Starter

2014 Revised Higher Physics

Scan the code and answer these:

Q15 **Q17** **Q20**

Section A · a.c., circuits, uncertainty

Show your working, not just the letter.

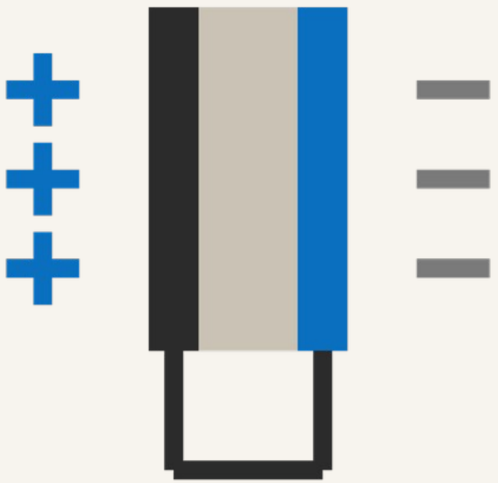
Scan for the paper

Marking scheme

ELECTRICITY 4 · CAPACITORS

Capacitors

Two plates and an insulator — and a store of charge that can empty in a flash.



Higher Physics

PART 1

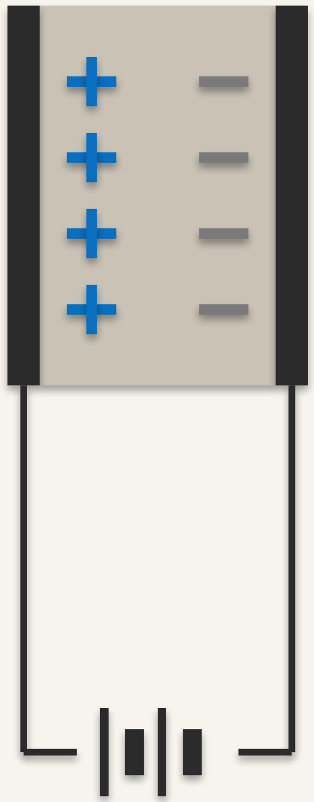
What a capacitor is

Two plates, an insulator, and a store of charge.

By the end of this part...

1. I can state what a capacitor is made of, and what it stores.
2. I can state what a capacitance of $1\ \mathrm{farad}$ means.
3. I can use $C = Q/V$ to find charge, p.d. or capacitance.

What a capacitor is



- Two parallel plates, separated by an insulator.
- Connect it to a supply and electrons shift from one plate to the other.
- Equal and opposite charge builds up on the plates.
- That separation stores energy in the electric field.

What changes the capacitance

Beyond the examined content — but it is how a capacitor is designed.

Plate area

More area, more charge for the same p.d.

Plate spacing

Closer plates hold more charge.

The dielectric

The insulator changes how much is held.

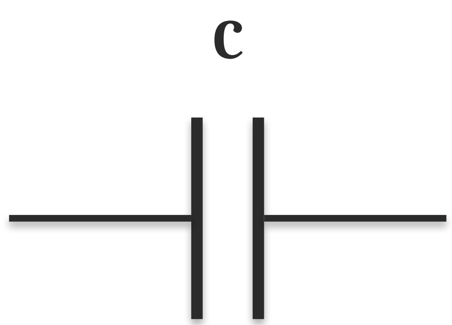
JOTTER NOTES

Capacitors

Two plates separated by an insulator.

Stores equal and opposite charge on the plates.

Energy is stored in the field between them.



Capacitance

JOTTER NOTES

How much charge a capacitor holds for every volt across it.

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

C	**Q**	**V**
capacitance in farads (F)	charge in coulombs (C)	p.d. in volts (V)

A 1 farad capacitor stores 1 coulomb for every 1 volt — so 1 F is enormous, and real ones are marked in μF or nF.

Worked example

A capacitor stores 36 μC of charge when the p.d. across it is 9·0 V. Calculate the capacitance of the capacitor.

$Q = 36 \times 10^{-6}$ C

$V = 9{\cdot}0$ V

$C = ?$

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

$$C = \frac{36 \times 10^{-6}}{9.0}$$

$\underline{C = 4{\cdot}0 \times 10^{-6}\ \text{F}}$

Show Me: capacitance

SHOW ME BOARDS

1. A capacitor stores $2{\cdot}4\ \mathrm{mC}$ at $6{\cdot}0\ \mathrm{V}$. Show that its capacitance is $400\ \mu\mathrm{F}$.
2. State what is meant by a capacitance of $4{\cdot}7\ \mu\mathrm{F}$.
3. A $2{\cdot}2\ \mu\mathrm{F}$ capacitor is charged until it stores $55\ \mu\mathrm{C}$. Calculate the p.d. across it.
4. The p.d. across a capacitor is doubled. State and justify the effect on the charge stored.
5. A $47\ \mu\mathrm{F}$ capacitor holds $2{\cdot}0 \times 10^{-3}\ \mathrm{C}$. Calculate the p.d., to the correct number of significant figures.

Show Me: capacitance

SHOW ME BOARDS

EXTRA PRACTICE

1. A capacitor stores $96\ \mu C$ at $12\ V$. Calculate its capacitance in μF.
2. A $220\ \mu F$ capacitor is charged to $15\ V$. Calculate the charge stored.
3. Sketch the graph of charge against p.d. for a capacitor, and state what its gradient gives.
4. A capacitor at $8{\cdot}0\ V$ stores $36\ \mu C$. Calculate the extra charge stored when the p.d. rises to $12\ V$.
5. Explain why a capacitor marked $1\ F$ would be unusual in the lab.

Task

Work through the capacitance questions. Show the relationship, the substitution and the unit every time.

Leckie and Leckie Exercise 4.1.2 (p324)
Past papers: 2025 Paper 2 Q12(b)

Past Paper Finder

Starter

2011 Higher Physics

Scan the code and answer these:

Q11 Q12 Q13

Section A · a.c., r.m.s., uncertainty

Show your working, not just the letter.

Scan for the paper

No marking scheme

PART 2

Charging and discharging

What the current and the p.d. do while it fills and empties.

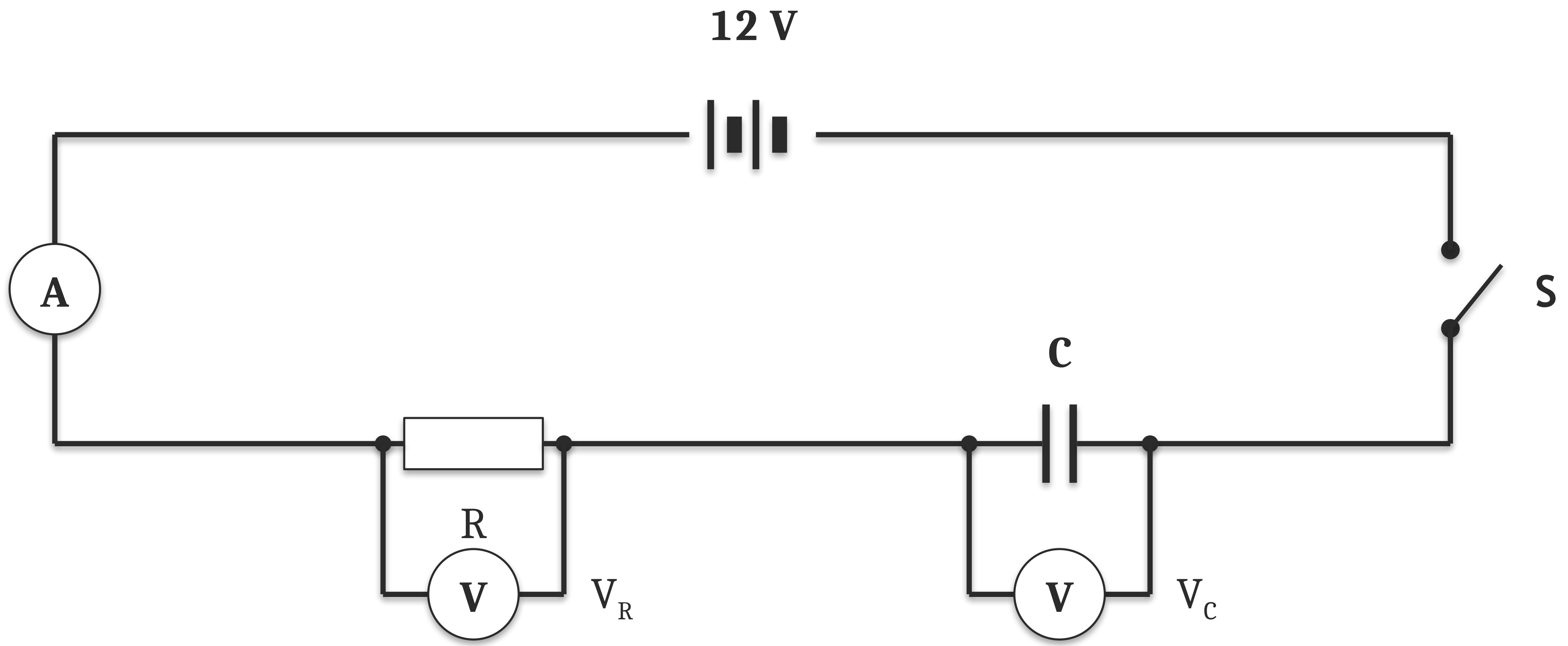
By the end of this part...

1. I can describe what I and V_c do as a capacitor charges.
2. I can sketch the charging and discharging curves for both.
3. I can describe the experiment used to investigate them.

The charging circuit

JOTTER NOTES

A capacitor, a resistor, a supply and a switch — an RC circuit.



What happens as it charges

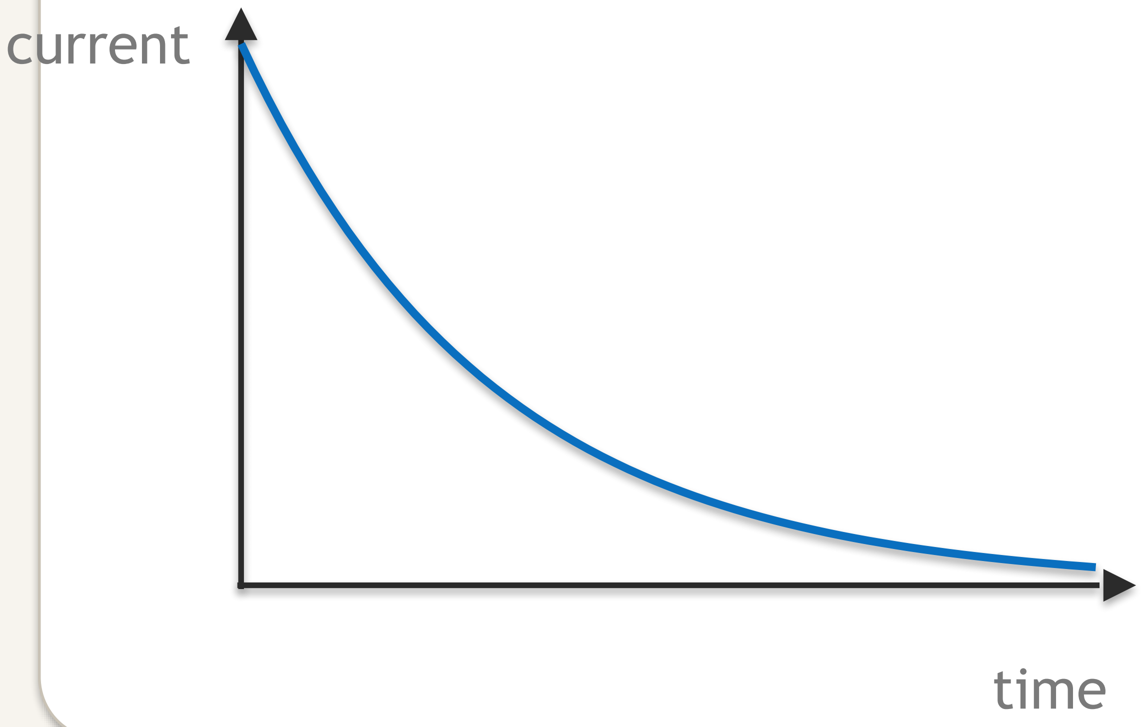
Stage	V_C	V_R	Current
Switch just closed	0 V	supply	maximum
While charging	rising	falling	falling
Fully charged	supply	0 V	zero

At every instant $V_R + V_C$ adds up to the supply voltage.

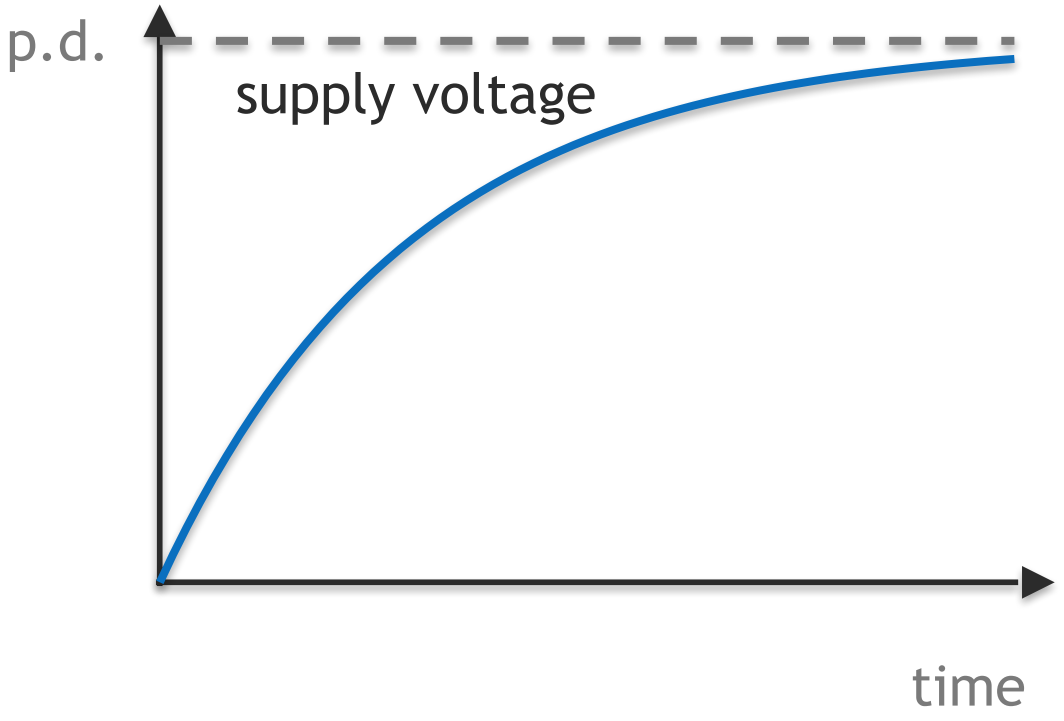
Charging curves

JOTTER NOTES

Current against time



p.d. across the capacitor



JOTTER NOTES

Charging a capacitor

Current: maximum, then falls to zero.

V_C: rises from zero to the supply.

V_R: falls from the supply to zero.

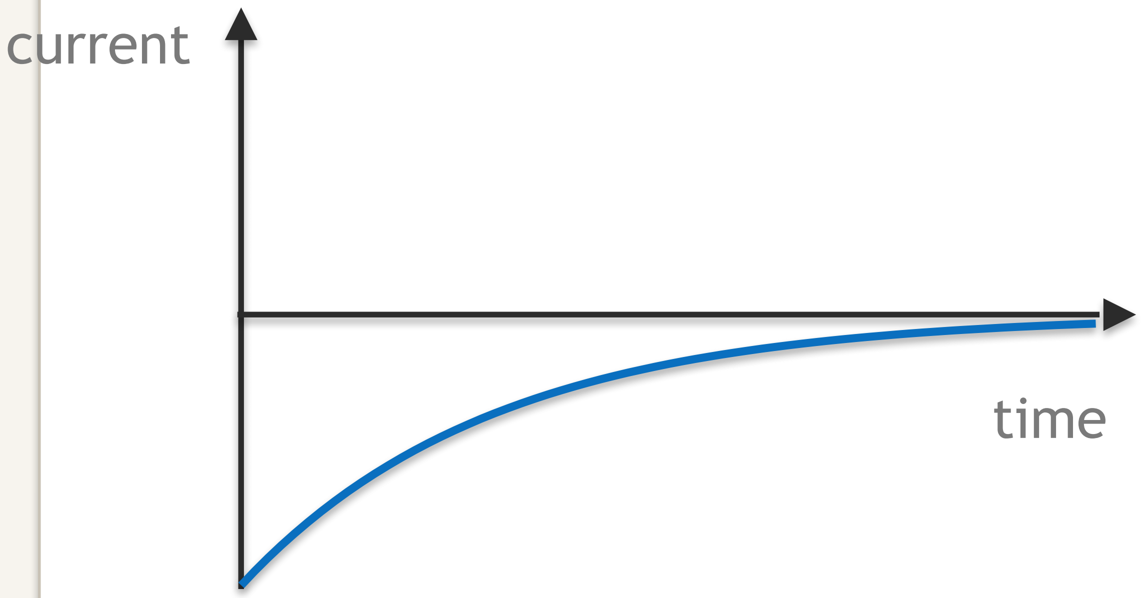
Always: $V_R + V_C$ = supply voltage.

Fully charged when I reaches zero.

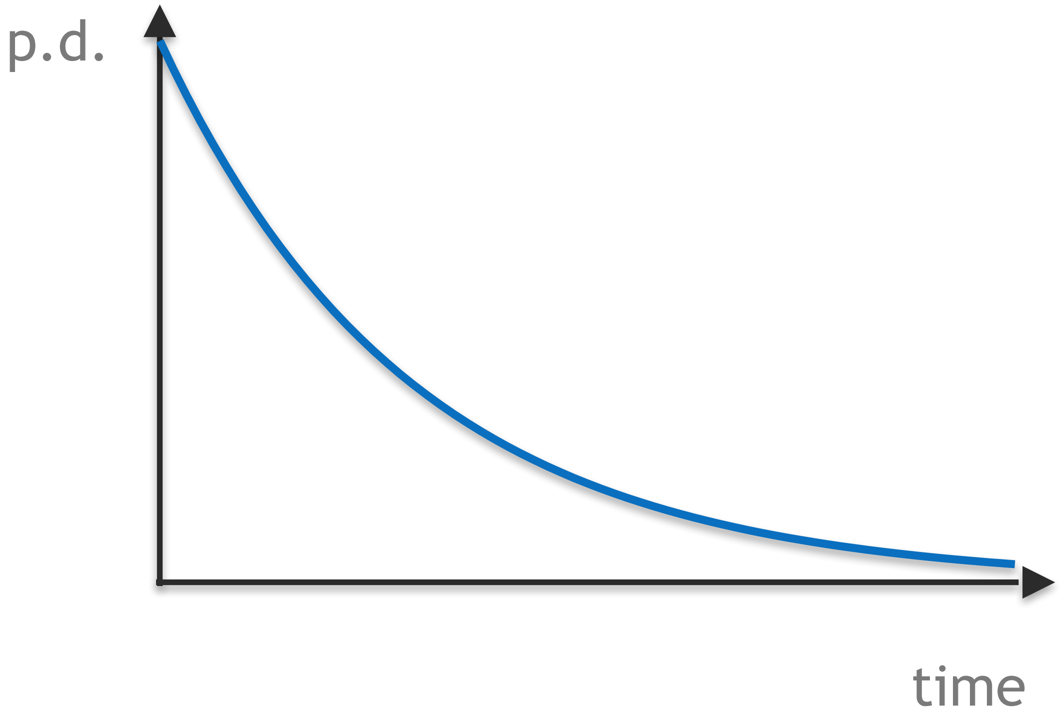
Discharging curves

JOTTER NOTES

Current against time



p.d. across the capacitor



JOTTER NOTES

Discharging a capacitor

The capacitor drives the current now.

Current: below the axis, dies to zero.

V_c: falls from the supply to zero.

Both graphs are decay curves.

Area under I-t = charge moved.

Watch Out: which graph is which

THE MISTAKE

- "The current rises as the capacitor charges."
- The p.d. and the current drawn rising together.
- Discharge current drawn like the charging one.

THE CORRECT ANSWER

- Charging current starts at its maximum and falls to zero.
- As V_C rises, V_R falls — so the current falls.
- It flows the other way — below the axis.

Show Me: the curves

SHOW ME BOARDS

1. Sketch the I-t and V_C-t graphs for a capacitor charging in an RC circuit.
2. A $12\ V$ supply, switch just closed: state V_R and V_C. Fully charged: state them again.
3. Explain, in terms of V_R, why the charging current falls to zero.
4. The supply p.d. is doubled. State and justify the effect on the initial charging current.
5. State what the area under an I-t graph represents, and give its unit.

Show Me: the curves

SHOW ME BOARDS

EXTRA PRACTICE

1. Sketch the I-t and V_C-t graphs for a capacitor discharging through a resistor.
2. Explain why the discharge current is drawn below the time axis.
3. A capacitor charged to $9{\cdot}0\ V$ discharges through a lamp. State V_C once the lamp has gone out.
4. State how the electron flow during discharge compares with charging.
5. While charging, $V_C = 5{\cdot}0\ V$ when $V_R = 7{\cdot}0\ V$. Calculate the supply voltage.

Experiments

Carry out the three capacitor experiments. Record your readings in a table before you plot anything.

Experiments 4.1.3a, 4.1.3b, 4.1.3c (p325 / p338)

Scan for the sheet

Homework

Complete the multiple-choice questions.
Hand in at the start of the next period.

1997 Paper 1 Q13-19

Scan for the paper

Starter

2014 Higher Physics

Scan the code and answer these:

Q27(a)

Section B · 6 marks

Show your working, not just the letter.

Scan for the paper

Marking scheme

PART 3

Charging rates

Same shape of curve every time — so what changes how long it takes?

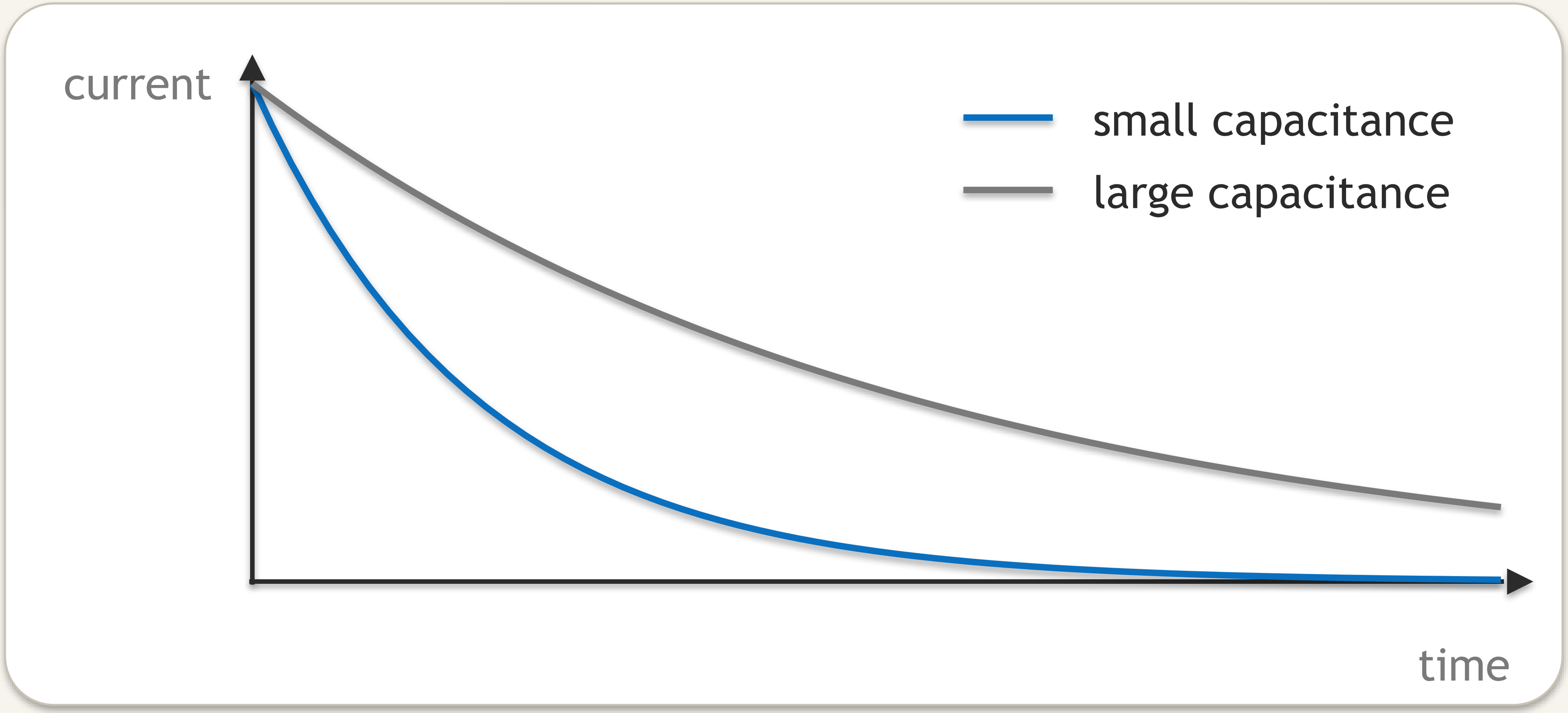
By the end of this part...

1. I can state and justify how R changes the charging time.
2. I can state and justify how C changes the charging time.
3. I can explain what the area under an I-t graph represents.

The effect of capacitance

JOTTER NOTES

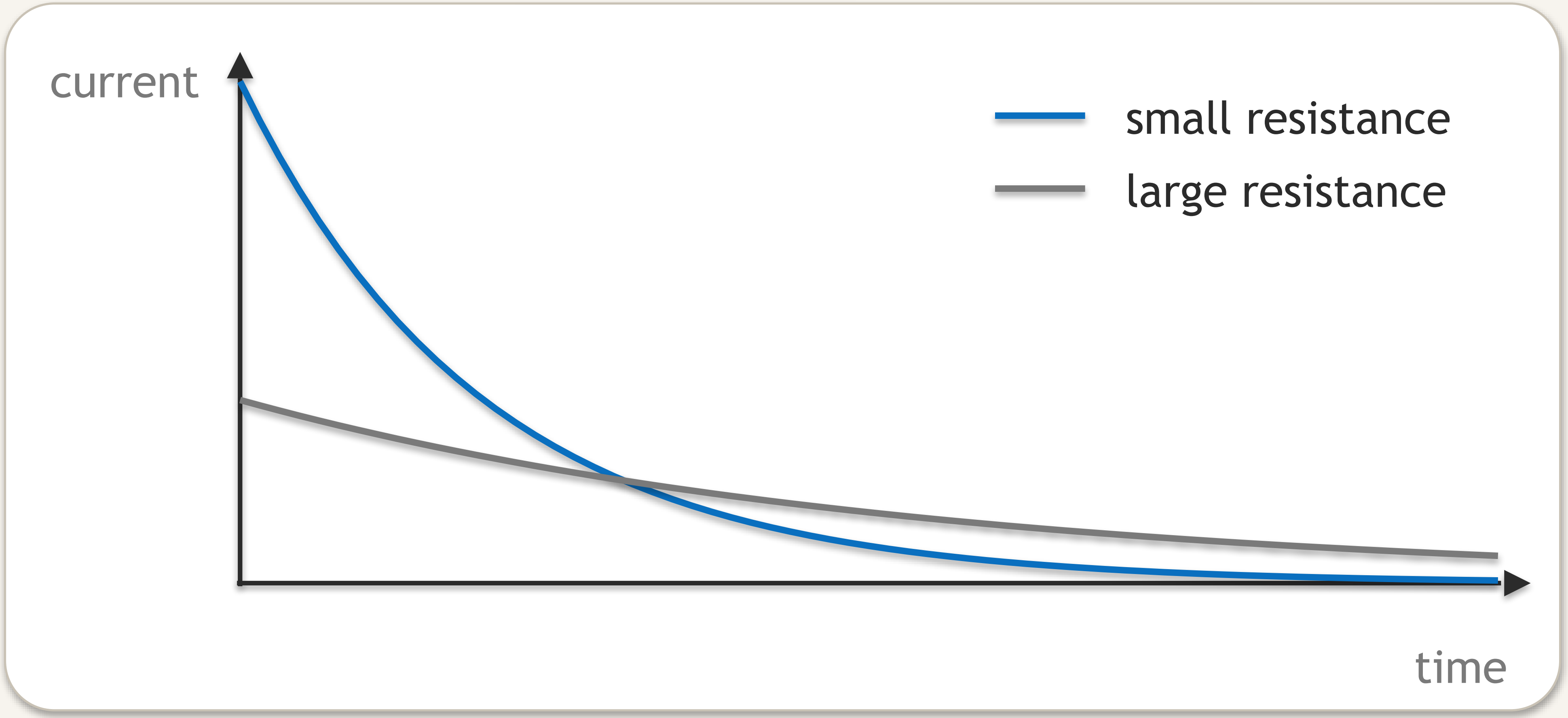
Same supply, same resistor — only the capacitor is swapped.



The effect of resistance

JOTTER NOTES

Same supply, same capacitor — only the resistor is swapped.



JOTTER NOTES

What changes the charging time

Bigger C: more charge — longer.

Bigger R: smaller current — longer.

Same shape; only the rate changes.

JOTTER NOTES

Charge stored, and the starting current

Area under I-t = charge stored.

Same C and supply: same charge, so equal areas.

Only the supply and R set the starting current.

Watch Out: what changes what

THE MISTAKE

- "A bigger capacitor gives a bigger starting current."
- "A bigger resistor stores more charge."
- Drawing the two resistance curves with different areas.

THE CORRECT ANSWER

- Only the supply and R set the starting current.
- The charge stored is set by the capacitance and the p.d.
- Same C, same supply, same charge: equal areas.

Show Me: charging rates

SHOW ME BOARDS

1. R is doubled. State and justify the effect on the time to fully charge.
2. C is doubled. State and justify the effect on the initial charging current.
3. Same supply and resistor: sketch I-t for $10\ \mu F$ and $47\ \mu F$ on one set of axes.
4. Explain why your two curves in question 3 enclose different areas.
5. A capacitor fully charges in $8\ s$ through $10\ k\Omega$. Estimate the time through $5\ k\Omega$.

Show Me: charging rates

SHOW ME BOARDS

EXTRA PRACTICE

1. R is halved. State and justify the effect on the initial current.
2. Same capacitor, same supply, R doubled: state and justify the effect on the total charge stored.
3. Sketch discharge I-t curves for a small and a large R, and compare their areas.
4. State the two quantities that set the initial charging current.
5. Both R and C are doubled. State and justify the effect on the charging time.

Task

Questions on how resistance and capacitance change the curves.
Sketch every graph — do not just describe it in words.

Leckie and Leckie Exercise 4.1.3 (p333)

Starter

2015 Higher Physics

Scan the code and answer these:

Q8 **Q10** **Q16**

Section A · the volt, a.c., uncertainty

Show your working, not just the letter.

Scan for the paper

Marking scheme

PART 4

Charge and energy stored

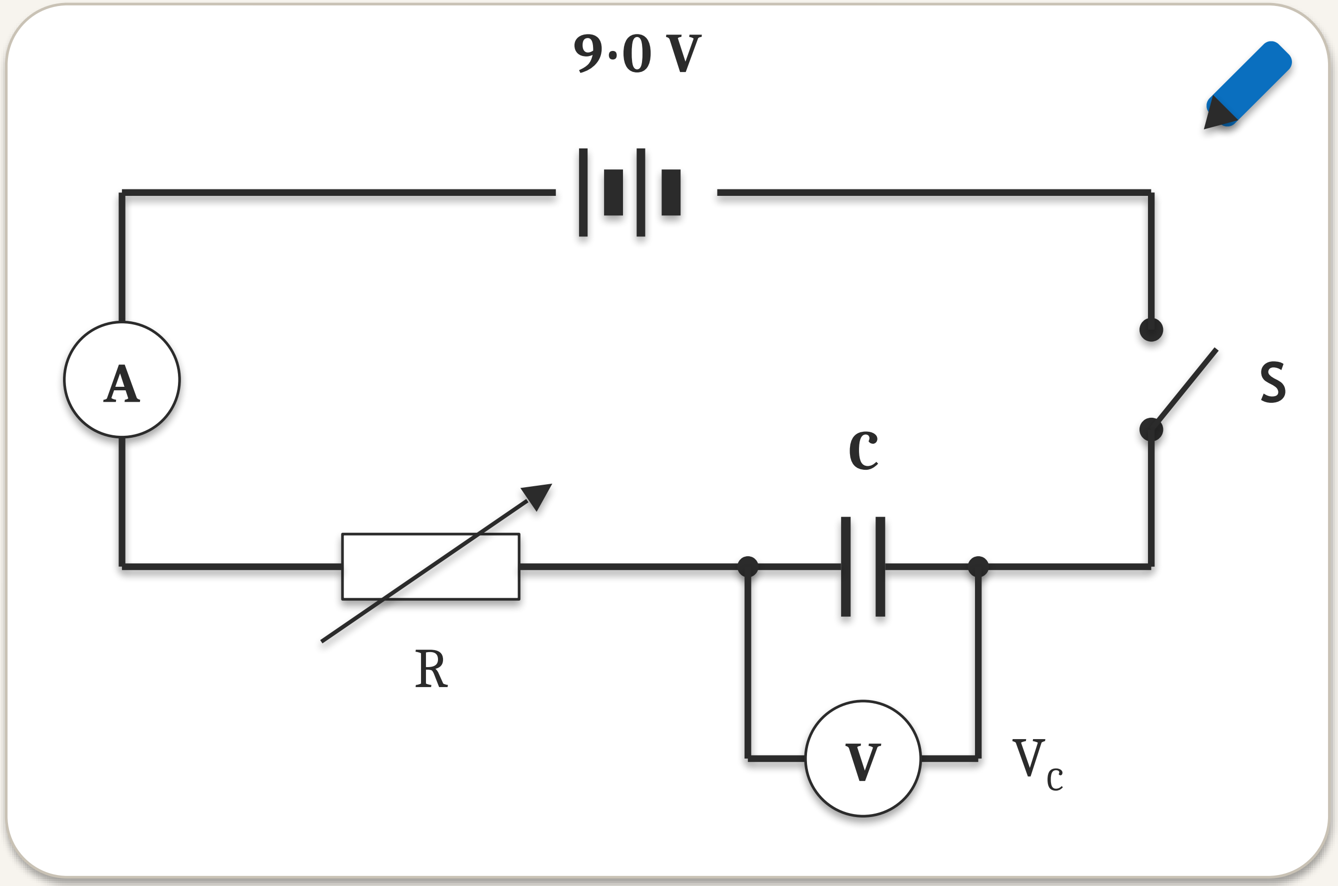
Charging a capacitor takes work. Where does that energy go?

By the end of this part…

1. I can use $Q = I\,t$ for a constant charging current.
2. I can explain why the energy is the area under a Q-V graph.
3. I can use $E = \frac{1}{2}QV$ to find the energy stored.

Charging at a constant current

Hold the current steady and the charge is simply $I \times t$.



- Charging current normally falls as C charges.
- Reduce R steadily to hold the current constant.
- With a constant current, $Q = I\,t$.
- Measure V at the end; $C = Q/V$ gives C.

JOTTER NOTES

Charge from a constant current

$$Q = It$$

Q = charge (C); I = current (A); t = time (s).

To keep I constant, DECREASE R steadily.

V_C rises, V_R falls — so R must fall too.

Then $C = Q / V$ gives the capacitance.

Worked example

A capacitor is charged at a constant current of 25 μA for 40 s. The p.d. across it is then 5·0 V. Calculate the capacitance.

$I = 25 \times 10^{-6}$ A

$t = 40$ s

$V = 5{\cdot}0$ V

$C = ?$

$$Q = It$$

$Q = 25 \times 10^{-6} \times 40 = 1{\cdot}0 \times 10^{-3}$ C

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

$$C = \frac{1 \cdot 0 \times 10^{-3}}{5 \cdot 0}$$

$\underline{C = 2{\cdot}0 \times 10^{-4}\ \text{F}}$

Show Me: constant current

SHOW ME BOARDS

1. A capacitor charges at a constant $40\ \mu A$. Calculate the charge stored after $1{\cdot}5$ minutes.
2. A capacitor charged at a constant $25\ \mu A$ for $32\ s$ reaches $8{\cdot}0\ V$. Calculate its capacitance.
3. State and justify how the variable resistor is adjusted to keep the charging current constant.
4. A $50\ \mu F$ capacitor must reach $6{\cdot}0\ V$ in $20\ s$ at constant current. Calculate that current.
5. At constant current, sketch charge against time and state what the gradient gives.

Show Me: constant current

SHOW ME BOARDS

EXTRA PRACTICE

1. A constant current of $120\ \mu A$ flows for $45\ s$. Calculate the charge delivered.
2. A capacitor charged at a constant $30\ \mu A$ for $40\ s$ reaches $4{\cdot}0\ V$. Calculate its capacitance.
3. A $680\ \mu F$ capacitor reaches $9{\cdot}0\ V$ after charging at constant current for $34\ s$. Calculate the current.
4. Explain why the charging current normally falls as a capacitor charges.
5. A charge of $2{\cdot}7\ mC$ is delivered in $1{\cdot}0$ minute. Calculate the average current.

Watch Out: state AND justify

THE MISTAKE

- “The resistance is decreased.” and no more.
- “Because the current has to stay the same.”
- Starting the next part again from the original data.

THE CORRECT ANSWER

- State the change, then justify it with the physics.
- As V_C rises, V_R falls, so R must fall to keep $I = V_R / R$.
- Carry your own value into the next part.

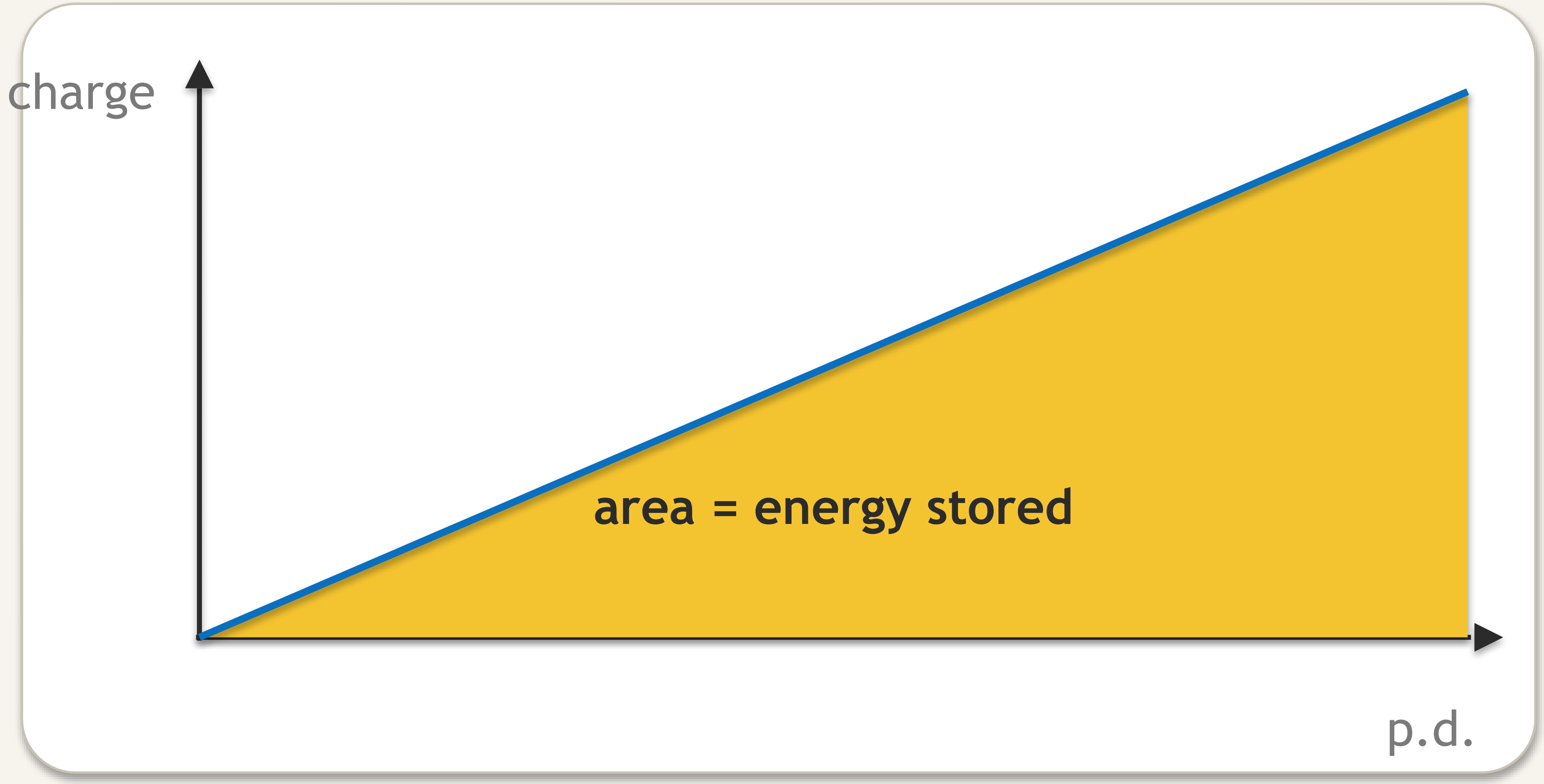
Why charging takes energy

- Work must be done to push each extra electron onto a plate.
- That plate is already negative, so it repels the next electron.
- As the charge builds up, the p.d. rises — so each coulomb costs more work.
- For a constant p.d., $W = Q\,V$. Here the p.d. is not constant, it is rising.

The energy is the area

JOTTER NOTES

Charge against p.d. is a straight line through the origin.



Energy stored in a capacitor

JOTTER NOTES

$$E = \frac{1}{2}QV$$

E	Q	V
energy in joules (J)	charge in coulombs (C)	final p.d. in volts (V)

JOTTER NOTES

Why the energy is half

Q-V graph: a straight line from 0.

Energy = AREA under the Q-V graph.

The area is a triangle: half the box.

Half, because the p.d. grew from 0 up to V.

Worked example

A capacitor stores a charge of $3{\cdot}0 \times 10^{-3}$ C at a p.d. of $8{\cdot}0$ V.

Calculate the energy stored in the capacitor.

$Q = 3{\cdot}0 \times 10^{-3}$ C

$V = 8{\cdot}0$ V

$E = ?$

$$E = \frac{1}{2}QV$$

$E = ½ \times 3{\cdot}0 \times 10^{-3} \times 8{\cdot}0$

$\underline{E = 1{\cdot}2 \times 10^{-2}\ \text{J}}$

Show Me: energy stored

SHOW ME BOARDS

1. A capacitor stores $6{\cdot}0\ \mathrm{mC}$ at $9{\cdot}0\ \mathrm{V}$. Calculate the energy stored.
2. Explain why the energy stored is $\frac{1}{2}QV$ and not QV.
3. A capacitor stores $40\ \mathrm{mJ}$ when charged to $20\ \mathrm{V}$. Calculate the charge stored.
4. The charge on a capacitor is doubled. State and justify the effect on the energy stored.
5. Sketch the Q–V graph and shade the energy stored when the p.d. reaches a value V.

Show Me: energy stored

SHOW ME BOARDS

EXTRA PRACTICE

1. A capacitor stores $150\ \mu C$ at $12\ V$. Calculate the energy stored.
2. A capacitor stores $5{\cdot}0 \times 10^{-2}\ J$ at $25\ V$. Calculate the charge stored.
3. Work is done charging a capacitor. State where this energy is stored.
4. The p.d. across a capacitor is halved. State and justify the effect on the energy stored.
5. Using the Q-V graph, explain why each extra coulomb stores more energy than the last.

Task

Watch the energy demonstration, then work through the questions.

Experiment 4.2.1 (p335) — demonstration
Leckie and Leckie Exercise 4.2.2 (p337)

Starter

2012 Revised Higher Physics

Scan the code and answer these:

Q17 Q18 Q19

Section A · e.m.f., networks, a.c.

Show your working, not just the letter.

Scan for the paper

Marking scheme

PART 5

Three ways to write it

One idea, three relationships — pick the one that fits your data.

By the end of this part...

1. I can derive $E = \frac{1}{2}CV^2$ and $E = \frac{1}{2}Q^2/C$ from $E = \frac{1}{2}QV$.
2. I can choose the energy relationship that fits the data given.
3. I can convert every prefix before substituting.

Substituting for the charge

Know C and V? Then you do not need Q.

$$E = \frac{1}{2}QV$$

$$Q = CV$$

$$E = \frac{1}{2}(CV)V$$

$$E = \frac{1}{2}CV^2$$

Use this when you are given C and V.

Substituting for the p.d.

Know Q and C? Then you do not need V.

$$E = \frac{1}{2}QV$$

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

$$E = \frac{1}{2}Q\left(\frac{Q}{C}\right)$$

$$E = \frac{1}{2}\frac{Q^2}{C}$$

Use this when you are given Q and C.

The three energy relationships

JOTTER NOTES

$$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$$

E	Q	V	C
energy in joules (J)	charge in coulombs (C)	p.d. in volts (V)	capacitance in farads (F)

JOTTER NOTES

Choosing the right one

Given Q and V: use $\frac{1}{2}QV$. Given C and V: use $\frac{1}{2}CV^2$.

Given Q and C: use $\frac{1}{2}Q^2/C$.

All three are on the relationships sheet — choose to fit your data.

Convert every prefix before you substitute.

Worked example

A 10 μF capacitor in a computer charges to a p.d. of 20 V.

Calculate the energy stored in the capacitor.

$C = 10 \times 10^{-6}$ F

$V = 20$ V

$E = ?$

$$E = \frac{1}{2}CV^2$$

$E = \frac{1}{2} \times 10 \times 10^{-6} \times 20^2$

$\underline{E = 2{\cdot}0 \times 10^{-3}\ \text{J}}$

Worked example

A camera flash lamp needs 4·0 J of energy, stored on a capacitor charged to 12 V. Calculate the capacitance required.

$E = 4{\cdot}0\ \text{J}$

$V = 12\ \text{V}$

$C = ?$

$$E = \frac{1}{2}CV^2$$

$$C = \frac{2E}{V^2}$$

$$C = \frac{2 \times 4 \cdot 0}{12^2}$$

$\underline{C = 5{\cdot}6 \times 10^{-2}\ \text{F}}$

Show Me: energy relationships

SHOW ME BOARDS

1. A $470\ \mu F$ capacitor is charged to $12\ V$. Calculate the energy stored.
2. A $2{\cdot}0\ mF$ capacitor stores $0{\cdot}40\ J$. Calculate the p.d. across it.
3. A $50\ \mu F$ capacitor stores $2{\cdot}5\ mC$. Calculate the energy stored.
4. State and justify which energy relationship you would choose when given C and Q.
5. The p.d. across a capacitor is tripled. State and justify the effect on the energy stored.

Show Me: energy relationships

SHOW ME BOARDS

EXTRA PRACTICE

1. A $100\ \mu F$ capacitor is charged to $50\ V$. Calculate the energy stored.
2. A capacitor stores $8{\cdot}0 \times 10^{-2}\ J$ at a charge of $4{\cdot}0\ mC$. Calculate its capacitance.
3. A defibrillator capacitor delivers $200\ J$ in $5{\cdot}0\ ms$. Calculate the mean power.
4. The charge is doubled at constant capacitance. State and justify what happens to V and to E.
5. A camera flash needs $9{\cdot}0\ J$ from a capacitor charged to $300\ V$. Calculate the capacitance required.

Watch Out: energy and prefixes

THE MISTAKE

- Energy stored written as $E = QV$.
- $470\ \mu F$ substituted into the relationship as 470.
- Rounding $5{\cdot}56 \times 10^{-2}$ to $0{\cdot}06$.

THE CORRECT ANSWER

- $E = \frac{1}{2} QV$ — the area under the graph is a triangle.
- Convert every prefix first: $470\ \mu F = 470 \times 10^{-6}\ F$.
- Two-figure data, two-figure answer: $5{\cdot}6 \times 10^{-2}\ F$.

Task

Mixed questions on all three energy relationships.
Write down which one you chose, and why, before you substitute.

Leckie and Leckie Exercise 4.4 (p341)
Past papers: 2025 Paper 2 Q12

Past Paper Finder

Checkpoint

SHOW ME BOARDS

1. State what is meant by a capacitance of $1\,\mathrm{farad}$.
2. A capacitor charged at a constant $50\,\mu\mathrm{A}$ for $24\,\mathrm{s}$ reaches $6{\cdot}0\,\mathrm{V}$. Calculate its capacitance, and the energy stored.
3. R in a charging circuit is increased. State what happens to the charging time, and justify it.

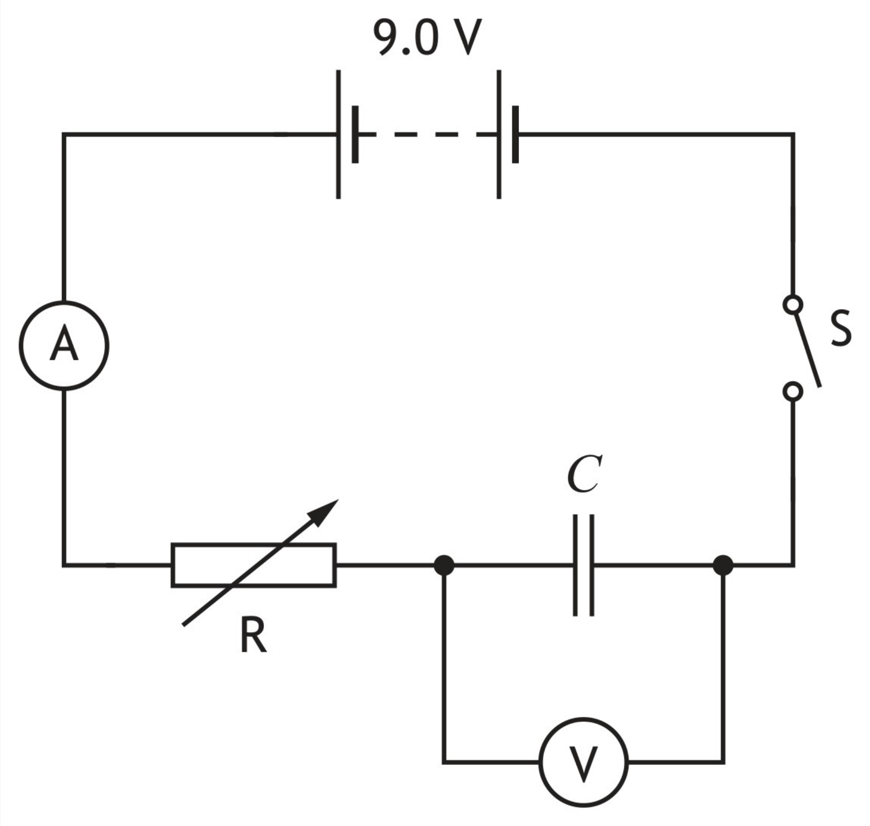
Exam Practice

Every one of these is a capacitor question from a recent past paper.

Paper	Question	Marks	What it asks you to do
2024 P1	Q21	1	Energy stored, constant current
2024 P1	Q22	1	Which I-t graph for a larger C
2025 P2	Q12(a)	3	Sketch I-t with values on both axes
2025 P2	Q12(b)(i)	2	State AND justify the change to R
2025 P2	Q12(b)(ii)	3	Charge from a constant current
2025 P2	Q12(b)(iii)	3	Capacitance from Q and V

Exam Practice: 2025 Paper 2 Q12(b)

The circuit the question is built on — 8 marks across three parts.



Source: SQA Higher Physics 2025, Paper 2, Question 12(b). Reproduced with acknowledgement to SQA.

NEXT LESSON

Forces on Charged Particles

Fields, accelerated electrons and the machines built from them.

Plenary

SHOW ME BOARDS

1. Define the farad.
2. A capacitor charged at a constant $75\ \mu\text{A}$ for $40\ \text{s}$ stores $3{\cdot}0\ \text{mC}$. Show these figures are consistent.
3. Sketch all four charge and discharge graphs from memory.
4. Describe the experiment used to investigate the charging curves.
5. A $25\ \mu\text{F}$ capacitor is charged to $40\ \text{V}$. Calculate the energy stored.

Plenary

SHOW ME BOARDS

EXTRA PRACTICE

1. State the unit of capacitance, and define it.
2. A capacitor stores $0{\cdot}60\ \mathrm{mC}$ at $12\ \mathrm{V}$. Calculate its capacitance AND the energy stored.
3. C is halved, same supply. State and justify the effect on the charge stored.
4. State and justify the effect of doubling R on the discharge time.
5. Write down, in SQA form, the relationship linking energy, charge and capacitance.

Extension

SHOW ME BOARDS

1. A 470 μF capacitor charged to 10 V discharges through a lamp in 0·50 s. Calculate the mean power of the flash.
2. 10 μF and 100 μF capacitors are charged to the same p.d. Compare the energies stored, with justification.
3. A capacitor is charged at constant current. Show that the energy stored grows with the square of the time.

Extension

SHOW ME BOARDS

EXTRA PRACTICE

1. A $2200\ \mu F$ capacitor at $16\ V$ runs a memory chip drawing $2{\cdot}0\ mW$. Estimate how long it can supply this power.
2. Explain, in terms of the plates, why halving the plate separation increases the capacitance.
3. During charging at constant current, sketch V_C against time. Justify the shape using $Q = I\,t$ and $C = Q/V$.