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|  | |  |  | | --- | --- | | **Physics A**  **Electric fields practise questions** |  | | Please note that you may see slight differences between this paper and the original.  Candidates answer on the Question paper.  **OCR supplied materials:** Additional resources may be supplied with this paper.  **Other materials required:** •   Pencil •   Ruler (cm/mm) | **Duration:** 120 mins | |  | | |  |

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## INSTRUCTIONS TO CANDIDATES

•   Write your name, centre number and candidate number in the boxes above. Please write clearly and in capital letters.  
•   Use black ink. HB pencil may be used for graphs and diagrams only.  
•   Answer **all** the questions, unless your teacher tells you otherwise.  
•   Read each question carefully. Make sure you know what you have to do before starting your answer.  
•   Where space is provided below the question, please write your answer there.  
•   You may use additional paper, or a specific Answer sheet if one is provided, but you must clearly show your candidate number, centre number  
    and question number(s).

## INFORMATION FOR CANDIDATES

•   The quality of written communication is assessed in questions marked with either a pencil or an asterisk. In History and Geography   
    a *Quality of extended response* question is marked with an asterisk, while a pencil is used for questions in which *Spelling, punctuation and  
    grammar and the use of specialist terminology* is assessed.  
•   The number of marks is given in brackets **[ ]** at the end of each question or part question.  
•   The total number of marks for this paper is **100**.  
•   The total number of marks may take into account some 'either/or' question choices.

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|  | |  |  | | --- | --- | |  |  | | **1(a).** | A beam of α-particles is incident on a thin gold foil. Most α-particles pass straight through the foil. A few are deflected by gold nuclei.  The diagram shows the path of one α-particle which passes close to a gold nucleus **N** in the foil. The α-particle is deflected through an angle of 60° as it travels from **A** to **B**.  **P** marks its position of closest approach to the gold nucleus.     |  | | --- | |  |   Another α-particle in the beam is deflected by the same gold nucleus **N** through an angle of 30°.     |  |  | | --- | --- | | Sketch its path onto the diagram above. | **[2]** | | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | The distance between **P** and **N** is 6.8 × 10–14 m.  Calculate the magnitude of the electrostatic force F between the α-particle and the gold nucleus when the α-particle is at **P**.     |  | | --- | | F = ..................................................... N **[4]** | | |

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|  | |  |  | | --- | --- | |  |  | | **2(a).** | A ball coated with conducting paint has weight 0.030 N and radius 1.0 cm. The ball is suspended from an insulating thread. The distance between the pivot and the centre of the ball is 120 cm.  The ball is placed between two vertical metal plates. The separation between the plates is 8.0 cm. The plates are connected to a 4.0 kV power supply.  The ball receives a positive charge of 9.0 nC when it is made to touch the positive plate. It then repels from the positive plate and hangs in equilibrium at a displacement x from the vertical, as shown below. The diagram is **not** drawn to scale.     |  | | --- | |  |  1. Show that the electric force acting on the charged ball is 4.5 × 10–4 N.   **[2]**   1. Draw, on the diagram above, arrows which represent the **three** forces acting on the ball. Label each arrow with the name of the force it represents.   **[2]**   1. By taking moments about the pivot, or otherwise, show that x = 1.8 cm.   **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | The ball is still positively charged.  The plates are now moved slowly towards each other whilst still connected to the 4.0 kV power supply. The plates are stopped when the separation is 5.0 cm.  Explain the effect that this has on the deflection of the ball and explain why the ball eventually starts to oscillate between the plates.                    **[4]** | |

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|  | |  |  | | --- | --- | |  |  | | **(c).** | When the ball oscillates between the plates, the current in the external circuit is 3.2 × 10–8 A.  A charge of 9.0 nC moves across the gap between the plates each time the ball makes one complete oscillation.  Calculate the frequency f of the oscillations of the ball.     |  | | --- | | f = ..................................................... Hz **[2]** | | |

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|  | |  |  | | --- | --- | |  |  | | **3(a).** | The diagram below shows the arrangement of the 3 protons inside the nucleus of lithium-6 .     |  | | --- | |  |   The separation between each proton is about 1.0 × 10−15 m.   1. Calculate the magnitude of the repulsive electric force *F* experienced by the proton **P**.      |  | | --- | | *F* = ...................................................... N **[4]** |  1. On the diagram above, draw an arrow to show the direction of the electric force *F* experienced by **P**.      |  | | --- | | **[1]** |  1. Explain how protons stay within the nucleus of lithium-6.         **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | A spherical metal dome shown below is charged to a potential of −12 kV.     |  | | --- | |  |   The dome is supported by a cylindrical plastic rod. The radius of the dome is 0.19 m.   1. Show that the magnitude of the total charge *Q* on the dome is 2.5 × 10−7 C.      |  | | --- | | **[2]** |  1. The dome discharges slowly through the plastic rod. It takes 78 hours for the dome to completely discharge.      |  |  |  | | --- | --- | --- | |  | **1** | Show that the mean current *I* in the plastic rod is about 9 × 10−13 A. | |  |  | **[2]** | |  | **2** | The average potential difference across the plastic rod during discharge is 6000 V. The rod has cross-sectional area 1.1 × 10−4 m2 and length 0.38 m.  Calculate the resistivity *ρ* of the plastic. | |  |  | *ρ* = .................................................. Ωm **[3]** | | |

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|  | |  |  | | --- | --- | |  |  | | **4.** | The electric potential at a distance *R* from the centre of a charge +*Q* is + 40 V.     |  | | --- | |  |   What is the potential at the point **P** for the arrangement of the charges +*Q* and −1.5*Q* as shown below?     |  | | --- | |  |      |  |  | | --- | --- | | A | − 20 V | | B | − 60 V | | C | + 80 V | | D | + 100 V |      |  |  |  | | --- | --- | --- | | Your answer |  | **[1]** | | |

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|  | |  |  | | --- | --- | |  |  | | **5(a).** | Fig. 22.1 shows two horizontal metal plates in a vacuum.     |  | | --- | | **Fig. 22.1** |   The plates are connected to a power supply. The potential difference V between the plates is constant. The magnitude of the charge on each plate is Q. The separation between the plates is d.  Fig. 22.2 shows the variation with d of the charge Q on the positive plate.     |  | | --- | | **Fig. 22.2** |  1. Use Fig. 22.2 to propose and carry out a test to show that Q is inversely proportional to d.      |  |  | | --- | --- | |  | Test proposed: | |  | Working:     |  | | --- | | **[2]** | |  1. Use capacitor equations to show that Q is inversely proportional to d.      |  | | --- | | **[2]** | | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | Fig. 22.3 shows a negatively charged oil drop between two oppositely charged horizontal plates in a vacuum.     |  | | --- | | **Fig. 22.3** |   The plates are fixed and connected to a variable power supply. The weight of the oil drop is 1.8 × 10–14 N.   1. The power supply is adjusted so that the potential difference between the plates is 200 V when the oil drop becomes **stationary**.  State the magnitude of the vertical electric force FE acting on the charged oil drop.      |  | | --- | | FE = ......................................................N **[1]** |  1. The potential difference between the plates is now increased to 600 V. The oil drop accelerates upwards.  Calculate the acceleration a of the oil drop.      |  | | --- | | a = ......................................................ms–2 **[3]** | | |

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|  | |  |  | | --- | --- | |  |  | | **(c).** | \* Fig. 22.4 shows an arrangement used by a student to investigate the forces experienced by a small length of charged gold foil placed in a uniform electric field.     |  | | --- | | **Fig. 22.4** |   The two vertical metal plates are connected to a high-voltage supply.  The foil is given a positive charge by briefly touching it to the positive plate. The angle θ made with the vertical by the foil in the electric field is given by the expression   where q is the charge on the foil, E is the electric field strength between the plates and W is the weight of the foil.  The angle θ can be determined by taking photographs with the camera of a mobile phone.  Describe how the student can safely conduct an experiment to investigate the relationship between θ and E. Identify any variables that must be controlled.                                                  **[6]** | |

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|  | |  |  | | --- | --- | |  |  | | **6.** | The electric field strength at a distance of 2.0 × 10–8 m from a nucleus is 3.3 × 108 N C–1.  What is the charge on the nucleus?     |  |  | | --- | --- | | **A** | 1.6 × 10–19 C | | **B** | 1.5 × 10–17 C | | **C** | 7.3 × 10–10 C | | **D** | 3.8 × 10–9 C |      |  |  |  | | --- | --- | --- | | Your answer |  | **[1]** | | |

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|  | |  |  | | --- | --- | |  |  | | **7.** | Which law indicates that charge is conserved?     |  |  | | --- | --- | | **A** | Lenz’s law | | **B** | Coulomb’s law | | **C** | Kirchhoff’s first law | | **D** | Faraday’s law of electromagnetic induction |      |  |  |  | | --- | --- | --- | | Your answer |  | **[1]** | | |

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|  | |  |  | | --- | --- | |  |  | | **8.** | A student wishes to determine the permittivity ε of paper using a capacitor made in the laboratory.  The capacitor consists of two large parallel aluminium plates separated by a very thin sheet of paper.  The capacitor is initially charged to a potential difference V0 using a battery. The capacitor is then discharged through a fixed resistor of resistance 1.0 MΩ.  The potential difference V across the capacitor after a time t is recorded by a data-logger. The student uses the data to draw the lnV against t graph shown in Fig. 22.  **Fig. 22**  Use Fig. 22 to determine the capacitance C of the capacitor. Describe how the student can then use this value of C to determine a value for ε. In your description, mention any additional measurements required on the capacitor.                                                  **[6]** | |

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|  | |  |  | | --- | --- | |  |  | | **9.** | A proton with kinetic energy 0.52 MeV is travelling directly towards a stationary nucleus of cobalt-59 in a head-on collision.   1. Explain what happens to the electric potential energy of the proton-nucleus system.       **[1]**   1. Calculate the **minimum** distance R between the proton and cobalt nucleus.      |  |  |  | | --- | --- | --- | | R = |  | m **[3]** | | |

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|  | |  |  | | --- | --- | |  |  | | **10.** | An electron is released at a distance r from the surface of a positively charged sphere. It is attracted towards the centre of the sphere and moves until it touches the surface.    Which of the following statements is/are correct?     |  |  |  | | --- | --- | --- | |  | 1 | The area under the F against r graph is equal to work done on the electron. | |  | 2 | The electric field strength E at distance r is equal to . | |  | 3 | The work done on the electron is equal to F × r. |      |  |  | | --- | --- | | **A** | Only 1 | | **B** | Only 1 and 2 | | **C** | Only 1 and 3 | | **D** | 1, 2 and 3 |      |  |  |  | | --- | --- | --- | | Your answer |  | **[1]** | | |

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|  | |  |  | | --- | --- | |  |  | | **11(a).** | A capacitor of capacitance 7.2 pF consists of two parallel metal plates separated by an insulator of thickness 1.2 mm. The area of overlap between the plates is 4.0 × 10−4 m2. Calculate the permittivity of the insulator between the capacitor plates.     |  |  | | --- | --- | |  | permittivity = ......................................... F m−1 **[2]** | | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | Fig. 21 shows a circuit.  **Fig. 21**  The capacitance of each capacitor is 1000 μF. The resistance of the resistor is 10 kΩ. The cell has e.m.f. 1.5 V and negligible internal resistance.   1. Calculate the total capacitance C in the circuit.      |  |  | | --- | --- | |  | C = ......................................... μF **[2]** |  1. The switch **S** is closed at time t = 0. There is zero potential difference across the capacitors at t = 0. Calculate the potential difference V across the resistor at time t = 12 s.      |  |  | | --- | --- | |  | V = ......................................... V **[2]** | | |

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|  | |  |  | | --- | --- | |  |  | | **12(a).** | The diagram below shows two parallel plates, **E** and **C**, in an evacuated glass tube.    Plate **E** is made from potassium, which is sensitive to light. Plate **C** is not sensitive to light.  The separation between the plates is 6.0 mm and the potential difference between the plates is 0.30 V.  Light of frequency 6.3 × 1014 Hz is incident on plate **E**. The photoelectrons emitted from this plate have **maximum** kinetic energy 0.30 eV (4.8 × 10−20 J). The photoelectrons are repelled by the negative plate **C**. The ammeter reading is zero because these photoelectrons reach plate **C** with zero kinetic energy.  This question is about a photoelectron emitted perpendicular to plate **E** and with an initial kinetic energy of 4.8 × 10−20 J.   1. Show that the magnitude of deceleration of this photoelectron is 8.8 × 1012 ms-2.   **[3]**   1. Show that the initial speed of the photoelectron is about 3 × 105 ms-1.   **[2]**   1. Calculate the time t taken by the photoelectron to travel from plate **E** to plate **C**.   t = ...................................................... s **[2]**   1. Using the axes shown below, sketch a graph of kinetic energy E k against distance x from plate **E**.   **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | Explain, in terms of photons, what happens to the ammeter reading when light of frequency greater than 6.3 × 1014 Hz is now incident on plate **E**.      **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **13.** | Fig. 3.1 shows a simple representation of a hydrogen iodide molecule. It consists of two ions , held together by electric forces.    **Fig. 3.1**   1. Draw on Fig. 3.1 a minimum of five lines to show the electric field pattern between the ions.   **[2]**   1. The charge on each ion has a magnitude e of 1.6 × 10−19 C. The ions are to be treated as point charges 5.0 × 10−10 m apart. Calculate the magnitude of the resultant electric field strength E at the **mid-point** between the ions.   E = ........................................................... N C−1  **[4]** | |

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|  | |  |  | | --- | --- | |  |  | | **14(a).** | Fig. 21.1 shows two oppositely charged ions to the left of a point **X**.    The separation between the centres of the ions is 3.0 × 10−10 m. Each ion has charge of magnitude 1.6 × 10−19 C.   1. Explain why the direction of the **resultant** electric field strength at point **X** is to the left.         **[2]**   1. Calculate the minimum energy in eV required to completely separate the ions.   energy = ........................................................... eV **[3]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | A **proton** travels from point **P** to point **Q** in a uniform electric field as shown in Fig. 21.2.    The velocity of the proton at **P** is 7.2 × 106 m s−1 and the velocity at **Q** is 2.4 × 106 m s−1. The distance between **P** and **Q** is 1.2 cm.  Calculate   1. the magnitude of the deceleration of the proton   deceleration = ........................................................... m s−2 **[2]**   1. the electric field strength E.   E = ........................................................... N C−1 **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **15(a).** | Fig. 20.1 shows a positively charged metal sphere and a negatively charged metal plate.  **Fig. 20.1**  On Fig. 20.1, draw a minimum of **five** electric field lines to show the field pattern between the sphere and the plate.     |  |  | | --- | --- | |  | **[2]** | | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | Define electric potential at a point in space.    **[1]** | |

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|  | |  |  | | --- | --- | |  |  | | **(c).** | A metal sphere is given a positive charge by connecting its surface briefly to the positive terminal of a power supply. The electric potential at the surface of the sphere is + 5.0 kV. The sphere has radius 1.5 cm.   1. Show that the charge Q on the surface of the sphere is 8.3 × 10−9 C.      |  |  | | --- | --- | |  | **[2]** |      1. Fig. 20.2 shows the charged sphere from **(i)** suspended from a nylon thread and placed between two oppositely charged vertical plates.   **Fig. 20.2 (not to scale)**  The weight of the sphere is 1.7 × 10−2 N. The string makes an angle of 4.0° with the vertical.   * 1. Show that the electric force on the charged sphere is 1.2 × 10−3 N.      |  |  | | --- | --- | |  | **[1]** |  * 1. Calculate the uniform electric field strength E between the parallel plates.      |  |  | | --- | --- | |  | E = ......................................... N C−1 **[2]** | | |

**END OF QUESTION PAPER**

# Mark scheme

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| **Question** | | | **Answer/Indicative content** | **Marks** | **Guidance** |
| 1 | a |  |  | B1  B1 | Path is initially horizontal **and** further up the page than original   Path ends at 300 to horizontal (angle must be labelled) in the direction shown   **Examiner’s Comments**  The common errors here were:   * not realising that, for the particle to be deflected through a smaller angle, it needed to be travelling further away from N * not labelling the final angle of 30° * not adding arrows to show the direction of travel * drawing a path that continued bending beyond the stated 30° (usually ending up parallel to the original path). |
|  | b |  | Q = 79e and q = 2e  F = (1/4πε0)Qq/r2  = 79 × 2 × (1.6 × 10−19)2/ [4π × 8.85 × 10−12 ×(6.8 × 10−14)2]  = 7.9 (N) | C1  C1   C1   A1 | **Apply ECF** for wrong charge(s), e.g. Q and / or q = e, or Q = 79 and / or q = 2, etc   **Examiner’s Comments**  The most common error here was to use incorrect values for the charges on the two ions. Even so, most candidates were able to gain most of the marks with ECF. |
|  |  |  | **Total** | **6** |  |
| 2 | a | i | F = QE = QV / d   **or**   E = 5(.0) x 104 (Vm−1)  F = 9.0 x 10−9 x 4000/ 8.0 x 10−2 (= 4.5 x 10−4 N) | C1  A1 | F = 5.0 x 104 x 9.0 x 10−9   **Examiner’s Comments**  Many lower ability candidates did not appreciate the uniform nature of the electric field between the plates and attempted to use Coulomb’s Law. |
|  |  | ii | weight; arrow vertically downwards  tension; arrow upwards in direction of string  electric (force); arrow horizontally to the right (not along dotted line) | B1 x 2 | All correct, 2 marks; 2 correct, 1 mark 1 mark maximum if more than 3 arrows are drawn **Ignore** position of arrows  **Allow** W **or** 0.030(N) (**not** gravity or g) **Allow** T **Allow** F **or** E or 4.5 x 10−4(N) or electrostatic **Ignore** repulsion or attraction **Not** electric field / electric field strength / electromagnetic   **Examiner’s Comments**  Most candidates scored a mark for showing the weight and tension forces accurately. Only a small proportion labelled the electric force arrow correctly and drew it as clearly perpendicular to the plates.     |  |  | | --- | --- | |  | **AfL** |   Do not use the word ‘gravity’ in place of ‘weight’ |
|  |  | iii | W x = F l    0.03 x  = 4.5 x 10−4 x 120 **or** = 4.5 x 10−4 x 1.2  x = 1.8 cm **or** x = 0.018 m | M1  M1  A0 | **Allow** any valid alternative approach e.g. M1 deflection angle θ = 1° M1 x = 120sinθ  1 mark for each side of the equation   **Examiner’s Comments**  Although most candidates knew the principle of moments, many were unable to apply it correctly in this situation. More practice at this sort of question is recommended. |
|  | b |  | Electric force/field (strength) increases  Ball deflected further from vertical / moves to the right / touches negative plate  Ball acquires the charge of the (negative) plate when it touches  (Oscillates because) constantly repelled from (oppositely) charged plate | B1  B1   B1   B1 | Must be clear which force is increasing          Must have the idea of a repeating cycle   **Examiner’s Comments**  The purpose of this question was to challenge the candidates to use their knowledge of electric fields in a novel practical situation. The word ‘oscillate’ confused many candidates, who tried to explain why the ball would perform simple harmonic motion. |
|  | c |  | I = Qf   **or**   Q = It  f = 3.2 x 10−8/9.0 x 10−9 = 3.6 (Hz) | C1  A1 |  |
|  |  |  | **Total** | **12** |  |
| 3 | a | i | (*F =*) 230 (N)  *F*2 = 2302 + 2302 – 2 × 230 × 230 × cos120° **or** *F* = 2 × 230cos30° *F* = 400 (N) | C1 C1 C1 | **Special case:**  loses this C1 mark, then ECF for the rest of the marks **Not** the first two C1 marks for incorrect charge, then allow ECF for the final C1A1 marks  **Note** force to 4 SF is 230.2 N  **Allow** sine rule / scale drawing **Allow** this mark for 230cos30° **or** 200 (N)   **Allow** ± 10 (N) if scale drawing used |
|  |  | ii | *F* / arrow vertical up the page | B1 | **Allow** correct arrow direction anywhere on the figure |
|  |  | iii | Strong (nuclear) force (acts on the protons)  The strong (nuclear) force is attractive | B1 B1 | **Ignore** gravitational force  **Allow** pulls / holds (the protons) / binds (the protons) for ‘attractive’ |
|  | b | i | *Q* = 2.5(4) × 10−7 (C) | C1 C1 A0 | |  |  | | --- | --- | | **Allow** *E =* (*V / d* =) 6.316 × 104 | **C1** | | and |  | |  | **C1** | |
|  |  | ii | |  |  | | --- | --- | | **1** | *t* = 78 × 3600  *I* = 8.9 × 10−13 (A) | | **2** | (*R* =) **or** 6.7 × 1015 (Ω) **or** *V* = *IR* and     *ρ* = 1.9 × 1012 (Ω m) | | C1 C1 A0 C1 C1 A1 | There is no ECF from **(b)(i)**  **Note** 2.54 × 10−7 gives an answer 9.0 × 10−13 A   There is no ECF from **(b)(ii)1** **Take** 12000 V as **TE** for this C1 mark, then ECF     **Note** 8.9 × 10−13 (A) gives an answer 2.0 × 1012 (Ω m) |
|  |  |  | **Total** | **14** |  |
| 4 |  |  | A | 1 |  |
|  |  |  | **Total** | **1** |  |
| 5 | a | i | Qd = constant      At least **two** pairs of values substituted to show that Qd = constant | C1      A1 | **Allow** straight-line graph of Q against 1/d passes through the origin **Allow** as d increases by a given factor (e.g. doubles) then Q decreases by the same factor (e.g. halves)  **Allow** numbers that show when d doubles then Q halves **Ignore** prefixes and POT errors  **Examiner’s Comments**  The question was not carefully examined by most candidates, because the reference to use **Fig. 22.2** was totally ignored. A significant number of candidates focused either on superfluous practical details or the proof of the relationship between Q and d – which was required in the next question. About a third of the candidates used at least two points on the graph to show that Qd = constant. The powers of ten were overlooked by examiners. A small number of candidates, mainly at the lower-end, calculated the gradient of the curve at arbitrary points to provide support for their incorrect reasoning. |
|  |  | ii | |  |  | | --- | --- | | Q = VC **and** C = |  |      |  |  | | --- | --- | | Hence |  | | C1  A1 | **Allow** ε  **Note** Q, or Q/V must be the subject here     |  |  | | --- | --- | | **Allow** Q ∞ C and C ∞ |  |   **Examiner’s Comments**     |  |  |  |  |  | | --- | --- | --- | --- | --- | | Most candidates successfully, and elegantly, provided the proof for the relationship. Correct answers ranged from the whole space filled with algebra to a couple of succinct lines. A small number of candidates finished off their working by | | | | | | writing |  | instead |  | the ‘equal’ | | and the ‘proportionality’ symbols are not equivalent. | | | | | |
|  | b | i | 1.8 × 10-14 (N) | B1 | **Ignore** sign  **Examiner’s Comments**  This question was designed to support candidates with the next question. The majority scored 1 mark for quoting the weight of the oil drop. A significant number of candidates, about 1 in 5, focused incorrectly on the term **stationary** in the question, and wrote 0 N on the answer line. |
|  |  | ii | (FE =) 3 × 1.8 × 10-14 (N) **or** (FE =) 5.4 × 10-14 (N)     |  |  | | --- | --- | | **or** (mass =) |  |   (resultant force = 3.6 × 10-14 N)     |  |  | | --- | --- | | (a =) |  |   a = 20 (ms-2) | C1     C1      A1 | **Note** this mark is for either electric force on the oil drop **or** the calculating the mass of the oil drop   **Allow** for ECF from **(b)(i)**      **Allow** g = 9.8, but not g = 10 **Note** answer to 3SF is 19.6 **Allow** 2 marks for a = 2g **Note** a bald answer of 20 will score 3 marks, if however, we see evidence for g = 10, then maximum score will be 2 mark  **Examiner’s Comments**  This was a perfect question for the higher and middle ability candidates. Securing full marks was very much dependent on candidates’ understanding of **resultant force**. The majority of the candidates scored 1 mark for calculating the weight of the oil drop in kg. Subsequent steps required the electric force on the oil drop to be 3 times the weight, or the resultant force being twice the weight. The key to getting the correct answer of 2g, or 19.6 m s-2, was deducing that the resultant force was 3.6 × 10-14 N. The most common incorrect answer was 29.4 ms-2 because the resultant force was taken as 5.6 × 10-14 N. The exemplar 9 below shows the most common incorrect solution.   **Exemplar 9**    This exemplar from a middle-grade candidate shows how lack of knowledge of resultant force on the oil drop led to just 1 mark. The only mark given was for the mass of the oil drop. Using as 5.6 × 10-14 N as the resultant force led to the incorrect response of 3g or 29.43 m s-2. |
|  | c |  | **Level 3 (5–6 marks)** Clear description **and** at least two from control of variables  There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.  **Level 2 (3–4 marks)** Some description **and** at least one from control of variables  There is a line of reasoning presented with some structure. The information presented is in the most part relevant and supported by some evidence.  **Level 1 (1–2 marks)** Any description but no control of variables **or** Limited mention of control of variable(s)  There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.  **0 marks** No response or no response worthy of credit. | B1× 6 | Use level of response annotations in RM Assessor **Indicative scientific points may include:**  **Description**   * E = V/d * Voltmeter used to measure p.d. * Ruler used to measure separation d plates * Plastic rod held in a stand * Safety: Do not touch the terminals of high-voltage supply / (positive) plate * Vary d or V to change E * θ determined for each value of E * Experiment repeated for several values of E * Sensible techniques used to determine θ, e.g. use a protractor * Plot tanθ against E **or** tanθ against 1/d graph * Straight line through origin (expected)   **Control of variables**   * Charge q kept constant (ignore method) * Method for keeping q constant (e.g. same V for the (positive) plate, use separate constant voltage supply, etc) * Use the same foil / keep W the same * Keep d or V constant * Foil in between plates (where the field is uniform) * Draught-free room * Do the experiment quickly to avoid leakage of charge   **Examiner’s Comments** This was the second level of response (LoR) question in this paper. This too was designed to assess practical skills of planning, implementation, analysis and evaluation. The context of the question was force experienced by a charged gold foil in the uniform electric field provided by two parallel plates. Candidates were not expected to have seen such an experiment, but they were expected to use their knowledge of electric field strength and practical skills to present plausible approaches. On occasions, the experimental methods showed poor appreciation of some basic ideas. Some candidates were charging the foil using large current that allegedly would cause heating issues for the foil, while others decided to use Q = It, ammeter and a stopwatch to determine the charge on the foil – failing to appreciate that the time constant will be too small for such a technique. However, on this occasion, such over ambitious techniques were generally overlooked by examiners.  As with **16d**, a holistic approach to marking was used, with marks given according answers matching the descriptors for the various levels. There is no one perfect answer for this question, examiners were expecting an eclectic approach. The key things examiners were looking for were:  - Methods for determining electric field strength E.  - Using the right instruments for the measurements.  - Plotting the correct graph to show the relationship given in the question was valid.  - Correctly identifying the variables that were being controlled (kept constant).  Access to higher level marks dependent on fully answering the question – and this included the last statement about control of variables. A significant number of candidates focused on the description and analysis of the data, without ever addressing the last sentence of the question. This question did discriminate well, with L1, L2 and L3 marks roughly distributed in the ratio 1:3:4. |
|  |  |  | **Total** | **14** |  |
| 6 |  |  | B | 1 | **Examiner’s Comments**  This question required knowledge of the equation , which is in the Data, Formulae and Relationship Booklet. The key, the correct answer, is **B**. The most common mistake made by candidates was not squaring r, or the equivalent where the electric potential V equation was used instead. This gave the incorrect answer of 7.3 × 10-10 C for the most recurrent distractor **C**. The exemplar 2 below shows a plausible method for getting to the correct answer.  **Exemplar 2**    This middle-grade candidate has shown all the working. A significant number of candidates wrote down the correct expression, circled the key data in the question and did the rest of the work on their calculators. A variety of techniques were use. |
|  |  |  | **Total** | **1** |  |
| 7 |  |  | c | 1 | **Examiner’s Comments**  This was a well-answered question with most candidates correctly recalling that charge is conserved according to Kirchhoff’s first law. A significant number of candidates distracted towards **B**; perhaps because of the unit of charge is the coulomb. |
|  |  |  | **Total** | **1** |  |
| 8 |  |  | **Level 3 (5–6 marks)** Clear description **and** correct value of C  There is a well-developed line of reasoning which is clear and logically structured. The information presented is relevant and substantiated.  **Level 2 (3–4 marks)** Clear description **and** some correct working **OR** Some description **and** correct value for C  There is a line of reasoning presented with some structure. The information presented is in the most-part relevant and supported by some evidence.  **Level 1 (1–2 marks)** Some description **OR** Some working  There is an attempt at a logical structure with a line of reasoning. The information is in the most part relevant.  **0 marks** No response or no response worthy of credit | **B1 × 6** | **Indicative scientific points may include:**  **Description**   * C = εA/d * A = area (of overlap) and d = separation. * Use ruler to measure the side / radius / diameter (andhence the area A) * Ensure total overlap of plates. * Measure the thickness / d of paper using micrometer /(vernier) caliper. * Take several readings of thickness and determine anaverage value for d   **Calculation of capacitance**   * gradient ≈ 85 * C ≈ 1.2 × 10−8 (F)   **Examiner’s Comments**  This was the second of the two LoR questions in this paper. It required application of practical skills from module 1.1 (Development of practical skills), knowledge of parallel plate capacitor and permittivity.  As with the other LoR question 17, examiners expect varied responses for the criteria for the three levels to be met. Unlike some of the analytical questions, there is no one perfect model answer for a specific question. For Level 3, correct value of the capacitance C was required together with a clear description of how to do the additional measurements that led to the determination of the permittivity of the paper. For Level 2, it was either clear description with some correct working or some description with the correct value for C. Level 1 required some description or some working.  As expected, there were diverse answers which demonstrated adequate experimental and practical skills. The thickness of the paper was invariably measured using a micrometer, but some candidates decided to measure the total thickness of a large number of sheets using a ruler and then calculating the thickness of each sheet. This technique was as good as using a micrometer or using Vernier calipers. Diverse answers are the characteristic of LoR questions.    The most common errors made were:   * Confusing permittivity with either relative permittivity or the permittivity of free space ε0. * Using C = 4πεR instead of C = εA/d. * Issues with powers of ten when determining the gradient – mainly because of the milli prefix on the time axis.   **Exemplar 10**    This exemplar illustrates a Level 2 performance from this top-end candidate.  The analysis is perfect, but the description is basic and there are no details of the instruments needed to make the measurement. It would have taken a couple more lines to elevate this answer to Level 3.  Compare and contrast this with the exemplar below for a Level 3 response.  **Exemplar 11**    This above is a typical Level 3 answer. Correct calculation and a description that has all the right ingredients. Notice how the appropriate measuring instruments are being used and how the uncertainty in the measurements is reduced. |
|  |  |  | **Total** | **6** |  |
| 9 |  | i | Kinetic energy (of proton) changes to potential (energy) **or** Potential energy increases as the kinetic energy (of the proton) decreases **or** Potential energy increases as work is done against the field / against repulsion / positive charge | **B1** | **Allow** ‘it’ / PE for (electric) potential energy **Allow** KE / Ek |
|  |  | ii | energy = 0.52 × 106 × 1.60 × 10−19 **or** 8.3(2) × 10−14 (J)    R = 7.5 × 10−14 (m) | **C1    C1    A1** | **Allow** 2 mark for 1.6 × 10−13 (m); Z = 59 used  **Allow** 2 mark for 8.9 × 10−14 (m); Z = 32 used  **Allow** 1 mark for 2.8 × 10−15 (m); Z = 1 used  **Allow** 1 mark for 1.2 × 10−32 (m); energy = 5.2 × 105 used   **Examiner’s Comments**  The above question on electric potential energy provided excellent discrimination with middle and upper quartile candidates showing how to produce immaculate answers – identify the physics, write down the correct physical equation, do any necessary conversions (e.g. MeV to J), rearrange the equation, substitute correctly and then write the final answer in standard form to the correct number of significant figures. About a third of the candidates scored full marks.    Some of the missed opportunities or errors were:   * Using an incorrect equation with the distance squared * Not correctly converting the kinetic energy 0.52 MeV into joule (J) * Using the equation r = r0A1/3 for the mean radius of a nucleus to determine the minimum distance |
|  |  |  | **Total** | **4** |  |
| 10 |  |  | **B** | **1** |  |
|  |  |  | **Total** | **1** |  |
| 11 | a |  | ε = 7.2 × 10-12 × 1.2 × 10-3/4.0 × 10-4   permittivity = 2.2 × 10-11 (F m-1) | **C1**   **A1** | **Allow** any subject **Allow** εo instead of ε  **Note** answer to 3 sf is 2.16 × 10-11 (F m-1) **Allow** 1 mark for bald 2.4; relative permittivity calculated  **Examiner’s Comment** Most candidates effortlessly used the equation C = εA / d to determine the permittivity s of the insulator between the capacitor plates. Once again, most answers were well-structured and showed good calculator skills. The most common errors were:   * Taking the prefix pico (p) to be a factor of 10-9. * Confusing permittivity ε and permittivity of free space ε0. * Calculating relative permittivity (2.4). |
|  | b | i | capacitance of two capacitors in series = 500 (πF)  C = 1000 + 500  C = 1500 (μF) | **C1**     **A1** | **Examiner’s Comment** The modal score here was two marks, with most scripts showing excellent understanding of capacitors in combination. Many candidates arrived at the final answer of 1500 μF without much calculation. A small number incorrect swapped the equations for series and parallel combinations and arrived at the incorrect answer of 670 μF. |
|  |  | ii | V = 1.5 × e-12/15  V = 0.67 (V) | **C1  A1** | Possible ecf from **(i)**  **Allow** 1 mark for 0.83 V, V = 1.5[1 - e-12/15] used  **Examiner’s Comment** Many candidates correctly calculated the time constant of the circuit and then either determined the p.d. across the capacitors (0.83 V) or the resistor (0.67 V) - the latter being the correct answer. The most common mistake was calculating e-12115 rather than 1.5 × e-12/15. Weaker candidates got nowhere by attempting to use V = IR and Q = VC. |
|  |  |  | **Total** | **6** |  |
| 12 | a | i | OR KE = ½ mv2 and v2 = u2 + 2as  OR KE = F× d and F = m × a    (Use of KE = ½ mv2 ) = 4.8 × 10−20 = ½ × 9.11 × 10−31 × v2 and (use of v2 = u2 + 2as =) v2 = (1.05 × 1011) = 2 × a × 6 × 10−3 (± 02)  (Use of KE = F × d ) = 4.8 × 10−20 = F × 6 × 10−3 and (use of F = m × a) F = (8.0 × 10−18) = 9.11 × 10−31 × a  a = 8.78 …. × 1012 (ms−2) | C1 M1 A1 | **Allow** u and v interchangeably throughout **Allow** calculation of E = (0.30 / 6 × 10−3) = 50 (V m−1) or v = 3.2 × 105 (ms−1) or v2 = 1.05 × 1011 (ms−1)2  or F = 8.0 × 10−18 (N) for C1 mark  Substitution mark – in any arrangement. Expect full substitutions including numerical value of me if appropriate Method 1: direct calculation of a    Method 2: using KE = ½ mv2 and v2 = u2 + 2as  Method 3: using KE = F × d and F = m × a  **Note** must be more than 2 SF (not paper SF penalty) **Ignore** negative sign   **Examiner’s Comments**  There were many different routes to showing the acceleration, and marks were given for each method or part method. No one method was seen significantly more than others, and some candidates used a variety of pathways to come to their answer.  The main principle in the question (and the subsequent one) where the candidate is being asked to “show that” a given value is correct is that the examiner must be convinced that the candidate has clearly demonstrated that they have carried out the calculation and evaluated it on their calculator. The instructions which examiners used was: first marking point for providing one (or two) equations that would lead to the solution, or calculation of an intermediate value; second marking point for a full substitution into one or more equations; third marking point for using this full substitution to produce an answer to more sf than given in the question. As the second marking point was deemed to be an M mark, the full substitution needed to be seen to gain the A mark.  A small number of (often higher end) candidates did not show the full substitution, often missing out the value of me in their calculation, and another common error was to not show the extra significant figure.  Over half of the candidates were able to achieve full marks on this question and it generally discriminated well.     |  |  | | --- | --- | |  | **Assessment for learning** |   When a question asks a candidate to “show that” a given value is correct, the following two points should be considered:   * Each stage of the calculation should be clearly shown. Preferably setting out any equation first, and then showing a full substitution of all values into that equation * If the value calculated by the candidate would correctly round to the given value, then the candidate should show their calculated value to at least one more significant figure than the given value.   Both of these are evidence that the complete calculation has taken place and that the candidate has not somehow artificially generated the required value. This advice should be viewed as “best practice” rather than a rigid set of rules.  Reverse arguments are often possible where a candidate can work backwards from their given value, however this is not the advised approach. |
|  |  | ii | (Use of KE = ½ mv2 ) = 4.8 × 10−20 = ½ × m × v2  OR (u2 = v2 − 2as) = 02 − [2 × (−) 8.8 × 1012 × s]  Full substitution leading to v = 3.2… × 105 (ms−1) | C1 A1 | **Allow** u and v interchangeably    Numerical value of me must be used if using KE method **Note** must be more than 1 SF (not paper SF penalty) **Note** 3.25 is acceptable for A1, but not 3.3   **Examiner’s Comments**  The vast majority of candidates were able to clearly show that the speed of the photoelectron could be calculated as 3.2 × 105 ms−1, most often through substitution into the kinetic energy formula. As in Question 19 (b) (i), it is important to show all variables and constants used in the equation for full marks and to give the answer to at least one more d.p. than given in the question, to show the calculation has taken place. An alternative solution using an equation of motion and the acceleration given (or calculated) in Question 19 (b) (i) would yield the same result. |
|  |  | iii | t = 3.6 × 10−8 (s) | C1 A1 | **Allow** correct full substitution into any suvat equation **Allow** 3 × 105 for v **Ignore** signs of substituted values  **Expect** values between 3.4 × 10−8 and 3.8 × 10−8 (s) **No** **ecf** from (b)(i) or (b)(ii)   **Examiner’s Comments**  Only around half of the candidates were able to obtain answers within the required range. Candidates used a variety of rounded or none-rounded values from prior calculations, so a generous range of responses was given to allow for this. A common error among less successful responses was to simply use speed = distance/time usually leading to 2.0 × 10−8 s. Those using s = ut + ½ at2 often encountered problems in solving the equation as it could lead to imaginary roots and tended to produce solutions way outside of the accepted values. However, marks could be given for setting up the calculation correctly. |
|  |  | iv | Any line with negative slope starting from 0, 4.8 × 10−20  A straight line finishing at 6.0,0 | M1 A1 | ½ square tolerance. **ALLOW** a curve with negative gradient. **ALLOW** a region of zero gradient, but not whole line  ½ square tolerance on axis intercepted   **Examiner’s Comments**  Nearly all candidates appreciated that this line would start at 4.8 × 10−20 J and decrease to zero at 6.0 mm. However, the vast majority drew a curved line of decreasing gradient. This may well have come from a confusion from KE ∝ v2 and attempting to draw a parabola. |
|  | b |  | Energy of photon increases    (max) kinetic energy / speed (of electrons) increases / (some) electrons (now) reach **C** **and** there is a current or reading (on ammeter) | B1 B1 | **Do not allow** increased kinetic energy of photons  **Do not allow** explanation in terms of increased number of **emitted** electrons (per second) **Allow** photoelectrons for electrons   **Examiner’s Comments**  There were several misconceptions in candidates’ responses to this question. Many candidates did not appreciate that the increased frequency would result in electrons of greater KE and thought that it was the increased energy of the photons crossing the 6.0mm gap that caused an ammeter reading. A significant number of candidates also described increasing frequency causing an increase in kinetic energy of photons, and some also linked the increasing frequency to a greater number of photons or photoelectrons. |
|  |  |  | **Total** | **11** |  |
| 13 |  | i | acceptable pattern with lines touching but not entering spheres | B1 | adequate drawing for 1 mark |
|  |  | i | lines perpendicular to spheres and arrows from plus ion to minus ion | B1 | award second mark for detail/quality |
|  |  | ii | E = kQ/r2 where k = 1/4пε0 | C1 | correct formula with Q = e |
|  |  | ii | E = 9 × 109 × 1.6 × 10−19/6.25 × 10−20 | C1 | correct substitution |
|  |  | ii | E = 2.3 × 1010 | C1 | evaluation |
|  |  | ii | 2E = 4.6 × 1010 (N C−1) | A1 | fields of charges add, **allow ecf** for E |
|  |  |  | **Total** | **6** |  |
| 14 | a | i | The direction of the electric field due to the negative charge is to the left and right for the positive charge. | B1 |  |
|  |  | i | The magnitude of the electric field strength due to the positive charge is smaller than that for the negative charge (because of greater distance).  (Hence the resultant electric field strength is to the left.) | B1 |  |
|  |  | ii | energy = | C1 |  |
|  |  | ii | energy = 7.67(2) × 10−19 (J) | C1 |  |
|  |  | ii | energy = 4.8 (eV) | A1 |  |
|  | b | i | (*v*2 = *u*2 + 2*as*) (2.4 × 106)2 = (7.2 × 106)2 + 2 × *a* × 1.2 × 10−2 | C1 | **Allow** other correct methods |
|  |  | i | *a* = (−) 1.9 × 1015 (m s−2) | A1 | **Allow** 1 mark for 1.9 × 1013; distance left in cm **Note** answer to 3 s.f. is 1.92 × 1015 (m s−2) **Ignore** sign |
|  |  | ii | *E* = *F*/*Q* and *F* = *ma* | C1 |  |
|  |  | ii |  | C1 | Possible ECF from **(i)** |
|  |  | ii | *E* = 2.0 × 107 (N C−1) | A1 | **Allow** 2 marks for 1.1 × 104; mass of electron used **Allow** 1 s.f. answer |
|  |  |  | **Total** | **9** |  |
| 15 | a |  | Correct pattern     Correct direction of the field | **B1**     **B1** | **Note:** At least five field lines must be drawn and of these, two must be perpendicular (by eye) to the surface of the sphere and plate  **Note:** This may be shown on just one line  **Examiner’s Comment** Most candidates drew decent field patterns and showed the correct direction of the electric field. It is difficult to draw curved field lines, but those who were careful and had the field lines perpendicular at both the surface of the sphere and the metal plate were rewarded. |
|  | b |  | (Electric potential) is the work done per (unit) charge in bringing a positive charge from infinity (to the point). | **B1** | **Allow:** work done / energy required to bring a unit positive charge from infinity (to the point)  **Examiner’s Comment** This was not well-answered; the modal mark was zero. Definition for electric potential lacked precision and often made no reference to a ‘unit **positive** charge’ or ‘per unit **positive** charge’. At times, other quantities such as electric field strength and gravitational field strength were being defined. This was a missed opportunity -definitions just need to be learnt. |
|  | c | i | |  |  | | --- | --- | | V = Q/4πε0r | (Allow any subject) |   Q = 4π × 8.85 × 10-12 × 0.015 × 5000     Q = 8.3(4) × 10-9 (C) | **C1   C1     A0** | **Note** using E **= V/d** with E = Ω/4πε0r2 is wrong physics and hence scores zero  **Note** if the value of ε0 is not given here, it could be implied in the correct 3sf answer **Allow** any subject here if the answer is given to more than 2sf **Allow** the use of 1/4πε0 = 9 × 109  **Examiner’s Comment** By contrast to the last question, the answers here were perfect. Correct values were substituted into the equation for electric potential to show that the charge was that stated in the question. In a ‘show’ question, always give the final answer to more significant figures than the required answer. It was good to see many scripts with the final answer written as 8.3**4** × 10-9 C. |
|  |  | ii | 1 (electric force =) 1.7 × 10-2 × tan4.0 (Allow any subject)  (electric force = 1.19 × 10-3 N) 2  E = 1.2 × 10-3/8.3(4) × 10-9  E = 1.4 × 105 (N C-1) | **M1   (A0)  C1  A1** | **Not** 1.7 × 10-2 sin4 or 1.7 × 10-2 cos86 **Allow** 1.7 × 10-2 × sin4/cos4    **Allow** 2 marks for 1.45 × 105 (N C-1), 8.3 × 10-9 used **Allow** 2 marks for 1.43 × 105 (N C-1), 1.19 × 10-3 (N) used  **Examiner’s Comment** This was a good discriminator with high-scoring candidates either using triangle of forces, or resolution of forces, to determine the electric force on the sphere. The value of the force was given so that it could be used to answer the next question. More than half of the candidates correctly calculated the electric field strength using the information provided in **(c)(i)** and **(c)(ii)1.** Some candidates used the elementary charge rather than the value from **(c)(i)** to calculate the field strength; this gave an incorrect answer of 7.5 × 1015 N C-1. |
|  |  |  | **Total** | **8** |  |