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A-Level · Physics

AP7D Fields and their Consequences: Depth and Exam Drill

AQA 7408 · Calculator allowed · about 125 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 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 2 is 7 marks)

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3 A communications satellite of mass 650 kg orbits Callira (mass 1.48×10^{23} kg, $G = 6.67 \times 10^{-11}$ N m^2/kg^2) in a circular orbit of radius r1 = 3.20×10^{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 = 3.20×10^{6} m and at a higher orbit r2 = 4.50×10^{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 3 is 11 marks)

4 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 4 is 10 marks)

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5 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 5 is 9 marks)

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6 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 6 is 8 marks)

7 A flat search coil of 250 turns and cross-sectional area 3.5×10^{-3} m^2 is placed with its plane perpendicular to a uniform magnetic field of flux density 0.045 T. The coil is then pulled completely out of the field in a time of 0.080 s.

(a) Calculate the magnetic flux through the coil while it is in the field. **(2)**

(b) Calculate the flux linkage of the coil while it is in the field. **(1)**

(c) Calculate the average EMF induced in the coil while it is being removed from the field. **(3)**

(d) State Lenz's law and use it to explain the direction of the induced current in the coil as it is removed from the field. **(2)**

(Total for Question 7 is 8 marks)

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8 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 8 is 8 marks)

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9 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 9 is 6 marks)

Mark scheme · AP7D Fields and their Consequences: Depth and Exam Drill

Question 1

- (a) **B1** the gravitational force per unit mass acting on a small test mass placed at that point oe
- **(a) Answer: The gravitational force per unit mass on a small test mass placed at that point.**
- (b) **B1** the work done per unit positive charge in bringing a small positive test charge from infinity to that point oe
- **(b) Answer: The work done per unit positive charge to bring a small positive test charge from infinity to that point.**
- (c) **B1** the magnitude of the induced EMF is directly proportional to the rate of change of flux linkage oe
- **(c) Answer: The magnitude of the induced EMF is proportional to the rate of change of flux linkage.**

Question 2

- (a) **M1** quote $g = GM/r^2$
- (a) **M1** substitute $g = (6.67 \times 10^{-11} \times 1.48 \times 10^{23}) / (2.63 \times 10^6)^2$
- (a) **A1** $g = 1.43$ m/s^2 cao
- **(a) Answer: 1.43 m/s^2**
- (b) **M1** quote $v(\text{escape}) = \sqrt{2GM/r}$
- (b) **M1** substitute $v(\text{escape}) = \sqrt{(2 \times 6.67 \times 10^{-11} \times 1.48 \times 10^{23}) / (2.63 \times 10^6)}$
- (b) **M1** carry out the calculation inside the square root
- (b) **A1** v(escape) = 2740 m/s (2.74 km/s) cao
- **(b) Answer: 2740 m/s (2.74 km/s)**

Question 3

- (a) **M1** equate gravitational force to centripetal force: $GMm/r^2 = mv^2/r$, giving $v = \sqrt{GM/r}$
- (a) **M1** substitute $v = \sqrt{(6.67 \times 10^{-11} \times 1.48 \times 10^{23}) / 3.20 \times 10^6}$
- (a) **A1** v = 1760 m/s cao
- **(a) Answer: 1760 m/s**
- (b) **M1** use $T = 2 \pi r / v$
- (b) **M1** calculate T in seconds: $2 \pi \times 3.20 \times 10^6 / 1756$
- (b) **A1** T = 3.18 hours cao
- **(b) Answer: 3.18 hours**
- (c) **M1** substitute $E1 = -(6.67 \times 10^{-11} \times 1.48 \times 10^{23} \times 650) / (2 \times 3.20 \times 10^6)$
- (c) **A1** $E1 = -1.00 \times 10^9$ J cao
- (c) **A1** $E2 = -(GMm)/(2 \times 4.50 \times 10^6) = -7.13 \times 10^8$ J cao
- **(c) Answer: $E1 = -1.00 \times 10^9$ J, $E2 = -7.13 \times 10^8$ J**
- (d) **M1** energy required = E2 - E1
- (d) **A1** energy required = 2.90×10^8 J cao
- **(d) Answer: 2.90×10^8 J**

Question 4

- (a) **M1** quote $F = k\ Q1\ Q2 / r^2$
- (a) **M1** substitute $F = (8.99 \times 10^9 \times 5.0 \times 10^{-6} \times 2.0 \times 10^{-6}) / 0.30^2$
- (a) **A1** F = 1.0 N, attractive (since the charges have opposite signs) cao
- **(a) Answer: 1.0 N, attractive**
- (b) **M1** calculate the field from Q1 alone at the midpoint (r = 0.15m): $E1 = kQ1/r^2 = 2.0 \times 10^6$ N/C, directed away from Q1 (towards Q2)
- (b) **M1** calculate the field from Q2 alone at the midpoint: $E2 = kQ2/r^2 = 7.99 \times 10^5$ N/C, directed towards Q2 (since Q2 is negative)
- (b) **B1** 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
- (b) **A1** total $E = 2.80 \times 10^6$ N/C cao
- **(b) Answer: 2.80×10^6 N/C, directed from Q1 towards Q2**
- (c) **M1** quote V = k(Q1 + Q2)/r, using the signed values of Q1 and Q2 (potential is scalar)
- (c) **M1** substitute $V = 8.99 \times 10^9 \times (5.0 \times 10^{-6} - 2.0 \times 10^{-6}) / 0.15$
- (c) **A1** $V = 1.80 \times 10^5$ V cao
- **(c) Answer: 1.80×10^5 V**

Question 5

- (a) **B1** C12 = C1 + C2 = 100 + 220 = 320 uF cao
- **(a) Answer: 320 uF**
- (b) **M1** quote 1/C(total) = 1/C12 + 1/C3
- (b) **M1** substitute 1/C(total) = 1/320 + 1/150
- (b) **A1** C(total) = 102 uF cao
- **(b) Answer: 102 uF**
- (c) **M1** $Q = C(\text{total}) \times V = 102 \times 10^{-6} \times 12$
- (c) **A1** $Q = 1.23 \times 10^{-3}$ C cao
- **(c) Answer: 1.23×10^{-3} C**
- (d) **M1** quote $E = 1/2\ C\ V^2$
- (d) **M1** substitute $E = 0.5 \times 102 \times 10^{-6} \times 12^2$
- (d) **A1** $E = 7.35 \times 10^{-3}$ J cao
- **(d) Answer: 7.35×10^{-3} J**

Question 6

- (a) **M1** F = (change in mass) x g = $0.42 \times 10^{-3} \times 9.81$
- (a) **A1** $F = 4.12 \times 10^{-3}$ N cao
- **(a) Answer: 4.12×10^{-3} N**
- (b) **M1** quote F = BIL
- (b) **M1** rearrange and substitute $B = 4.12 \times 10^{-3} / (3.5 \times 0.12)$
- (b) **A1** $B = 9.81 \times 10^{-3}$ T cao
- **(b) Answer: 9.81×10^{-3} T**
- (c) **B1** the magnetic field exerts a force on the current-carrying wire (the force being measured)
- (c) **B1** by Newton's third law, the wire exerts an equal and opposite force on the magnets (and hence on the balance holding them)
- (c) **B1** this reaction force changes the apparent weight registered by the balance, which is read as an apparent change in mass oe
- **(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 7

- (a) **M1** flux = B A = 0.045 x 3.5 x 10^{-3}
- (a) **A1** flux = 1.58 x 10^{-4} Wb cao
- **(a) Answer: 1.58 x 10^{-4} Wb**
- (b) **B1** flux linkage = N x flux = 250 x 1.575 x 10^{-4} = 0.0394 Wb turns cao
- **(b) Answer: 0.0394 Wb turns**
- (c) **M1** quote EMF = change in flux linkage / time taken
- (c) **M1** substitute EMF = 0.0394 / 0.080
- (c) **A1** EMF = 0.49 V cao
- **(c) Answer: 0.49 V**
- (d) **B1** Lenz's law: the direction of an induced current is such that it opposes the change (in flux) that produced it
- (d) **B1** as the coil is removed, the flux through it is decreasing, so the induced current flows in the direction that creates a magnetic field trying to maintain the original flux (oppose the decrease) through the coil oe
- **(d) Answer: Lenz's law states the induced current opposes the change that produced it; as the coil leaves the field the flux decreases, so the induced current flows in the direction that creates its own magnetic field to try to maintain (oppose the decrease in) the original flux through the coil.**

Question 8

- (a) **B1** 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
- (a) **B1** 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
- **(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) **M1** set Eq = Bqv, so v = E/B = 2.4 x 10^4 / 0.060
- (b) **A1** v = 4.0 x 10^5 m/s cao
- **(b) Answer: 4.0 x 10^5 m/s**
- (c) **M1** quote r = mv/(Bq), rearranged to q/m = v/(Br)
- (c) **M1** substitute q/m = 4.0 x 10^5 / (0.060 x 0.085)
- (c) **M1** carry out the calculation
- (c) **A1** q/m = 7.8 x 10^7 C/kg cao
- **(c) Answer: 7.8 x 10^7 C/kg**

Question 9

- **Level 3** (5-6): 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.
- **Level 2** (3-4): 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).
- **Level 1** (1-2): 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.
- **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.