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|  | |  |  | | --- | --- | | **Physics A**  **Capacitors 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.** | The diagram below shows a circuit used to charge a capacitor.     |  | | --- | |  |   The power supply has electromotive force (e.m.f.) 10 V and negligible internal resistance. The capacitor has capacitance *C* and the resistor has resistance *R*. The switch is closed at time *t* = 0. The table below shows potential difference *V* across the resistor at various values of time *t*.     |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | |  |  |  |  |  | | --- | --- | --- | --- | --- | | ***V* / V** | 10 | 6.3 | 5.0 | 3.7 | | ***t* / s** | 0 | 2.8 | 4.2 | 6.0 | |  |   What is the product *C* × *R* for this circuit?     |  |  | | --- | --- | | A | 0 s | | B | 2.8 s | | C | 4.2 s | | D | 6.0 s |      |  |  |  | | --- | --- | --- | | Your answer |  | **[1]** | | |

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|  | |  |  | | --- | --- | |  |  | | **2.** | 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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|  | |  |  | | --- | --- | |  |  | | **3(a).** | A student is investigating how the discharge of a capacitor through a resistor depends on the resistance of the resistor. The equipment is set up as shown in Fig. 3.1.    **Fig. 3.1**  The student charges the capacitor of capacitance C and then discharges it through a resistor of resistance R using switch **S**. After a time t = 15.0 s the student records the potential difference V across the capacitor.  The student repeats this procedure for different values of R.  It is suggested that V and R are related by the equation    where V0 is the initial potential difference across the capacitor and t is the time over which the capacitor has discharged.  The student decides to plot a graph of ln (V / V) on the y-axis against on the x-axis to obtain a straight line graph. Show that the magnitude of the gradient is equal to     |  |  | | --- | --- | |  | **[2]** | | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | Values of R and V at t = 15.0 s are given in the table below.     |  |  |  |  | | --- | --- | --- | --- | | **R / k**Ω | **V / V** |  | **ln (V / V)** | | 56 | 3.0 ± 0.2 | 18 |  | | 68 | 3.7 ± 0.2 | 15 | 1.31 ± 0.06 | | 100 | 5.0 ± 0.2 | 10 | 1.61 ± 0.04 | | 150 | 6.4 ± 0.2 | 6.7 | 1.86 ± 0.03 | | 220 | 7.3 ± 0.2 | 4.5 | 1.99 ± 0.03 | | 330 | 8.1 ± 0.2 | 3.0 | 2.09 ± 0.03 |    |  |  | | --- | --- | | Complete the missing value of ln (V / V) and its absolute uncertainty in the table above. | **[1]** |    |  |  | | --- | --- | | Use the data to complete the graph of Fig. 3.2. Four of the six points have been plotted for you. | **[2]** |  2. **Fig. 3.2** 3. Use the graph to determine a value for C. Include the absolute uncertainty and an appropriate unit in your answer.   C =....................± .................... unit .................... **[4]** | |

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|  | |  |  | | --- | --- | |  |  | | **(c).** | Determine the value of R, in kΩ, for which the capacitor discharges to 10% of its original potential difference  in 15.0 s. Show your working.  R = ......................................... kΩ **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **4.** | The graph below shows the variation of potential difference V with charge Q for a capacitor.    Which row is correct for the gradient of the graph and the area under the graph?     |  |  |  | | --- | --- | --- | |  | **Gradient of graph** | **Area under the graph** | | **A** | capacitance−1 | work done | | **B** | capacitance−1 | permittivity | | **C** | capacitance | power | | **D** | capacitance | energy |      |  |  |  | | --- | --- | --- | | Your answer |  | **[1]** | | |

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|  | |  |  | | --- | --- | |  |  | | **5(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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|  | |  |  | | --- | --- | |  |  | | **6(a).** | This question is about investigating the charging and discharging of capacitors.  Two students are given the circuit shown in Fig. 6.1. It consists of two resistors and two uncharged capacitors, a 10 V supply and a two-way switch **S**.    The first student is asked to investigate the charging of the capacitor C1 when **S** is connected to **A**. She selects an ammeter of range 0 to 100 μA reading to 2 μA and a stopwatch reading to 0.1 s.  Discuss whether she has made a sensible choice of equipment for this experiment.                **[4]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | A student is asked to investigate the change of potential difference (voltage) *V* with time *t* across each capacitor from the instant that **S** is moved from **A** to **B**.   1. Explain why the final potential difference across each capacitor is 5.0 V.         **[2]**   1. Predict the outcome of the experiment by sketching **two** graphs on Fig. 6.2 to display the results that the student should obtain for each capacitor. Label them C1 and C2.     **[3]** | |

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|  | |  |  | | --- | --- | |  |  | | **7(a).** | A student designs an investigation to learn more about an old instrument called a hot wire ammeter.  A fine resistance wire stretched between two retort stands sags when heated by the current being measured. This sag is converted into a reading on a non-linear scale.  A current-carrying wire is clamped at each end as shown in Fig. 2.1.    The deflection *y* at the centre of the wire is measured for various currents *I* in the wire. It is suggested that *y* and *I* are related by the equation  *y* = *aIb*  where *a* and *b* are constants. This equation can also be written as  lg *y* = lg *a* + *b* lg *I*.  A graph is plotted of lg *y* on the *y*-axis against lg *I* on the *x*-axis. State expressions for the gradient and *y*-intercept in terms of *a* and *b*.  gradient = ...................................................................  *y*-intercept = ...................................................................  **[1]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | For different values of the current *I*, the vertical deflection *y* is recorded. A table of results is shown with further columns giving values of lg (*I* / 10−2 A) and lg (*y* / mm), including the absolute uncertainties.     |  |  |  |  | | --- | --- | --- | --- | | ***I* / 10−2 A** | ***y* / mm** | **lg (*I* / 10−2 A)** | **lg (*y* / mm)** | | 50 | 2.6 ± 0.2 |  |  | | 60 | 3.4 ± 0.2 | 1.78 | 0.53 ± 0.03 | | 70 | 4.4 ± 0.2 | 1.85 | 0.64 ± 0.02 | | 80 | 5.4 ± 0.2 | 1.90 | 0.73 ± 0.02 | | 90 | 6.6 ± 0.2 | 1.95 | 0.82 ± 0.01 | | 95 | 7.2 ± 0.2 | 1.98 | 0.86 ± 0.01 |  1. Complete the missing values in the table, including the absolute uncertainty for lg (*y* / mm).   **[2]**   1. Fig. 2.2 shows the axes for a graph of lg (*y* / mm) on the *y*-axis against lg (*I* / 10−2 A) on the *x*-axis. The last four points have been plotted including error bars for lg (*y* / mm). By plotting the two remaining points, complete the graph. Draw a line of best fit.   **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **(c).** | 1. Use the line of best fit through the data points in Fig. 2.2 to determine numerical values of  **1**     *b*   *b* = ............................. **[1]**  **2**     *a*.  *a* = ............................. **[2]**   1. Determine the absolute uncertainty in the value of *b*.   uncertainty in *b* = ± ............................. **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **8(a).** | This question is about capacitors.  Fig. 4.1 shows two capacitors **A** and **B** connected in series to a battery.    The capacitance of **B** is twice the capacitance of **A**. Explain why the potential difference across capacitor **A** is twice the potential difference across capacitor **B**.        **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | Fig. 4.2 shows a circuit with an arrangement of capacitors and resistors.    Calculate the time constant of the circuit.  time constant = ........................................................... s **[3]** | |

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|  | |  |  | | --- | --- | |  |  | | **(c).** | A charged capacitor of capacitance 1200 μF is connected across the terminals of a resistor of resistance 40 kΩ. Fig. 4.3 shows the variation of the current I in the resistor against time t.     1. Use Fig. 4.3 to calculate the initial charge stored by the capacitor.   charge = ........................................................... C **[2]**   1. The capacitor is charged again to the same initial potential difference. It is now discharged across two 40 kΩ resistors connected in **parallel**. On Fig. 4.3 draw carefully a graph to show the variation of the current I in the combination of resistors with time t.   **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **9.** | A capacitor consists of two parallel plates separated by air. The capacitor is connected across a d.c. supply. The charged capacitor is then disconnected and the separation between the plates is doubled.  Which statement is correct about the charge stored by the capacitor?     |  |  | | --- | --- | | **A** | The charge is the same. | | **B** | The charge doubles. | | **C** | The charge halves. | | **D** | The charge quarters. |   Your answer    **[1]** | |

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|  | |  |  | | --- | --- | |  |  | | **10(a).** | **Fig. 20.3** shows a capacitor-resistor circuit.    Describe how the time constant of this circuit can be determined experimentally in the laboratory.                  **[3]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | **Fig. 20.2** shows an arrangement of capacitors connected to a battery.    The e.m.f. of the battery is 12 V.  Calculate the total energy *E* stored by the capacitors in this circuit.  *E* = .................................... J  **[4]** | |

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|  | |  |  | | --- | --- | |  |  | | **11.** | Fig. 4.2 shows an electrical circuit.    The cell has e.m.f. 1.4 V and negligible internal resistance. The values of the capacitors and the resistor are shown in Fig. 4.2. A mechanical switch vibrates between contacts **X** and **Y** at a frequency of 120 Hz.   1. Calculate the time constant of the circuit.      |  | | --- | | time constant = ........................................................... s **[1]** |  1. Calculate the value of the average current I in the resistor. Assume that the capacitors are fully discharged between each throw of the switch.      |  | | --- | | I = ........................................................... A **[3]** |  1. The frequency of vibration of the mechanical switch is doubled. Explain why the average current in the circuit is not doubled.         **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **12(a).** | A student designs a circuit with a time constant of 5.0 s. State suitable values for resistance R and capacitance C for this circuit.     |  |  | | --- | --- | | R = ........................................ | C = ........................................ |      |  | | --- | | **[1]** | | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | Define the time constant of a capacitor-resistor discharge circuit.      **[1]** | |

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|  | |  |  | | --- | --- | |  |  | | **(c).** | Fig. 4.1 shows a circuit with a capacitor of capacitance 0.010 F.    A tight bundle of wire is made from 5.0 m of insulated wire of diameter 0.12 mm and resistivity 4.9 × 10–7 Ω m. The material of the wire has density 8900 kg m–3 and specific heat capacity 420 J kg–1 K–1.   1. Calculate the time constant of the circuit.      |  | | --- | | time constant = ........................................................... s **[3]** |  1. Switch **S2** is open. Switch **S1** is closed. Explain in terms of the movement of electrons how **X** and **Y** acquire equal but opposite charge.                 **[3]**   1. Switch **S1** is opened. The potential difference across the capacitor is 12V. Switch **S2** is now closed. Assume that all the energy stored by the capacitor is used to heat up the bundle of wire. Calculate the increase in the temperature of the bundle of wire.      |  | | --- | | increase in temperature = ........................................................... °C **[4]** |  1. State and explain how your answer to **(iii)** would change when a 24V power supply is used to carry out the experiment.         **[2]** | |

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|  | |  |  | | --- | --- | |  |  | | **13.** | The diagram below shows a simple capacitor.    The capacitor consists of two horizontal metal plates in a vacuum. The magnitude of the charge on each plate is Q 0. The potential difference (p.d.) between the plates is V 0. The capacitor plates have capacitance C 0. The separation between the plates is d. The energy stored by the capacitor is E 0. The top plate is moved vertically upwards. The new separation between the plates is 2d. The charge on each plate remains the **same**. The energy stored by the capacitor **increases**.   1. Determine the new:      |  |  |  | | --- | --- | --- | |  | **1** | capacitance in terms of C 0 | | capacitance = ...................................................... C 0 **[1]** | | | |  | **2** | p.d. between the plates in terms of V 0 | | p.d. = ...................................................... V 0 **[1]** | | | |  | **3** | energy stored in terms of E 0. | | energy = ...................................................... E 0 **[1]** | | |  1. Explain, in terms of forces between the plates, why the energy stored increases.     **[1]** | |

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|  | |  |  | | --- | --- | |  |  | | **14.** | Define the **time constant** of a circuit containing a capacitor of capacitance C and a resistor of resistance R.    **[1]** | |

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|  | |  |  | | --- | --- | |  |  | | **15.** | A student discharges a capacitor of capacitance C through a variable resistor of resistance R using the arrangement below.    The capacitor is made from two parallel metal plates separated by a sheet of paper of thickness 8.0 × 10−5 m. The area of overlap between the plates is 3.1 × 10−2 m2.  The capacitor is charged fully by closing switch **S**. At time t = 0, **S** is opened and the capacitor discharges through the resistor. After t = T, the potential difference across the capacitor is halved. The student repeats this for several values of R.   1. The student decides to plot T against R to obtain a straight-line graph.  Show that the line has gradient = C ln2.   **[2]**   1. The data points plotted by the student are shown below.      |  |  | | --- | --- | | **1** | Draw a best-fit straight line through the data points and use the gradient of this line to determine C.  C = ...................................................... F **[3]** |      |  |  | | --- | --- | | **2** | Use your answer in **(ii)1** to calculate the permittivity ε of the paper.  ε = ...................................................... F m−1 **[2]** | | |

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|  | |  |  | | --- | --- | |  |  | | **16(a).** | The diagram below shows a circuit to charge a capacitor.     |  | | --- | |  |   The electromotive force (e.m.f.) E of the cell is 1.48 V and it has negligible internal resistance. The resistance of the resistor is 120 kΩ and the capacitance of the capacitor is 2000 μF. At time t = 0 the capacitor is uncharged. The switch is closed at time t = 0.  Calculate the time t when the potential difference across the capacitor is 1.00 V.  t = ....................................................... s **[4]** | |

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|  | |  |  | | --- | --- | |  |  | | **(b).** | A capacitor of capacitance C is connected across a strip of conductive paper.     |  | | --- | |  |   The switch is moved from **X** to **Y**, and the time t for the potential difference across the capacitor to halve is measured.  The time t is given by the expression  t = (Ck ln2) × L  where k is the resistance of the conductive paper per unit length and L is the length of the conductive paper.  The value of C is 1.2 × 10–3 F.  In an experiment, L is changed and t measured.  The data points are plotted on a t against L grid as shown below.     |  | | --- | |  |   Draw a straight line of best fit through the data points, and use the gradient of this line to determine k.  k = ............................................... Ω m–1 **[4]** | |

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|  | |  |  | | --- | --- | |  |  | | **17.** | A student is modelling the decay of charge for a capacitor discharging through a resistor using the equation = – 0.2Q. The student decides to use Δt = 0.5 s. The initial charge on the capacitor is 1000 μC.  Part of the modelling spreadsheet from the student is shown below.     |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  | | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | | |  |  |  | | --- | --- | --- | | **t / s** | **Charge Q left on capacitor at time t / μC** | **Charge ΔQ decaying in the next 0.5 s / μC** | | 0 | 1000 | 100 | | 0.5 | 900 |  | | 1.0 |  |  | | 1.5 |  |  | |  |   What is the value of Q in μC at t = 1.5 s?     |  |  | | --- | --- | | **A** | 700 | | **B** | 720 | | **C** | 729 | | **D** | 800 |      |  |  |  | | --- | --- | --- | | Your answer |  | **[1]** | | |

**END OF QUESTION PAPER**

# Mark scheme

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| **Question** | | | **Answer/Indicative content** | **Marks** | **Guidance** |
| 1 |  |  | D | 1 |  |
|  |  |  | **Total** | **1** |  |
| 2 |  | 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. | | | | | |
|  |  |  | **Total** | **4** |  |
| 3 | a |  | Take In to give lnV = −(t / C).1/R + In V0 gradient (m) = (−) t / C where t = 15 | **M1 A1** | **allow** ln (V / V0)= −(t / C).1/R **Examiner’s Comments** The whole question produced a full range of marks and discriminated well. About 70% gained more than half marks. In (a) here was some confusion about V0. Many candidates correctly stated that  ln( V / V0) = −t / RC but some looked again at the question and wrote ln( V / V) instead not realising that V here related to the unit volt. A smaller number correctly stated the expanded form ln V = −t / RC + ln V0. |
|  | b | i | 1.10 ± 0.07 | **B1** | value plus uncertainty required for the mark |
|  |  | ii | two points plotted correctly to within ½ small square on x-axis;  line of best fit | **B1  B1** | **ignore** accuracy of length of error bar;  **ecf bi** value  **or both** worst acceptable lines drawn |
|  |  | iii | gradient (= 15/C) = 6.6 (× 104); C = 15 / 6.6 × 104 = 2.3 × 10−4 (F) worst acceptable straight line drawn       (C) ± 0.3 × 10−4 F | **C1 A1 B1       B1** | **accept** 6.4 to 6.8 **ignore** power of 10 **accept** 2.3 ± 0.1 × 10−4 **allow ecf** for the point calculated incorrectly in **b(ii);** steepest or shallowest possible line that passes through all the error bars; should pass from top of top error bar to bottom of bottom error bar **or** bottom of top error bar to top of bottom error bar **allow** e.g. (C) ± 0.2 × 10−4; **allow** value of C to 4 SF **but N.B.** the uncertainty and the value of  C **must be**to the same number of decimal places **allow** 230 ± 30 μF etc **allow** equivalent unit including s Ω−1, C V−1, A s V−1  **Examiner’s Comments** Candidates were given several opportunities to score marks by plotting points, drawing the best and worst lines on a graph and then extracting data from the graph. Many failed to draw the worst straight line losing themselves two possible marks. Many forgot the power of 10−6 in the unit on the x-axis. The normal requirement that the final value for the capacitance  C should to be given to 2 significant figures (SF) and the absolute uncertainty to 1 SF (e.g. 230 ± 0.20 μF) was waived. However the absolute uncertainty had to be stated to the same number of decimal places as the calculated value of C to gain the mark. |
|  | c |  | ln(0.1) = −15/RC **or** R = −15/C ln(0.1) **or**  R = 0.65/C R = 0.65/2.3 × 10−4 giving R = 28 kΩ | **C1  A1** | ln(0.1) = −2.30  **ecf (b)(iii)**  **Examiner’s Comments** About half of the candidates gained full marks here. Some confused 10% and 90% and about a tenth of the candidates did not attempt an answer. |
|  |  |  | **Total** | **11** |  |
| 4 |  |  | **A** | **1** |  |
|  |  |  | **Total** | **1** |  |
| 5 | 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** |  |
| 6 | a |  | Time constant of charging = 10 s | B1 | **allow** alternative but equivalent statements |
|  |  |  | maximum current = 10/100k = 100 μA | B1 | **e.g.** current falls to 37 mA in 10 s |
|  |  |  | statements about adequate sensitivity of meter and stopwatch | B1 B1 | **e.g.** readings can be taken every 3 to 5 s so can collect at least 8 sets of values before approaching change of less than 2 μA; sensitivity of 0.5 s adequate |
|  | b | i | 1 the (total stored) charge is constant | B1 | **max** 2 out of 3 marking points |
|  |  | i | 2 capacitors in parallel must come to the same voltage | B1 | **allow** mathematical argument, e.g. initial Q = 1 mC final Q on each is 0.5 mC as identical Cs in parallel |
|  |  | i | 3 capacitors are identical so each stores half/same charge so final V is 5 V | A0 | so V = 0.5 × 10−3 × 1.0 × 10−4 = 5.0 V **or** total C × total Q gives 5 V |
|  |  | ii | C1 curve : exponential decay curve from 10 V to 5 V | B1 |  |
|  |  | ii | C2 curve: 10 − C1 curve | B1 |  |
|  |  | ii | time axis: curves to be horizontal at 5V about 25 s | B1 | time constant of 5 s |
|  |  |  | **Total** | **9** |  |
| 7 | a |  | gradient = b and *y*-intercept = lg a | B1 |  |
|  | b | i | 1.70; | B1 | both values for the mark |
|  |  | i | 0.41 ± 0.03 | B1 | **allow ecf** to find uncertainty value |
|  |  | ii | two points plotted correctly; | B1 | **ecf** value and error bar of first point |
|  |  | ii | line of best fit | B1 | **allow ecf** from points plotted incorrectly |
|  | c | i | b = gradient = 1.60 | B1 | **allow** 1.56 to 1.64; **allow** 1.6 |
|  |  | i | y = 0.86 (± 0.01); × = 1.98 so *y*-intercept = 0.86 − 1.6 × 1.98 = −2.3(1) | B1 | **ecf** gradient in finding y-intercept |
|  |  | i | a = 10−2.3 = 0.005 | B1 |  |
|  |  | ii | worst acceptable straight line | B1 | steepest or shallowest possible line that passes through the error bars; should pass from top of top error bar to bottom of bottom error bar **or** bottom of top error bar to top of bottom error bar **allow (**1.6) ± 0.1 or 0.2 where plausible working is shown |
|  |  | ii | b = gradient of steepest line = 1.75 giving uncertainty ± 0.15 | B1 |  |
|  |  |  | **Total** | **10** |  |
| 8 | a |  | The charge / *Q* on each capacitor is the same | M1 |  |
|  |  |  | *V* ∝ *C*−1 | A1 | **Allow** *Q* = *VC* and some explanation  **Examiner's Comments**  The success in this question relied on knowing that each capacitor in a series circuit stored the same charge. Failure to mention this important idea led to no marks. This question favoured the top-end candidates, who once again gave brief answers such as *‘the charge is the same on each capacitor and the p.d. is twice because V ∝ 1/C’*. Some candidates attempted to answer the question in terms of sharing p.d., but without mentioning the charge being the same for each capacitor. Weaker candidates often spoilt their answers by referring to the current being the same in a series capacitor, no doubt confusing the circuit with resistors in series. |
|  | b |  | (total resistance =) 27 (kΩ) or 27000 (Ω) | C1 |  |
|  |  |  | (total capacitance =) 100 (μF) or 1.0 × 10−4 (F)  (time constant =) 27 × 103 × 100 × 10−6 | C1 | **Allow** 10−4 (F) |
|  |  |  | time constant = 2.7 (s) | A1 | **Note** 2.7 × 10n with n ≠ 0 scores 2 marks  **Examiner's Comments**  The answers to this question were generally well-structured and easy to follow. Most candidates were familiar with the equations to determine the total resistance, total capacitance and time constant. Only a small number of candidates struggled with the prefixes kilo k and micro μ. The two most commons mistakes in the calculations were:   * total capacitance = 400 μF * total resistance = 18 + (18−1 + 18−1) = 18.1 kΩ |
|  | c | i | (V = )1.5 × 10−4 × 40 × 103 or 6 (V) (Q = ) 6.0 × 1200 × 10−6 | C1 | **Allow** I in the range 1.50 to 1.55 **Allow** other correct methods |
|  |  | i | charge = 7.2 × 10−3 (C) | A1 | Possible POT error   **Examiner's Comments**  This question proved to be both challenging and discriminating. The majority of the upper quartile candidates scored two marks for calculating the initial charge stored by the capacitor. Many of these candidates derived and used the equation ‘initial charge = I0RC’ or ‘initial charge = I0 × time constant’. A significant number of candidates got nowhere by using the exponential decay equation or determining the area under the curve. |
|  |  | ii | Current starts at 3.0 (× 10−4 A) | B1 | **Allow** ± 0.05 × 10− (A) |
|  |  | ii | Graph showing shorter time constant | B1 | **Examiner's Comments**  Although the modal mark for this question was one, the discharge curves were often poorly drawn. Most candidates did figure out that the time constant of the circuit was halved, but very few realised that the initial discharge current was 3.0 × 10−4 A. Candidates do need to improve their graph sketching skills. |
|  |  |  | **Total** | **9** |  |
| 9 |  |  | A | 1 |  |
|  |  |  | **Total** | **1** |  |
| 10 | a |  | Connect a voltmeter or data-logger or oscilloscope across the resistor (or capacitor) or an ammeter in series with the resistor. | B1 |  |
|  |  |  | A stopwatch is started when the switch is opened and stopped when the p.d. or the current to decreases to 37% of its initial value. | B1 |  |
|  |  |  | The time constant is the time taken for the p.d. or the current to decreases to 37% of its initial value. | B1 |  |
|  | b |  | series capacitors: *C* = (100−1 + 220−1)−1 = 68.75 (μF) | C1 |  |
|  |  |  | total capacitance = 500 + 68.75 = 568.75 (μF) | C1 |  |
|  |  |  | *E* = ½ × 122 × 568.75 × 10−6 | C1 |  |
|  |  |  | *E* = 4.1 × 10−2 (J) | A1 |  |
|  |  |  | **Total** | **7** |  |
| 11 |  | i | (time constant = 6.9 × 10−6 × 240) time constant = 1.7 × 10−3 (s) | B1 | **Note**: Answer to 3 sf 1.66 × 10−3 (s)   **Examiner's Comments**  Almost all candidates attempted this question, with most gaining a mark for the correct value for the time constant. There were fewer errors with powers of ten. Very few candidates calculated the total capacitance of the capacitors using the reciprocal equation. |
|  |  | ii | charge = 6.9 × 10−6 × 1.4 (= 9.66 × 10−6 C) | C1 | Possible ecf from **(b)(i)** for value of total capacitance |
|  |  | ii | (Δt = 1/120 = 0.0083 s) |  |  |
|  |  | ii | current = | C1 |  |
|  |  | ii | current = 1.2 × 10−3 (A) | A1 | **Note**: Answer to 3 sf 1.16 × 10−3 (A) **Allow**: 2 marks for 9.66 × 10−6 × 60 = 5.8 × 10−4 (A); Δt = 1/60 s used **Allow**: 2 marks for 9.66 × 10−6 × 240 = 2.3 × 10−3 (A); Δt = 1/240 s used   **Examiner's Comments**  This was an unfamiliar question and the success hinged on doing exactly what was stated in the second sentence of the question. A good number of candidates correctly calculated the total charge stored by the capacitors. In order to calculate the average current, this charge had to be divided by the time between each throws; 0.0083 s or simply 1/120 s. This is where many candidates slipped. They divided by time constant or half the time between each throws. Some candidates calculated the maximum power dissipated in the resistor or the maximum current in the 240 Ω resistor. About a quarter of the candidates, mainly in the upper quartile, gained full marks. |
|  |  | iii | The capacitors do not fully discharge (AW) | B1 |  |
|  |  | iii | Any one from:   * Period (of switching) is (halved to) 4.2 × 10−3 (s) (and this time is comparable to the time constant) * The time constant (of the circuit) and period of mechanical switch are comparable / similar | B1 | **Examiner's Comments**  Most candidates struggled here. Those who scored one mark did so for stating that the ‘capacitors cannot fully discharge’. |
|  |  |  | **Total** | **6** |  |
| 12 | a |  | Any suitable values with units, eg: 5 MΩ and 1 μF. | B1 | **Examiner's Comments**  All candidates had to do was to provide suitable values for the resistance and capacitance with appropriate units; this they did with great skill. Only a small number of candidates omitted either one or both units and lost this accessible mark. |
|  | b |  | The time taken for the p.d / current / charge to decrease to 1/*e* of its (initial) value. | B1 | **Allow** 37% instead of 1/*e*. **Not** time constant = *CR* on its own.  **Examiner's Comments**  There were missed opportunities with the definition of time constant of a capacitorresistor discharge circuit. The majority of candidates were aware of the 37% or e−1 ideas, but these were not integrated into their definitions. Answers such as *‘it is the time taken for the capacitor to discharge to 37%’* without any reference to current, charge or p.d, were quite common. Some even had the *‘capacitance decreases to 37% of its initial value’*. Examiners did not allow time constant = capacitance × resistance as a definition for time constant. |
|  | c | i | or R = 217 (Ω) | C1 | **Note** : An incorrect equation here for A prevents this and any subsequent marks. |
|  |  | i | time constant = 0.010 × 217 | C1 |  |
|  |  | i | time constant = 2.2 (s) | A1 | **Allow** 2 marks for 0.54 (s) - diameter of 0.12 mm used instead of radius 0.06 mm.   **Examiner's Comments**  Most candidates picked up two or more marks in this synoptic question. Most candidates correctly used the resistivity equation to first determine the resistance of the bundle of wire and then the time constant of 2.2 s for the circuit. A very small number of candidates used ρ = 8900 for the resistivity of the metal instead of ρ = 4.9 ×10−7 Ωm. This was taken as a monumental error of physics and prevented the candidates from picking up any marks in this question. |
|  |  | ii | Electrons are removed from **X** or electrons are deposited on **Y**. | B1 | **Allow** electrons move anticlockwise (in the circuit). |
|  |  | ii | **X** becomes positive or **Y** becomes negative | B1 | There is no ecf from the previous B1 mark. |
|  |  | ii | (The size of charge is the same because) an equal number of electrons are removed and deposited (on the plates). | B1 | **Examiner's Comments**  There was a good spread of marks, with many candidates scoring two or more marks. Most candidates did explain the charging of the two plates in terms of the flow of electrons in the circuit. Most candidates realised that the electrons would gather at plate **Y** giving it a negative charge. However, many could not adequately explain why the plates acquired equal but opposite charges. A significant number of candidates, mainly at the top-end, had no problems and gave superb answers in terms of equal number of electrons deposited and removed from the two plates. |
|  |  | iii | or E = 0.72 (J) | C1 |  |
|  |  | iii | m = 8900 × [π × (0.06 × 10−3)2 × 5.0] or 5.0(3) × 10−4(kg) | C1 | **Note** : An incorrect equation here for m or V prevents this and any subsequent marks. |
|  |  | iii | 5.03 × 10−4 × 420 × Δθ = 0.72 | C1 | Correct substitution into mcΔθ = 0.72; **allow** any subject. |
|  |  | iii | increase in temperature = 3.4 (°C) | A1 | **Note** : Do not penalise using diameter here again if already penalised in **(i)**.   **Examiner's Comments**  The majority of candidates scored full marks. Answers were well-structured and showed excellent synoptic knowledge of specific heat capacity. A significant number of candidates struggled when calculating the volume and hence the mass of the bundle of wire. Some candidates used to determine the volume of the wire. Such elementary errors are unjustifiable at this level. |
|  |  | iv | Energy or V2 increases by a factor of 4. | B1 | **Allow** the label E or W for energy. |
|  |  | iv | The (change in temperature) increases by a factor of 4 (because Δθ∝ E). | B1 | **Allow** Δθ = 13.6 (°C) for this B1 mark - possible ecf from **(iii)**.   **Examiner's Comments**  This question discriminated well with the majority of the candidates realising that the increase in the temperature would be four times greater. The explanations were often correct and elegantly presented in terms of energy ∝ p.d2 for the energy stored in the capacitor. A small cohort of candidates gave qualitative answers and took no account of the potential difference doubling. |
|  |  |  | **Total** | **14** |  |
| 13 |  | i | |  |  | | --- | --- | | **1** | 0.5 (C0) | | **2** | 2 (V0) | | **3** | 2 (E0) | | B1 B1 B1 | **Allow** ½  **Ignore working** No ecf  **Ignore working**  No ecf   **Examiner’s Comments**  Around two thirds of candidates were able to score all of these marks. Most showed some limited (but helpful) working, such as writing the equation for the parallel plate capacitor and C = Q/V, to assist them in appreciating how each of the factors change. For this question, there is a quite large amount of introductory text and the bold text is there as a supportive guide. The most common incorrect responses were a simple reversal of the correct responses. |
|  |  | ii | Work done against attractive forces | B1 | **Allow** WD for work done   **Examiner’s Comments**  This proved to be a challenging question and only the higher end candidates were able to give a clear and correct response. The question stated, “in terms of forces” and most candidates did not explain the idea of attraction between the plates. Common incorrect responses included using E = ½ QV or using W = F × d as a starting point. |
|  |  |  | **Total** | **4** |  |
| 14 |  |  | time taken for current (**or** charge **or** voltage) to fall to 1/e of its initial value | B1 | **Not** capacitance **Not** to fall by (a factor of) 1/e **Allow** to decrease to 37% of its initial value **Allow** to decrease by 63% **Ignore** time constant = *CR*  **Examiner’s Comments**  To find the time constant of a capacitor, we look at the time taken for the charge on a discharging capacitor to fall from any initial value to 37% (1/*e*) of that value. We could also take values of current or voltage. However, it is not the time taken for the capacitance to fall from *Co* to *Co*/*e* – the capacitance remains constant.  Care is needed with wording here. Either the charge falls to 37% of its initial value, or it falls by 63% from its initial value.     |  |  | | --- | --- | |  | **Misconception** |   Capacitance × resistance is not the definition of the time constant; it is one way of calculating the time constant if the values of capacitance and resistance are known. |
|  |  |  | **Total** | **1** |  |
| 15 |  | i | Evidence of use of V = V0 e−t/CR leading to ln (½) = −T/CR or ln2 = T/CR    T = Cln2 × R compared with y = mx with gradient = Cln2 | M1 A1 | **Must** see exponential decay as starting point (allow Q for V) **Allow** t for T **Allow** x for V and x0 for V0  **Not** T/R = gradient   **Examiner’s Comments**  The treatment of natural logs was generally well done across the ability range and those who started from a correct exponential equation were generally able to score the first mark. There was some confusion among the less successful responses about the role of the negative sign, without them appreciating that ln(2) = − ln (½) and it was evident that some simply ignored it. Although many candidates were able to get to the correct equation, few linked it appropriately to the equation of a straight line and did not show that the gradient was Cln2, as required. Exemplar 3 shows a candidate producing elegant solution.    A response that works through the logs clearly and then relates it well to the form of y = mx + c. |
|  |  | ii | |  |  | | --- | --- | | **1** | Best-fit line drawn correctly  gradient = 5.4 (× 10−9)  C = (gradient / ln2) = 7.8 × 10−9 (F) | | **2** | 7.8 × 10−9 =   ε = 2.0 × 10−11 (Fm−1) | | B1 B1 B1 C1 A1 | **Note** line must pass through all (vertical part of) error-bars. If more than one line drawn, all lines must pass through all error-bars (1/2 square tolerance).  **Allow** ± 0.2 (× 10−9) **Ignore** POT  **Ecf** from incorrect gradient, but penalise POT error here  Possible ECF from **(b)(ii)1**    **Allow** 1 mark if final answer is relative permittivity correctly calculated (ε divided by 8.85 x× 10−12)   **Examiner’s Comments**  In part 1, nearly all the candidates were able to draw a correct straight best-fit line which passed through all the error bars. It was actually rather difficult not to do this, although several candidates did multiple lines (assuming they were unable to remove an original) and if any fell outside of the error bars, then it could not be given marks. In calculating the gradient, misreads from the graph were common either from the vertical scale or often assuming that the horizontal scale started from zero. A common mistake among the range of abilities was to miss out the 106 in the denominator of the gradient. Several candidates may have interpreted the question as meaning that the gradient was C, as they calculated the gradient but took it no further.  Part 2 was generally well done by many candidates. Some of the less successful responses were unable to rearrange the capacitance equation correctly, often swapping over the d and A values. A small proportion calculated the relative permittivity and as long as this was done correctly, it could score the first mark. A common error was to attempt to use C = 4πεr which proved to be unproductive.     |  |  | | --- | --- | |  | **Assessment for learning** |   Good practice for straight best-fit lines includes:   * A single straight line – not a line drawn in two or more parts. * Use of a sharp pencil – once a line is drawn in pen, it is almost impossible to correct. * Aiming to have an equal number of data points above and below the line – not always possible due to potential variations in data, but this should be a general aim. * Looking for anomalous points – should not form part of the best-fit. * Being aware of a false origin – if present then the line should not necessarily be expected to go through this point. * Drawing a line through the origin – would (0,0) be expected to be a data point, and consideration of a potential systematic error in the data. * Use of error bars – if present (generally in the dependent data), then the line must pass through the vertical error bars on every point. |
|  |  |  | **Total** | **7** |  |
| 16 | a |  | (CR =) 2000 × 10-6 × 120 × 103  1.00 = 1.48 × [1 – e-t/240] **or** 0.48 = 1.48e-t/240  (t =) - 240 × ln(0.48/1.48)  t = 270 (s) | C1  C1  C1  A1 | CR = 240 (s)   Special case: 94 (s) for use of discharging equation. Max 2 marks  **Examiner’s Comments**  This question comes from the learning outcome 6.1.3(c) in the use of an equation in a capacitor-resistor circuit. Candidates are required to determine the time at which a potential difference is met, which involves the use of logarithms. It was noted that many candidates were confident in their use of logarithms and were able to make some progress through their solution. Most candidates calculated the time constant correctly, taking into account the unit prefixes, and substituted this into an equation. However a large proportion used the discharging (rather than the charging) equation to calculate the time and some credit could be allowed for this. Less than one fifth of candidates scored all marks on this question.     |  |  | | --- | --- | |  | **Misconception** |   Many candidates seemed uncertain which equation to use, applying the simpler discharging equation. While the charging and discharging equations are given in the data booklet, it is not stated which is which, so candidates must make sure they know which to apply. |
|  | b |  | Line of best fit drawn through the data points  Gradient = 38  (Ckln2 = gradient)  1.2 × 10-3 × k × ln2 = 38  k = 4.6 × 104 (Ω m-1) | B1  C1  C1  A1 | Allow ± 2. Not calculated through use of a single point.   Possible ECF from incorrect gradient  **Note**: gradient of 40 gives 4.8 × 104 and gradient of 36 gives 4.3 × 104  **Examiner’s Comments**  This question is likely to be an unfamiliar scenario to many candidates and so required some careful reading. The first mark is for a single straight line of best fit; many candidates simply joined up the first and last point, which produced a line that did not produce an even distribution of points above and below. The gradient calculation was well done by most candidates, leading to a value within the tolerance. Although the given equation is likely to be unknown, most candidates were able to appreciate how to determine the value of k and did so successfully. Over half of the candidates were able to achieve full marks on this question. |
|  |  |  | **Total** | **8** |  |
| 17 |  |  | C | 1 | **Examiner’s Comments**  The correct response is **C**. Although this question may not have followed the traditional route for a capacitor decay, it proved to be accessible to many candidates. Several filled in the table completely which appeared to be a helpful strategy, or set up stages of the calculation alongside the question. Those that showed little or no working tended to opt for response **A** using a constant subtraction for each time interval. |
|  |  |  | **Total** | **1** |  |