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Oxford Cambridge and RSA

AS and A LEVEL

Delivery Guide

PHYSICS A

H156/H556
For first teaching in 2015

Capacitors

Version 2

Introduction

AS and A LEVEL
PHYSICS A

Delivery guides are designed to represent a body of knowledge about teaching a particular topic and contain:

- Content: A clear outline of the content covered by the delivery guide;
- Thinking Conceptually: Expert guidance on the key concepts involved, common difficulties students may have, approaches to teaching that can help students understand these concepts and how this topic links conceptually to other areas of the subject;
- Thinking Contextually: A range of suggested teaching activities using a variety of themes so that different activities can be selected which best suit particular classes, learning styles or teaching approaches.

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Curriculum content

The study of capacitors provides the catalyst for understanding the nature of electrical charge, enhancing experimental skills, improving analytical skills and understanding the importance of exponential functions.

The table below summarises the key learning outcomes for the topic of capacitors.

6.1.1 Capacitors; including parallel plate capacitor 6.2.3(b)	6.1.2 Energy stored by capacitors	6.1.3 Charging and discharging of capacitors
• The basic construction of a capacitor, e.g. two parallel plates separated by an insulator. • How the capacitor plates acquire equal but opposite charges. • Capacitance C of a capacitor and the equation $Q = VC$. • Capacitors connected in combinations. • The equations $C = (C_1^{-1} + C_2^{-1} + ...)^{-1}$ and $C = C_1 + C_2 + ...$ • Analysis of circuits with capacitors. • Parallel plate capacitor and and $C = \frac{\varepsilon A}{d}$	• The area under a graph of p.d. against charge being equal to energy. • Energy stored by a capacitor. • The equations $W = \frac{1}{2}QV$ $W = \frac{1}{2}\frac{Q^2}{C}$ and $W = \frac{1}{2}V^2C$ • Uses of capacitors.	• Charging and discharging capacitors through a resistor. • Time constant of a circuit. • The equations $x = x_0 e^{-\frac{t}{CR}}$ and $x = x_0(1 - e^{-\frac{t}{CR}})$ • Modelling the discharge of a capacitor using a spreadsheet. • Exponential decay of charge, current and p.d. in a C-R circuit.

Approaches to teaching the content

Physics is, by its very nature, a practical subject. Experimental work must be carried out by the students, or at least demonstrated by the teacher, if the learners are to understand the intricacies of capacitors.

The following websites provide helpful resources for teachers.

- National STEM Centre; short video clip on a bin-bag capacitor: http://www.nationalstemcentre.org.uk/elibrary/resource/4097/bin-bag-capacitor
- Simulation of charging a capacitor: http://phet.colorado.edu/en/simulation/capacitor-lab
- Applet; charging capacitor: http://lectureonline.cl.msu.edu/~mmp/kap23/RC/app.htm
- YouTube; factors affecting capacitance: http://www.youtube.com/watch?v=jOBoDixh7lY
- HyperPhysics; capacitors: http://hyperphysics.phy-astr.gsu.edu/hbase/electric/capac.html
- Institute of Physics; Teaching Advanced Physics (TAP) on capacitor: https://spark.iop.org/collections/capacitors

Common misconceptions and difficulties

Physics cannot be taught theoretically. Ideas need to be challenged through discussions and backed up by hands-on practical work. Whenever possible, practical work and theory must be interwoven.

Examination papers reveal a number of areas where students struggle. The table below, which by no means is exhaustive, offers possible strategies to resolve some of the issues.

Misconceptions and difficulties	Comments
The term capacitance	A-level students can comfortably use the equation $Q = VC$ to solve problems. However, many struggle to appreciate that the capacitance C of a capacitor is independent of both potential difference across the capacitor and the charge stored on each capacitor plates. The capacitance C depends on the physical construction of the capacitor – the insulation used between the plates, the separation between the plates and the area of overlap between the plates. Solution: • Teacher demonstration of charge proportional to potential difference experiment using a parallel plate capacitor, e.h.t. supply and coulomb-meter. • Students can build a capacitor using card and aluminium foil and then investigate the factors affecting its capacitance using a mutimeter set to the capacitance range. See Lesson Element – Build and test your own capacitor
Charge stored by capacitors in series	The idea that two capacitors of very different capacitances connected in series to a battery will each store the same charge is an enigma to many students. Solution: • It is vital for teachers to discuss the physics of why the charge stored is the same. This must then be supported by a class experiment in which two known capacitors are connected in series, the p.d. across each capacitor is measured using a digital voltmeter and then $Q = VC$ is applied to each capacitor. Non-electrolytic capacitors work well in such experiments.

Thinking conceptually

Misconceptions and difficulities	Comments
Energy stored by a capacitor	Many students can effortlessly use all three equations for the energy stored. However, the simple idea that stored energy ∝ p.d.^{2} for a given capacitor is often not appreciated. Solution: • Connect a small electric motor across a 0.1 F capacitor. The capacitor is charged and then discharged through the motor which raises a small blob of Blu-Tack. It is clear to see that the gain in GPE of the load is definitely more than doubled when the p.d. is doubled. Discussion can focus on energy ∝ p.d.^{2}
The exponential decay of charge (or current or p.d.) for a discharging capacitor	Teachers will be aware of the misuse of the term 'exponential decay'. For many students, any non-linear decreasing curve represents exponential decay. The constant-ratio property of exponential decay is also not appreciated. It is important for a teacher to invest some time on simple graphs before launching into the complex equations for a discharging capacitor. Solution: • Use an Excel spreadsheet to show data for a variety of equations, including exponential decay. Use the data to show that only the exponential decay function has a constant-ratio characteristic.
Using spreadsheets to model the discharge of a capacitor	The use of spreadsheets in Physics A is new and a requirement from Ofqual. The idea of modelling and iterative techniques may also be new to teachers. Solution: • Teachers must become competent with using spreadsheets (eg Excel). They can then effectively guide their students when modelling the discharge of a capacitor using the equation $\frac{\Delta Q}{\Delta t} = -\frac{Q}{CR}$

OCR has provided PAG resources available from the practical activities page of the OCR website at:

https://www.ocr.org.uk/qualifications/as-and-a-level/physics-a-h156-h556-from-2015/planning-and-teaching/

This includes:

PAG9.1 Investigating charging and discharging capacitors

PAG9.2 Capacitors in series and parallel

PAG9.3 Investigating factors affecting the capacitance of a capacitor

Activities

The following activities are designed for the students to reinforce key learning points in the topic of capacitors. The activities can either be done in class or as part of independent learning at home.

Learner Activity 1

Core Activity: A book capacitor.

Learner Resource 1 shows a capacitor made from two lengths of aluminium foil and a book. A multimeter is connected to the foils using crocodile clips. The multimeter is set to measure capacitance. This arrangement can be used to investigate how capacitance *C* is affected by the separation *d* between the capacitor plates.

The table shows the results collected by a student.

Number of sheets	d / 10^{-3} m	d^{-1} / m^{-1}	C / 10^{-9} F
18	1.75	571	0.516
30	2.92	342	0.318
60	5.85	171	0.175
122	11.89	84.1	0.099
154	15.01	66.6	0.085
217	21.15	47.3	0.061

Thickness of 318 sheets of paper = 31 mm

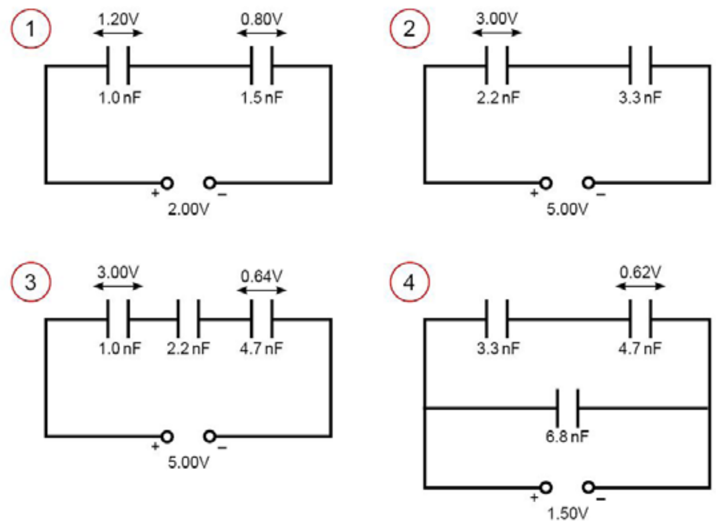
1. Plot a graph of C against d^{-1} and draw a line of best fit.
2. Suggest a possible relationship between C and d.
3. The graph of C against d^{-1} does not pass through the origin because of possible zero errors with the meter and stray capacitance. However, you can still use the gradient to determine an approximate value for the permittivity of paper. What is the gradient of the graph in terms of ε, the permittivity of paper, and the area A between the plates?
4. The cross-sectional area of each plate is 3.1×10^{-2} m^2. Use the gradient to determine an approximate value of ε.

Learner Activity 2

Core Activity: Analysis of charge stored by capacitors in series.

The results shown for each circuit are from actual experiments conducted by a group of A level students. The suggestion made by the group is that 'in each circuit, the charge *Q* on each capacitor when connected in **series** is the same'.

Use your knowledge of electrical circuits, and the equation $Q = VC$, to confirm that the suggestion made by the group is correct.



Extension work

1. Explain why the charge stored by two capacitors in series is always the same.
2. What is the ratio of the potential differences across the two capacitors in terms of their capacitances?

Activities

Learner Activity 3

Core Activity: Exponential decay.

Graphs can convey lots of useful information. In A level Physics, you do need to know about exponential decay graphs. It is important not to confuse such graphs with other similar looking graphs, such as those

produced by the equations $y = \frac{k}{x}$ and $y = \frac{k}{x^2}$

In this task you will learn about the constant-ratio property of an exponential decay function. The general equation for exponential decay is $y = ke^{-x}$, where k is a constant. For a given interval Δx, the ratio of the y values will be a constant – hence the term *constant-ratio property*.

The tables below shows the data for the three equations $y = \frac{k}{x}$, $y = \frac{k}{x^2}$ and $y = ke^{-x}$.

1 Equation: $y = \frac{10}{x}$ Choose $\Delta x = 3.0$

ratio = $\frac{\text{new } y \text{ value}}{\text{previous } y \text{ value}}$

x	$y = \frac{10}{x}$	
1.0	**10.0**	
2.0	5.00	
3.0	3.33	
4.0	**2.50**	ratio = 2.50/10.0 = 0.250
5.0		
6.0		
7.0		ratio =
8.0		
9.0		
10.0		ratio =

Complete the table.

Calculate the ratios; the first one has been done for you.

Is there a constant-ratio property? The answer should be NO.

Core Activity: Exponential decay continued.

2 Equation: $y = \frac{10}{x^2}$ Choose $\Delta x = 2.0$

ratio = $\frac{\text{new } y \text{ value}}{\text{previous } y \text{ value}}$

x	$y = \frac{10}{x^2}$	
1.0		
2.0		
3.0		ratio =
4.0		
5.0		ratio =
6.0		
7.0		ratio =
8.0		
9.0		ratio =

Complete the table.

Calculate the ratios.

Is there a constant-ratio property? The answer should be NO

Core Activity: Exponential decay continued

3 Equation: $y = 100e^{-x}$. Choose $\Delta x = 0.2$

ratio = $\frac{\text{new } y \text{ value}}{\text{previous } y \text{ value}}$

x	$y = 100e^{-x}$	
0.10		
0.20		
0.30		ratio =
0.40		
0.50		ratio =
0.60		
0.70		ratio =
0.80		
0.90		ratio =

Complete the table.

Calculate the ratios.

Is there a constant-ratio property? The answer should be YES.

Conclusion: In a given interval Δx, the value of y decreases by the same factor. For the example 3 above, the value of y decreases to about 82% of its previous value.

Learner Activity 3

Core Activity: Interpreting current-time graph.

This activity will show how you can extract useful information by carefully examining the current-time graph for a C-R circuit. It is important that you work in the correct units at all times.

An unmarked capacitor is discharged through an unmarked resistor, see Figure 1. The p.d. across the capacitor is 10.0 V at time $t = 0$.

Figure 1

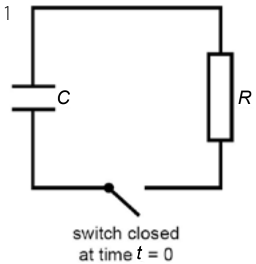
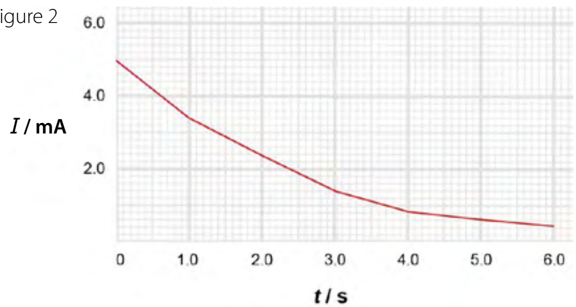


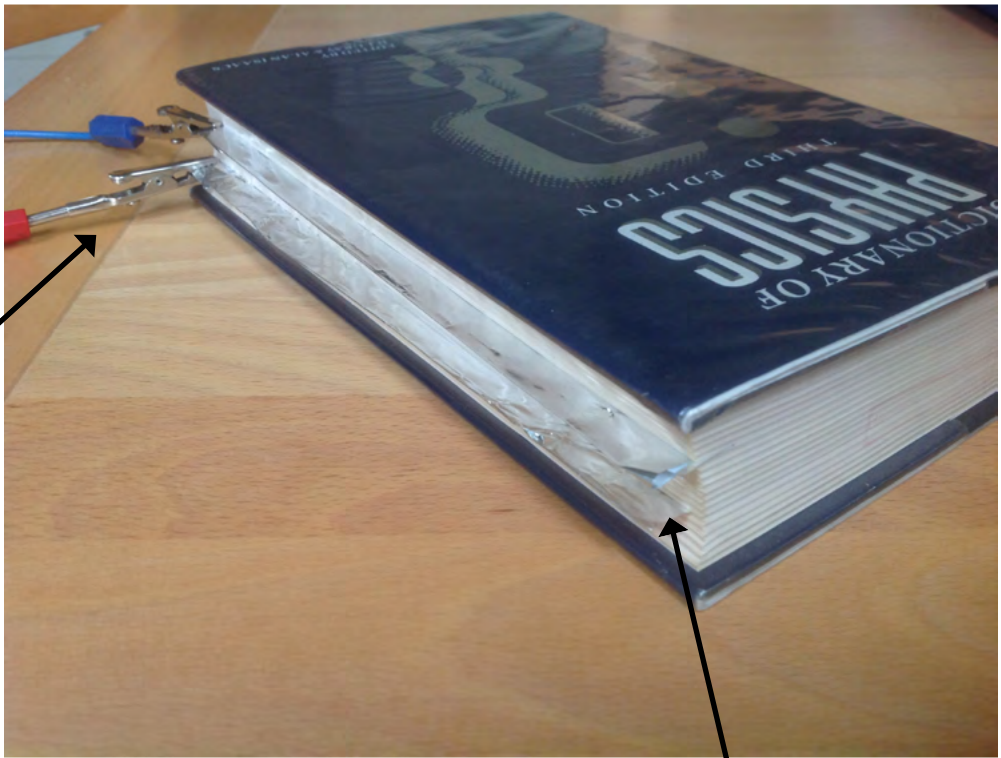
Figure 2 shows a graph of current against time for this circuit.

Figure 2



1. Use the information provided at time $t = 0$ to determine the resistance R of the resistor. Hint: *$V = IR$ at all times.*
2. Use the graph to determine the time constant of the circuit. Hint: *The current decreases to* e^{-1} *of its initial value at a time equal to the time constant. Also, time constant = CR.*
3. Use the information given above to determine the value of the capacitance C of the capacitor.
4. Use the equation $I = I_0 e^{-\frac{t}{CR}}$ and a data point from the graph to show that the time constant is the same as 2 above. Hint: $\ln I = \ln I_0 - \frac{t}{CR}$

Example of a capacitor



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