inkPhysics

ANSWER BOOK

Capacitors and energy stored

Capacitance · Year 13

AQA 3.7.4.1, 3.7.4.2, 3.7.4.3 · CIE 19.1.1, 19.1.2, 19.1.3, 19.1.4, 19.2.1, 19.2.2
OCR A 6.1.1(a), 6.1.1(c), 6.1.1(d), 6.1.1(e)(i), 6.1.2(a), 6.1.2(b), 6.1.2(c), 6.2.3(b)

19 questions · 56 marks

NAVY EDITION

SECTION A · Warm-up

A1 Charge stored per unit potential difference, $C = Q/V$ (1); unit: farad (F), equal to one coulomb per volt (1). [2]

A2 $C = Q/V = (6.0 \times 10^{-3})/12$ (1)
$C = 5.0 \times 10^{-4}$ F (500 μF) (1) [2]

A3 $E = \frac{1}{2}QV$ (1); $E = \frac{1}{2}CV^2$ (1); $E = \frac{1}{2}Q^2/C$ (1). [3]

A4 The capacitance of the capacitor, since the gradient is $Q/V = C$ (1). [1]

A5 $C = Q/V = 0.36/1800$ (1)
$C = 2.0 \times 10^{-4}$ F (200 μF) (1) [2]

A6 $V = Q/C = (4.0 \times 10^{-3})/(50 \times 10^{-6})$ (1)
$V = 80$ V (1) [2]

SECTION B · Standard

B1 $Q = CV = 100 \times 10^{-6} \times 20 = 2.0 \times 10^{-3}$ C (1)
$E = \frac{1}{2}CV^2 = \frac{1}{2} \times 100 \times 10^{-6} \times 20^2$ (1)
$E = 0.020$ J (1) [3]

B2 $E = \frac{1}{2}QV = \frac{1}{2} \times 5.0 \times 10^{-3} \times 8.0$ (1)
$E = 0.020$ J (1) [2]

B3 $C = \varepsilon_0 A/d = (8.85 \times 10^{-12} \times 0.020)/(1.0 \times 10^{-3})$ (1)
$C = 1.77 \times 10^{-10}$ F (177 pF) (1) [2]

B4 $Q = CV = 470 \times 10^{-6} \times 9.0 = 4.23 \times 10^{-3}$ C (1)
$E = \frac{1}{2}CV^2 = \frac{1}{2} \times 470 \times 10^{-6} \times 9.0^2$ (1)
$E = 0.019$ J (1) [3]

B5 $A = 4.0 \times 10^{-4}$ m^2 and $d = 1.0 \times 10^{-4}$ m (1)
$C = \varepsilon_0 \varepsilon_r A/d = (8.85 \times 10^{-12} \times 5.0 \times 4.0 \times 10^{-4})/(1.0 \times 10^{-4})$ (1)
$C = 1.77 \times 10^{-10}$ F (177 pF) (1) [3]

B6 The gradient is $V/Q = 1/C$, so $C = Q/V = (3.6 \times 10^{-3})/12$ (1) [4]
$C = 3.0 \times 10^{-4}$ F (300 μF) (1)
Energy = area under the line = $\frac{1}{2}QV = \frac{1}{2} \times 3.6 \times 10^{-3} \times 12$ (1)
$E = 0.022$ J (1)

B7 $E = \frac{1}{2}CV^2 = \frac{1}{2} \times 1500 \times 10^{-6} \times 6.0^2$ (1) [3]
$E = 0.027$ J = 27 mJ (1)
$P = E/t = 0.027/0.30 = 0.090$ W (1)

SECTION C · Stretch

C1 $C = \varepsilon_0\varepsilon_r A/d$, so C increases by a factor of 4.0 (1) [3]
$C = 4.0 \times 177 = 708$ pF (1)
At fixed V, $E = \frac{1}{2}CV^2$, so the energy stored also increases by a factor of 4.0 (1).

C2 $E = \frac{1}{2}Q^2/C = \frac{1}{2} \times (3.3 \times 10^{-3})^2/(220 \times 10^{-6})$ (1) [4]
$E = 0.0247$ J (1)
$V = Q/C = (3.3 \times 10^{-3})/(220 \times 10^{-6})$ (1)
$V = 15$ V (1)

C3 The polar molecules rotate to align with the electric field between the plates (1); the aligned molecules produce a field that opposes the applied field, reducing the net field and hence the potential difference for a given charge (1); since $C = Q/V$, more charge is stored per volt, so the capacitance increases (1). [3]

C4 Use of $E = \frac{1}{2}CV^2$ at the maximum rated pd (1) [4]
$E_P = \frac{1}{2} \times 0.10 \times 6.3^2 = 1.98$ J (1)
$E_Q = \frac{1}{2} \times 0.022 \times 16^2 = 2.82$ J (1)
Only Q stores more than 2.5 J; P falls short, so the designer should choose Q (1).

C5 $C = \varepsilon_0\varepsilon_r A/d$, so removing the dielectric reduces the capacitance by a factor of 2.5 (1). The charge is unchanged: the capacitor is disconnected, so there is no path for charge to leave the plates (1). $V = Q/C$, so the pd increases by a factor of 2.5 (1). $E = \frac{1}{2}Q^2/C$ increases by a factor of 2.5; the extra energy is the work done against the attraction of the plates in withdrawing the sheet (1). [4]

C6 The first charge transferred arrives when the capacitor pd is (almost) zero, so it needs (almost) no work (1); as charge builds up the pd rises (in proportion, since $V = Q/C$), so each successive amount of charge is moved through a larger pd (1); the average pd during charging is $V/2$, so the energy stored is $Q \times V/2 = \frac{1}{2}QV$, the area under the graph of pd against charge (1). The capacitor can release its whole store in a very short time (about a millisecond) (1); this gives a very large power, $P = E/t$, far greater than the battery could deliver directly (1); the battery instead recharges the capacitor slowly at low power between flashes (1). [6]