V = -(6.67 \times 10^{-11} \times 6.42 \times 10^{23}) / (3.39 \times 10^{6})$ **M1**

(b) $V = -1.3 \times 10^{7}$ J/kg (awrt -1.3×10^{7} J/kg, cao) **A1**

(b) Answer: $V = -1.26 \times 10^{7}$ J/kg (awrt -1.3×10^{7} J/kg)

(c) correct substitution $v = \sqrt{2 \times 6.67 \times 10^{-11} \times 6.42 \times 10^{23} / 3.39 \times 10^{6}}$ **M1**

(c) correct evaluation inside the square root, awrt 2.5×10^{7} **M1**

(c) $v = 5.0 \times 10^{3}$ m/s (awrt 5.0×10^{3} m/s, cao) **A1**

(c) Answer: $v = 5.0 \times 10^{3}$ m/s (5.0 km/s)

(d) at this speed the kinetic energy of the object equals the magnitude of the gravitational potential energy at that point (oe) **B1**

(d) so the object has just enough energy to reach an infinite distance (where gravitational PE = 0) with zero final kinetic energy, i.e. it is not pulled back (oe) **B1**

(d) Answer: KE at launch equals magnitude of GPE, so the object can just reach infinity with zero remaining speed

Question 6

(a) correct substitution $F = 8.99 \times 10^9 \times (3.2 \times 10^{-9} \times 5.0 \times 10^{-9}) / (0.15)^2$ **M1**

(a) $F = 6.4 \times 10^{-6}$ N (awrt 6.4×10^{-6} N, cao) **A1**

(a) attractive, since the charges have opposite signs **B1**

(a) Answer: $F = 6.4 \times 10^{-6}$ N, attractive

(b) correct substitution $E = 8.99 \times 10^9 \times 3.2 \times 10^{-9} / (0.15)^2$ **M1**

(b) $E = 1.3 \times 10^3$ N/C (awrt 1.3×10^3 N/C, cao) **A1**

(b) Answer: $E = 1.28 \times 10^3$ N/C (awrt 1.3×10^3 N/C)

(c) radial field, with field lines becoming more widely spaced further from the charge (field strength decreases with distance) **B1**

(c) field lines point radially outwards, away from the positive charge **B1**

(c) Answer: Radial field pointing outwards from the charge, spacing increasing with distance

(d) force due to A: $F_A = 8.99 \times 10^9 \times 3.2 \times 10^{-9} \times 1.6 \times 10^{-19} / (0.075)^2 = 8.2 \times 10^{-16}$ N (awrt), directed away from A (repulsive, A positive) **M1**

(d) force due to B: $F_B = 8.99 \times 10^9 \times 5.0 \times 10^{-9} \times 1.6 \times 10^{-19} / (0.075)^2 = 1.3 \times 10^{-15}$ N (awrt), directed towards B (attractive, B negative) **M1**

(d) recognises both forces act in the same direction (from A towards B) at the midpoint, so they add **M1**

(d) resultant force = 2.1×10^{-15} N (awrt 2.1×10^{-15} N), directed from A towards B **A1**

(d) Answer: F_resultant = 2.1×10^{-15} N, directed from A towards B

Question 7

(a) quote $g = GM/r^2$ **M1**

(a) substitute $g = (6.67 \times 10^{-11} \times 1.48 \times 10^{23}) / (2.63 \times 10^6)^2$ **M1**

(a) $g = 1.43$ m/s^2 cao **A1**

(a) Answer: 1.43 m/s^2

(b) quote $v(\text{escape}) = \sqrt{2GM/r}$ **M1**

(b) substitute $v(\text{escape}) = \sqrt{(2 \times 6.67 \times 10^{-11} \times 1.48 \times 10^{23}) / (2.63 \times 10^6)}$ **M1**

(b) carry out the calculation inside the square root **M1**

(b) v(escape) = 2740 m/s (2.74 km/s) cao **A1**

(b) Answer: 2740 m/s (2.74 km/s)

Question 8

(a) C12 = C1 + C2 = 100 + 220 = 320 uF cao **B1**

(a) Answer: 320 uF

(b) quote 1/C(total) = 1/C12 + 1/C3 **M1**

(b) substitute 1/C(total) = 1/320 + 1/150 **M1**

(b) C(total) = 102 uF cao **A1**

(b) Answer: 102 uF

(c) $Q = C(\text{total}) \times V = 102 \times 10^{-6} \times 12$ **M1**

(c) $Q = 1.23 \times 10^{-3}$ C cao **A1**

(c) Answer: 1.23×10^{-3} C

(d) quote $E = 1/2\ C\ V^2$ **M1**

(d) substitute $E = 0.5 \times 102 \times 10^{-6} \times 12^2$ **M1**

(d) $E = 7.35 \times 10^{-3}$ J cao **A1**

(d) Answer: 7.35×10^{-3} J

Question 9

(a) F = (change in mass) x g = $0.42 \times 10^{-3} \times 9.81$ **M1**

(a) $F = 4.12 \times 10^{-3}$ N cao **A1**

(a) Answer: 4.12×10^{-3} N

(b) quote F = BIL **M1**

(b) rearrange and substitute $B = 4.12 \times 10^{-3} / (3.5 \times 0.12)$ **M1**

(b) $B = 9.81 \times 10^{-3}$ T cao **A1**

(b) Answer: 9.81×10^{-3} T

(c) the magnetic field exerts a force on the current-carrying wire (the force being measured) **B1**

(c) by Newton's third law, the wire exerts an equal and opposite force on the magnets (and hence on the balance holding them) **B1**

(c) this reaction force changes the apparent weight registered by the balance, which is read as an apparent change in mass oe **B1**

(c) Answer: The field exerts a force on the wire; by Newton's third law the wire exerts an equal and opposite force back on the magnets, which sit on the balance, so the balance registers this reaction force as an apparent change in mass.

Question 10

(a) correct substitution $F = 0.40 \times 1.6 \times 10^{-19} \times 2.5 \times 10^6$ **M1**

(a) $F = 1.6 \times 10^{-13}$ N (cao) **A1**

(a) Answer: $F = 1.6 \times 10^{-13}$ N

(b) the magnetic force is always perpendicular to the proton's velocity, so it does no work on the proton and its speed (kinetic energy) stays constant (oe) **B1**

(b) the force therefore acts only to change the direction of motion, providing a centripetal force, which produces circular motion (oe) **B1**

(b) Answer: Force always perpendicular to velocity does no work (constant speed) and acts as the centripetal force (circular path)

(c) correctly equates $BQv = mv^2/r$ **M1**

(c) correctly rearranges (cancelling one factor of v) to give $r = mv/(BQ)$ (cso, matches given expression) **A1**

(c) Answer: $r = mv/(BQ)$

(d) correct substitution $r = (1.67 \times 10^{-27} \times 2.5 \times 10^6) / (0.40 \times 1.6 \times 10^{-19})$ **M1**

(d) $r = 6.5 \times 10^{-2}$ m (awrt 6.5×10^{-2} m, cao) **A1**

(d) Answer: $r = 6.52 \times 10^{-2}$ m (awrt 6.5 cm)

(e) compares r (6.5 cm) with the field width (5.0 cm) **M1**

(e) correctly identifies that since r is greater than the field width, the proton reaches the far boundary before its path can curve back towards the entry boundary **M1**

(e) correct conclusion: the proton crosses completely through the field region and emerges from the far boundary, since r (6.5 cm) > field width (5.0 cm) **A1**

(e) Answer: The proton crosses completely through the field region, since r = 6.5 cm is greater than the 5.0 cm field width

Question 11

(a) correctly equates $GMm/r^2 = m(4\pi^2 r)/T^2$ **M1**

(a) cancels m from both sides and rearranges to isolate T^2 (e.g. $GM/r^2 = 4\pi^2 r / T^2$) **M1**

(a) $T^2 = 4\pi^2 r^3 / (GM)$ (cso, matches the given expression) **A1**

(a) Answer: $T^2 = 4\pi^2 r^3 / (GM)$

(b) correct substitution $T^2 = 4\pi^2 \times (2.0 \times 10^7)^3 / (4.28 \times 10^{13})$ **M1**

(b) T^2 evaluated as awrt 7.4×10^9 s^2 **M1**

(b) $T = \sqrt{T^2}$ evaluated as awrt 8.6×10^4 s **M1**

(b) T = 23.9 hours (awrt 23.9 hours, cao, after dividing by 3600) **A1**

(b) Answer: $T = 8.59 \times 10^4$ s = 23.9 hours

(c) a synchronous orbit is one where the orbital period equals the rotation period of the planet (oe); remaining above the same point additionally requires a circular, equatorial orbit in the direction of the planet's rotation **B1**

(c) not synchronous, since 23.9 hours does not equal 24.6 hours; a slightly larger orbital radius would be needed to increase T to 24.6 hours (oe, allow ft on T from (b)) **B1**

(c) Answer: A synchronous orbit has the same period as the planet's rotation. This satellite is not synchronous: T = 23.9 h is not equal to Mars's 24.6 h rotation period

Question 12

(a) the work done per unit positive charge in bringing a small test charge from infinity to that point (oe) **B1**

(a) Answer: Work done per unit positive charge moving a small charge from infinity to the point

(b) correct substitution $V = 8.99 \times 10^9 \times 3.2 \times 10^{-9} / 0.075$ **M1**

(b) $V = 3.8 \times 10^2$ V (awrt 380 V, cao) **A1**

(b) Answer: V = 384 V (awrt 380 V)

(c) correct substitution $W = 1.6 \times 10^{-19} \times 383.6$ (ft from (b)) **M1**

(c) $W = 6.1 \times 10^{-17}$ J (awrt 6.1×10^{-17} J, ft from (b)) **A1**

(c) Answer: $W = 6.14 \times 10^{-17}$ J (awrt 6.1×10^{-17} J)

(d) **L1** Basic, isolated statements about gravitational or electric fields with little or no valid comparison. Limited use of correct physics terminology. **1-2**

(d) **L2** Some valid points of comparison and/or contrast are made, with partially correct links between force, field strength and potential for both field types. Explanation lacks full coherence. **3-4**

(d) **L3** A clear, well-linked comparison covering the inverse-square form of both forces, the definitions of field strength and potential for each field, and the key difference arising from the sign of the sources (mass vs charge). The answer is coherent and uses correct physics terminology throughout. **5-6**

(d) Indicative content:

- Both forces obey an inverse square law: F = GMm/r^2 for gravity and F = Qq/(4 pi epsilon0 r^2) for electric charges.
- Gravitational field strength g = GM/r^2 and electric field strength E = kQ/r^2 have the same mathematical form, force per unit mass and force per unit charge respectively.
- Gravitational potential V = -GM/r is always negative (taking zero at infinity) because mass is always positive and the force is always attractive.
- Electric potential V = kQ/r can be positive or negative depending on the sign of the source charge, because charge can be positive or negative.
- Gravitational force is always attractive because there is no negative mass; electric force can be attractive or repulsive depending on the signs of the two charges.
- Both fields can be represented by radial field lines around a point source, and both have field strength related to the gradient of the potential.
- Gravitational fields are generally far weaker than electric fields for comparable point sources, because G is very much smaller in magnitude than k = 1/(4 pi epsilon0).

(d) Answer: Levels-of-response: see indicative content

Question 13

(a) correct substitution E = 500/0.020 **M1**

(a) E = 2.5 x 10^4 V/m (cao) **A1**

(a) Answer: E = 2.5 x 10^4 V/m

(b) correct substitution F = 1.6 x 10^{-19} x 2.5 x 10^4 (ft from (a)) **M1**

(b) F = 4.0 x 10^{-15} N (cao, ft from (a)) **A1**

(b) Answer: F = 4.0 x 10^{-15} N

(c) correct substitution a = 4.0 x 10^{-15} / 9.11 x 10^{-31} (ft from (b)) **M1**

(c) a = 4.4 x 10^{15} m/s^2 (awrt 4.4 x 10^{15} m/s^2, ft from (b)) **A1**

(c) Answer: a = 4.39 x 10^{15} m/s^2 (awrt 4.4 x 10^{15} m/s^2)

(d) correct substitution t = 0.040 / 2.0 x 10^7 **M1**

(d) t = 2.0 x 10^{-9} s (cao) **A1**

(d) Answer: t = 2.0 x 10^{-9} s

(e) correct substitution y = 0.5 x 4.4 x 10^{15} x (2.0 x 10^{-9})^2 (ft from (c) and (d)) **M1**

(e) y = 8.8 x 10^{-3} m (awrt 8.8 mm, ft) **A1**

(e) compares y to the maximum allowed deflection of 0.010 m (half the 0.020 m gap) and correctly concludes that the electron leaves the plates without striking one, since 8.8 mm < 10 mm **B1**

(e) Answer: y = 8.8 x 10^{-3} m; electron exits without hitting a plate (8.8 mm < 10 mm maximum)

Question 14

(a) equate gravitational force to centripetal force: GMm/r^2 = mv^2/r, giving v = $\sqrt{GM/r}$ **M1**

(a) substitute v = $\sqrt{(6.67 \times 10^{-11} \times 1.48 \times 10^{23}) / 3.20 \times 10^6}$ **M1**

(a) v = 1760 m/s cao **A1**

(a) Answer: 1760 m/s

(b) use T = 2 π r / v **M1**

(b) calculate T in seconds: 2 π x 3.20 x 10^6 / 1756 **M1**

(b) T = 3.18 hours cao **A1**

(b) Answer: 3.18 hours

(c) substitute E1 = -(6.67 x 10^{-11} x 1.48 x 10^{23} x 650) / (2 x 3.20 x 10^6) **M1**

(c) E1 = -1.00 x 10^9 J cao **A1**

(c) E2 = -(GMm)/(2 x 4.50 x 10^6) = -7.13 x 10^8 J cao **A1**

(c) Answer: E1 = -1.00 x 10^9 J, E2 = -7.13 x 10^8 J

(d) energy required = E2 - E1 **M1**

(d) energy required = 2.90 x 10^8 J cao **A1**

(d) Answer: 2.90 x 10^8 J

Question 15

(a) quote F = k Q1 Q2 / r^2 **M1**

(a) substitute F = (8.99 x 10^9 x 5.0 x 10^{-6} x 2.0 x 10^{-6}) / 0.30^2 **M1**

(a) F = 1.0 N, attractive (since the charges have opposite signs) cao **A1**

(a) Answer: 1.0 N, attractive

(b) calculate the field from Q1 alone at the midpoint (r = 0.15m): E1 = kQ1/r^2 = 2.0 x 10^6 N/C, directed away from Q1 (towards Q2) **M1**

(b) calculate the field from Q2 alone at the midpoint: E2 = kQ2/r^2 = 7.99 x 10^5 N/C, directed towards Q2 (since Q2 is negative) **M1**

(b) both fields point in the same direction (from the positive charge towards the negative charge), because the field from a positive charge points away from it while the field from a negative charge points towards it, so at the midpoint they reinforce rather than cancel **B1**

(b) total E = 2.80 x 10^6 N/C cao **A1**

(b) Answer: 2.80 x 10^6 N/C, directed from Q1 towards Q2

(c) quote V = k(Q1 + Q2)/r, using the signed values of Q1 and Q2 (potential is scalar) **M1**

(c) substitute V = 8.99 x 10^9 x (5.0 x 10^{-6} - 2.0 x 10^{-6}) / 0.15 **M1**

(c) V = 1.80 x 10^5 V cao **A1**

(c) Answer: 1.80 x 10^5 V

Question 16

(a) an ion travels undeflected only when the electric force and the magnetic force on it are equal in magnitude and opposite in direction, so the net force is zero **B1**

(a) since the magnetic force depends on speed (F = Bqv) but the electric force does not (F = Eq), this balance only occurs at one specific speed oe **B1**

(a) Answer: The ion travels straight through only when the electric force (Eq) and magnetic force (Bqv) balance exactly; since the magnetic force depends on speed but the electric force does not, this balance holds only at one particular speed.

(b) set Eq = Bqv, so v = E/B = 2.4 x 10^4 / 0.060 **M1**

(b) v = 4.0 x 10^5 m/s cao **A1**

(b) Answer: 4.0 x 10^5 m/s

(c) quote r = mv/(Bq), rearranged to q/m = v/(Br) **M1**

(c) substitute q/m = 4.0 x 10^5 / (0.060 x 0.085) **M1**

(c) carry out the calculation **M1**

(c) q/m = 7.8 x 10^7 C/kg cao **A1**

(c) Answer: 7.8 x 10^7 C/kg

Question 17

Level 3 Correctly identifies the mathematical similarity (both forces follow an inverse-square law with force proportional to the product of the two masses/charges divided by r^2), correctly identifies at least two genuine differences (gravity is always attractive whereas the electric force can be attractive or repulsive; gravitational field strength/force is vastly weaker than the electric field strength/force for typical particle-scale masses and charges; there is no 'neutral' or shielded gravitational equivalent of an earthed conductor), and gives a well-reasoned evaluation of why gravity dominates at large scales, correctly explaining that ordinary matter is electrically neutral overall (equal positive and negative charge cancel almost exactly), so the immense electric forces between individual charged particles cancel out over large bodies, while mass has no equivalent cancellation and gravitational contributions always add. **5-6**

Level 2 Identifies the inverse-square similarity and at least one valid difference between the two fields, with a partially developed explanation of why gravity dominates at large scales (e.g. mentioning that matter is electrically neutral, without fully explaining the cancellation argument). **3-4**

Level 1 States that both fields obey an inverse-square law or names one difference, with little or no attempt to explain why gravity dominates at astronomical scales. **1-2**

Indicative content:

- Similarity: both gravitational force (F = GMm/r^2) and electric force (F = kQ1Q2/r^2) follow an inverse-square law with distance, and both have a field strength defined as force per unit mass/charge that also falls off as 1/r^2.
- Difference: gravitational force is always attractive, since mass is always positive; electric force can be attractive or repulsive, since charge can be positive or negative.
- Difference: the gravitational constant G is extremely small compared with the electrostatic constant k, so at the scale of individual particles the electric force is vastly stronger (by many orders of magnitude) than the gravitational force between the same particles.
- Difference: electric fields can be shielded/cancelled locally (e.g. by an earthed conductor or by equal and opposite charges); there is no known way to shield a gravitational field, and no negative mass exists to cancel a gravitational field.
- Evaluation of large-scale dominance: bulk matter (planets, stars) contains almost exactly equal numbers of positive and negative charges, so the electric forces from individual particles very nearly cancel when summed over a large, overall neutral body, leaving a net electric force close to zero between large objects.
- Mass, in contrast, has no equivalent cancellation: every particle's mass contributes positively to the total gravitational attraction, so gravitational effects always add up constructively as the amount of matter increases, allowing gravity (despite its intrinsic weakness) to dominate the net force between astronomically large, electrically neutral bodies.