Exercise walk-through

19.1
Capacitors and capacitance

A-Level Physics

Sheet 19.1 – what you need to know

You must be able to:

- define capacitance and use $C = Q/V$
- derive and use the series and parallel rules
- reduce a network; share charge between capacitors

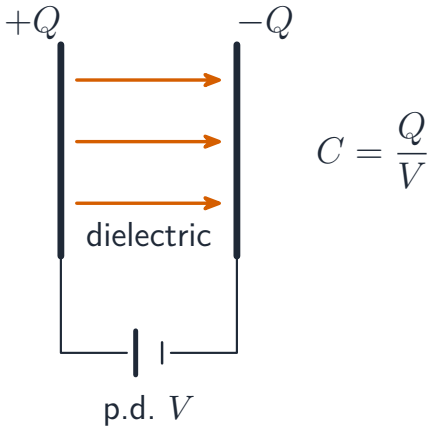
What the exam asks

"Complete Table 6.1 to indicate how Q_S, Q_1 and Q_2 relate to each other, and how V_S, V_1 and V_2 relate." **[4]**

"Complete Table 7.1 to show expressions, in terms of Q and V, for the final p.d.s across, and the final charges on, the two capacitors." **[3]**

"Sketch the variation of the total energy E stored in the capacitors with C_Q." **[2]**

What a capacitor does



$$C = \frac{Q}{V}$$

A **capacitor** stores charge: two **conductor** plates with an **insulator** between them – a **dielectric**, or just a **vacuum** – with a **potential difference** V across the gap.

- connected to a battery, $+Q$ builds on one plate, $-Q$ on the other

The two charges are equal and opposite – the capacitor stores charge separation, not net charge.

Capacitance $C = Q/V$

$$C = \frac{Q}{V}, \qquad [C] = \mathrm{F} = \mathrm{C\,V^{-1}}$$

- set by size and dielectric, so C is constant
- double Q and V doubles too – the ratio holds
- an isolated sphere: $C = 4\pi\varepsilon_0 r$

> A farad is huge – real capacitors run from pF to mF.



Worked example – charge stored

A $100\,\mu\mathrm{F}$ capacitor is charged to $12\,\mathrm{V}$. Find the charge stored.

$$Q = CV = (100 \times 10^{-6})(12)$$
$$= 1.2 \times 10^{-3}\,\mathrm{C} = 1.2\,\mathrm{mC}$$

Put the μF in as $\times 10^{-6}\,\mathrm{F}$. A stored mC is a lot of separated charge for such a small device.

Parallel: the charges add

Same p.d. V across each, so the charges sum:

$$C_{\text{parallel}} = C_1 + C_2 + \dots$$

A parallel bank has larger capacitance than any one.

> More plate area $\Rightarrow$ more room for charge – adding in parallel is like widening the plates.

Exercises 2.1·2.3

2.1 Define **capacitance**. [1]

2.2 State the **unit** of capacitance. [1]

2.3 A capacitor holds 60 μC of charge at 12 V. Find its **capacitance**. [2]

Exercises 2.1–2.3

2.1 Define **capacitance**. [1]

2.1

- the **charge stored per unit potential difference** ($C = Q/V$)

2.2 State the **unit** of capacitance. [1]

2.2

- the **farad** (F)

2.3 A capacitor holds 60 μC of charge at 12 V. Find its **capacitance**. [2]

2.3

- $C = Q/V$

$$C = \frac{Q}{V} = \frac{60 \times 10^{-6}\ \text{C}}{12\ \text{V}} = \mathbf{5.0}\ \mu\text{F}$$

Exercises 2.4·3.1

2.4 Write the formula for capacitors in **parallel**. [1]

3.1 The unit of capacitance is the: [1]

- [ ] **A** coulomb
- [ ] **B** farad
- [ ] **C** volt
- [ ] **D** ohm

Exercises 2.4·3.1

2.4 Write the formula for capacitors in **parallel**. [1]

2.4

- $C = C_1 + C_2 + \ldots$

3.1 The unit of capacitance is the: [1]

- ☐ **A** coulomb
- **B** farad
- **C** volt
- **D** ohm

3.1 B

- the SI unit of capacitance is the **farad**

Exercises 3.2·3.3

3.2 A 100 μF capacitor is charged to 9.0 V. Calculate the **charge** stored. [2]

3.3 A 4.0 μF and a 2.0 μF capacitor are connected in **series**. Calculate the combined capacitance. [3]

Exercises 3.2·3.3

3.2 A 100 μF capacitor is charged to 9.0 V. Calculate the **charge** stored. [2]

3.2

- $Q = CV$

$$Q = CV = (100 \times 10^{-6}\ \text{F})(9.0\ \text{V}) = \mathbf{9.0 \times 10^{-4}}\ \text{C}$$

3.3 A 4.0 μF and a 2.0 μF capacitor are connected in **series**. Calculate the combined capacitance. [3]

3.3

- series: $1/C = 1/C_1 + 1/C_2$

$$\frac{1}{C} = \frac{1}{4.0\ \mu\text{F}} + \frac{1}{2.0\ \mu\text{F}} = \frac{3}{4.0\ \mu\text{F}}$$

- $C = \mathbf{1.3}\ \mu$F

Exercise 3.4

3.4 Write the formula for capacitors in **series**. [1]

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3.4

- $1/C = 1/C_1 + 1/C_2 + \ldots$

Exercise 3.5 (a)

3.5 Three capacitors are available: $C_1 = 120\ \mu\text{F}$, $C_2 = 180\ \mu\text{F}$ and $C_3 = 220\ \mu\text{F}$.

(a) C_1 and C_2 are connected in **series** across a supply. **Complete** the table to show how the charge on each and the p.d. across each relate to the total charge Q_S and the supply p.d. V_S. [2]

quantity	**relationship**
charges Q_1, Q_2 and Q_S	_____
p.d.s V_1, V_2 and V_S	_____

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quantity	**relationship**
charges Q_1, Q_2 and Q_S	_____
p.d.s V_1, V_2 and V_S	_____

(a) charges: $Q_1 = Q_2 = Q_\text{S}$ – the same charge passes through every capacitor in a series chain

- p.d.s: $V_1 + V_2 = V_\text{S}$

Exercise 3.5 (b)

3.5 Three capacitors are available: $C_1 = 120\ \mu\text{F}$, $C_2 = 180\ \mu\text{F}$ and $C_3 = 220\ \mu\text{F}$.

(b) **Determine** the combined capacitance of C_1 and C_2 in series. [2]

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(b) **Determine** the combined capacitance of C_1 and C_2 in series. [2]

(b) in series, $\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2}$

$$C = \frac{C_1 C_2}{C_1 + C_2} = \frac{(120\ \mu\text{F})(180\ \mu\text{F})}{300\ \mu\text{F}} = \mathbf{72}\ \mu\text{F}$$

Exercise 3.5 (c)

3.5 Three capacitors are available: $C_1 = 120\ \mu\text{F}$, $C_2 = 180\ \mu\text{F}$ and $C_3 = 220\ \mu\text{F}$.

(c) The supply provides 12 V. **Calculate** the charge stored by that series combination, and the p.d. across C_1. [3]

Exercise 3.5 (c)

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(c) The supply provides 12 V. **Calculate** the charge stored by that series combination, and the p.d. across C_1. [3]

(c) $Q = CV$

$$Q = CV = (72 \times 10^{-6}\ \text{F})(12\ \text{V}) = \mathbf{8.6 \times 10^{-4}}\ \text{C}$$

$$V_1 = \frac{Q}{C_1} = \frac{8.64 \times 10^{-4}\ \text{C}}{120 \times 10^{-6}\ \text{F}} = \mathbf{7.2}\ \text{V}$$

- the **smaller** capacitor takes the larger share of the p.d.

Exercise 3.5 (d)

3.5 Three capacitors are available: $C_1 = 120\ \mu\text{F}$, $C_2 = 180\ \mu\text{F}$ and $C_3 = 220\ \mu\text{F}$.

(d) C_3 is now connected in **parallel** with the series pair. **Determine** the total capacitance of the whole network, and the total charge it now stores at 12 V. [3]

Exercise 3.5 (d)

3.5 Three capacitors are available: $C_1 = 120\ \mu\text{F}$, $C_2 = 180\ \mu\text{F}$ and $C_3 = 220\ \mu\text{F}$.

(d) C_3 is now connected in **parallel** with the series pair. **Determine** the total capacitance of the whole network, and the total charge it now stores at 12 V. [3]

(d) capacitors in parallel add: $C_{\text{total}} = C_1 + C_2 = 72\ \mu\text{F} + 220\ \mu\text{F} = \mathbf{292}\ \mu\text{F}$

$$Q_{\text{total}} = C_{\text{total}} V = (292 \times 10^{-6}\ \text{F})(12\ \text{V}) = \mathbf{3.5 \times 10^{-3}}\ \text{C}$$

Exercise 3.5 (e)

3.5 Three capacitors are available: $C_1 = 120\ \mu\text{F}$, $C_2 = 180\ \mu\text{F}$ and $C_3 = 220\ \mu\text{F}$.

(e) **State and explain** which single capacitor in the network stores the **most** charge. [2]

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(e) **State and explain** which single capacitor in the network stores the **most** charge. [2]

(e) C_3

- it has the full 12 V across it and the largest capacitance, so $Q = CV$ is largest; the series pair shares the same p.d. and behaves as only 72 μF