

Kirchhoff's rules and RC transients

AP Physics C (Mechanics and E&M, calculus-based) · Test answers (mark scheme)

Award marks as shown. Accept answers within rounding, and carry forward an earlier slip without penalising it twice. Take off a mark once if a final answer has no unit.

Level: AP Physics C (Mechanics and E&M, calculus-based) · **Curriculum:** AP PC:E&M Unit 11

Question 1 Kirchhoff's rules (2 marks)

(a) The junction rule expresses conservation of electric charge: charge cannot accumulate at a junction in steady state. (b) The loop rule expresses conservation of energy: the net change in potential around a closed loop is zero.

Marking: 1 mark for each correct principle.

Question 2 Battery and load (2 marks)

$$I = \varepsilon / (R + r) = 15 / 5.0 = \mathbf{3.0\ A}. \quad V = \varepsilon - Ir = 15 - 3.0 = \mathbf{12\ V}.$$

Marking: 1 mark for the current; 1 mark for the terminal voltage.

Question 3 Charging a capacitor (3 marks)

$$(a) \tau = RC = (5.0 \times 10^4)(20 \times 10^{-6}) = \mathbf{1.0\ s}.$$

$$(b) V_c = 10(1 - e^{-2}) = \mathbf{8.6\ V}.$$

$$(c) I = (10 / 5.0 \times 10^4)e^{-2} = (2.0 \times 10^{-4})(0.1353) = \mathbf{27\ \mu A}.$$

Marking: 1 mark each part.

Question 4 Discharge time (3 marks)

$$\tau = (1.0 \times 10^3)(470 \times 10^{-6}) = 0.47\ \text{s}. \quad 4.0 = 12e^{-t/\tau} \text{ gives } t = \tau \ln 3 = (0.47)(1.0986) = \mathbf{0.52\ s}.$$

Marking: 1 mark for τ ; 1 mark for the equation; 1 mark for the answer with unit.

Question 5 Limits in time (2 marks)

At $t = 0$ it has no voltage across it, so it acts like a wire and the current is ε/R . After a long time its voltage equals ε , so the current is zero and it behaves like an open circuit.

Marking: 1 mark for each limit.

Question 6 Derive the equation (3 marks)

Loop rule: $\varepsilon - R(dq/dt) - q/C = 0$. With $q = C\varepsilon(1 - e^{-t/RC})$, $dq/dt = (\varepsilon/R)e^{-t/RC}$, so $R(dq/dt) + q/C = \varepsilon e^{-t/RC} + \varepsilon(1 - e^{-t/RC}) = \varepsilon$, which satisfies the equation.

Marking: 1 mark for the equation; 1 mark for the derivative; 1 mark for the substitution.

Question 7 Energy balance (3 marks)

Battery: $C\varepsilon^2 = (100 \times 10^{-6})(36) = \mathbf{3.6 \text{ mJ}}$. Stored: $\frac{1}{2}C\varepsilon^2 = \mathbf{1.8 \text{ mJ}}$. Dissipated: $3.6 - 1.8 = \mathbf{1.8 \text{ mJ}}$.

Marking: 1 mark for each energy.

Question 8 Sketching the current (2 marks)

The sketch is a decaying exponential from $I_0 = V_0/R$ at $t = 0$, concave up, approaching zero. At $t = \tau$ the current is marked at $0.37 I_0$, where $I_0 e^{-1} = \mathbf{0.37 I_0}$.

Marking: 1 mark for the shape and intercept; 1 mark for τ marked at 37 %.