3.7 Fields and their Consequences: 30-minute Pack

AQA 7408 · Calculator allowed · about 30 minutes

Total Marks

Name: _____ Date: ____ / ____ / _____

Answer ALL questions. Show all your working.

1 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 1 is 3 marks)

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2 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 2 is 10 marks)

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3 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 3 is 7 marks)

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4 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 4 is 6 marks)

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Mark scheme · 3.7 Fields and their Consequences: 30-minute Pack

Question 1

(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 2

(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 3

(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 4

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.

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