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## GCE A LEVEL – CAPACITANCE QUESTION PACK

1325-01 (Legacy PH5)

**REVISE**  
.wales

## PHYSICS – UNIT 4 TOPIC 1

### *Capacitance – charge, energy, RC discharge & dielectrics*

*Every capacitance question from the legacy WJEC PH5 papers (June 2010 – June 2016)*

LEGACY 2008 SPECIFICATION · MAPS TO NEW UNIT 4 TOPIC 1

**Estimated time for entire question pack: ~1 hour 45 minutes**

*Derived from the legacy PH5 pace of ~1.3 min/mark (80 marks in 1¾ hours).*

*You are advised to **not** attempt to complete all of this in one sitting.*

*For Examiner's use only*

Q	Source	Max	Mark	Q	Source	Max	Mark
1	Jun 11 Q1	10		5	Jun 12 Q3	10	
2	Jun 13 Q3	10		6	Jun 15 Q1	11	
3	Jun 14 Q3	10		7	Jun 16 Q3	11	
4	Jun 10 A3	20		<b>Total</b>		<b>82</b>	

### ABOUT THIS QUESTION PACK

This is a **comprehensive practice question pack**, not a single mock paper. It contains every capacitance question (charge, energy, RC discharge, parallel/series combinations and dielectrics) from the legacy WJEC PH5 papers between June 2010 and June 2016.

Questions are grouped by sub-topic, then ordered roughly by difficulty.

### INSTRUCTIONS

Use black ink or black ball-point pen. Answer all questions in the spaces provided.

*A calculator is required. The Data Booklet is allowed.*

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## Unit 4 Topic 1 – Capacitance

WJEC GCE A Level Physics (from 2015) · Unit 4 Assessment Unit *Fields & Options*. Topic 1 (Capacitance) maps directly onto the legacy PH5 specification, which placed the same content in the core PH5 paper.

### Capacitance defined **A**

- $C = \frac{Q}{V}$  – capacitance is the charge stored per unit p.d.
- Unit: farad (F).  $1 \text{ F} = 1 \text{ C V}^{-1}$ .
- Practical capacitors are typically pF, nF,  $\mu\text{F}$ .

### Parallel-plate capacitor **A**

- $C = \frac{\epsilon_0 \epsilon_r A}{d}$  where  $A$  is plate area and  $d$  is plate separation.
- $\epsilon_0 = 8.85 \times 10^{-12} \text{ F m}^{-1}$ .
- $\epsilon_r$  is the relative permittivity (dielectric constant) – vacuum/air  $\approx 1$ .

### Energy stored **A**

- $W = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$ .
- All three forms equivalent – pick the one that matches the known quantities.
- Area under a  $V$ - $Q$  graph = energy stored.

### Series & parallel combinations **B**

- **Parallel:**  $C_{\text{total}} = C_1 + C_2 + \dots$
- **Series:**  $\frac{1}{C_{\text{total}}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$
- In series, each capacitor stores the *same charge*. In parallel, each has the *same p.d.*

### Charge & discharge through $R$ **B**

- Discharge:  $Q = Q_0 e^{-t/RC}$ ,  $V = V_0 e^{-t/RC}$ ,  $I = I_0 e^{-t/RC}$ .
- Charging:  $Q = Q_0(1 - e^{-t/RC})$ .
- Time constant  $\tau = RC$  (units: seconds).

### Dielectrics & permittivity **A**

- Inserting a dielectric of  $\epsilon_r > 1$  multiplies  $C$  by  $\epsilon_r$ .
- Water is a particularly strong dielectric – the basis of moisture/fog sensors.
- Practical capacitors use thin polymer/ceramic dielectrics to maximise  $C$  in a small package.

## Section index for this question pack

<b>A</b>	<b>Single capacitor: charge, energy &amp; dielectrics</b>	Calculating $C = \epsilon_0 A/d$ , charge $Q = CV$ , energy $\frac{1}{2}CV^2$ , plus discharging through a single resistor and the effect of dielectrics, plate separation and isolation on charge/energy.	50 marks · pp 5-13
<b>B</b>	<b>Combinations, RC analysis &amp; graphs</b>	Reducing series/parallel combinations to a single equivalent, calculating $R$ from discharge data, current at $t = 0$ , and the time taken to lose a given fraction of charge.	32 marks · pp 15-20

# Capacitance in one page

Quick-reference notes – revisit before each section.

## Definition of capacitance

For any capacitor at p.d.  $V$  storing charge  $Q$ :

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

- SI unit: farad (F) = C V<sup>-1</sup>.
- Useful sizes: pF (10<sup>-12</sup>), nF (10<sup>-9</sup>), μF (10<sup>-6</sup>).

## Parallel-plate formula

For a plate area  $A$ , separation  $d$ , with dielectric of relative permittivity  $\epsilon_r$ :

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

- $\epsilon_0 = 8.85 \times 10^{-12}$  F m<sup>-1</sup>.
- To increase  $C$ : increase  $A$ , decrease  $d$ , or increase  $\epsilon_r$ .

## Energy stored – three forms

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

- Choose the form that uses what you know.
- Half of the work done by the supply in charging is dissipated in the wires – the rest is stored.

## Parallel combinations

Connected across the same p.d.:

$$C_{\text{total}} = C_1 + C_2 + C_3 + \dots$$

- Each capacitor stores its own charge  $Q_i = C_i V$ .
- Total charge sums; total energy sums.

## Series combinations

Same charge  $Q$  flows onto each capacitor:

$$\frac{1}{C_{\text{total}}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots$$

- For two:  $C_{\text{total}} = \frac{C_1 C_2}{C_1 + C_2}$ .
- Total  $C$  is smaller than the smallest capacitor.

## RC discharge

Discharging through a resistor  $R$ :

$$Q = Q_0 e^{-t/RC}$$

- $V$  and  $I$  obey the same exponential decay.
- Time constant  $\tau = RC$  – the time to fall to ~37% of initial.
- Half-life of charge:  $t_{1/2} = RC \ln 2 \approx 0.693 RC$ .

## RC charging

Charging via a resistor from a supply of emf  $V_0$ :

$$Q = Q_0 (1 - e^{-t/RC})$$

- After  $1\tau$ : ~63% charged.
- After  $5\tau$ : essentially fully charged.

## Energy vs charge half-life

- $W \propto Q^2$ , so when  $Q$  halves,  $W$  falls to  $\frac{1}{4}$ .
- Energy half-life is *shorter* than charge half-life:  $t_{W,1/2} = \frac{1}{2}RC \ln 2$ .
- Worth memorising for “compare half-lives” explain questions.

## Dielectrics

Inserting a material of relative permittivity  $\epsilon_r$  between the plates:

- Multiplies  $C$  by  $\epsilon_r$  (everything else fixed).
- Water has high  $\epsilon_r \approx 80$  – fog/moisture detection.
- Air/vacuum:  $\epsilon_r \approx 1$ .

## Isolated capacitor: change $d$

If the capacitor is disconnected (so  $Q$  is fixed) and plates are pulled apart:

- $C = \epsilon_0 A/d$  decreases.
- $V = Q/C$  increases.
- $W = Q^2/(2C)$  increases: the extra energy comes from work done against the attractive force.

## Capacitor + electric field

Between the plates, the field is uniform:

$$E = \frac{V}{d}$$

- Force on charge  $q$ :  $F = qE$ .
- Acceleration of an electron:  $a = eE/m_e$ .
- Kinetic energy gained crossing  $V$ :  $eV$ .

## Strategy – 4 steps

1. Identify what is fixed: supply still connected ( $V$  fixed) or isolated ( $Q$  fixed)?
2. Simplify networks: reduce series/parallel groups to a single  $C$ .
3. For exponentials, work in the form  $\ln(Q/Q_0) = -t/RC$ .
4. Sanity:  $\tau = RC$  has units of seconds; if not, you have an algebra error.

# SECTION A

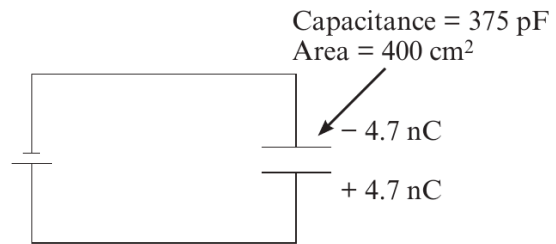
*Single capacitor: charge, energy & dielectrics*

Questions 1 - 4 · 50 marks

SECTION A

Examiner only

1. A parallel plate capacitor with no dielectric between the plates is charged by a cell as shown in the diagram.



- (a) (i) Calculate the emf of the cell. [2]

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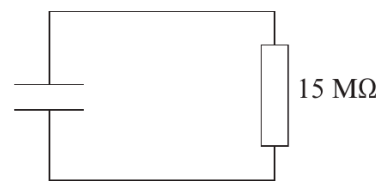
- (ii) Calculate the separation of the plates of the capacitor. [2]

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- (b) The capacitor is now discharged through a 15 MΩ resistor.



Calculate the time for the charge on the capacitor to drop from 4.7 nC to 0.7 nC.

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- (c) The capacitor is employed as a fog detector and uses the fact that water is a good dielectric. Explain briefly how the capacitor could detect the presence of fog. [2]

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3. (a) A 131 nF capacitor is charged using a potential difference of 1.62 V. Calculate the charge stored by the capacitor. [2]

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(b) This 131 nF capacitor is then disconnected from the power supply and a large resistor connected across its terminals. As the capacitor discharges, the pd across it decreases from 1.62 V to 0.47 V in 220 ms. Calculate the resistance of the resistor. [4]

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(c) The plates of this 131 nF capacitor are square and are separated by 0.15 mm. Calculate the length of a side of the capacitor plate. [3]

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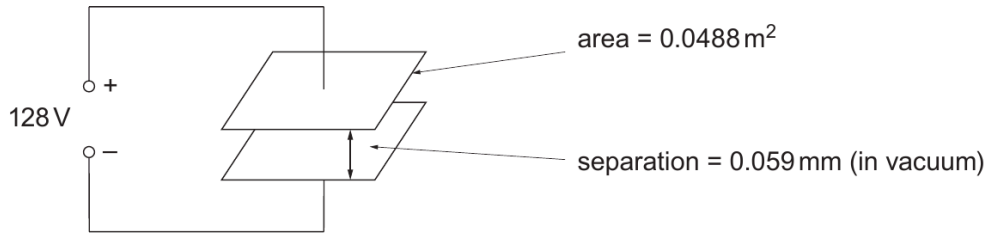
(d) In practice, how could the capacitance of this capacitor be increased by a factor of 100? [1]

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3. (a)



(i) Calculate the charge stored by the capacitor. [3]

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(ii) Use (a)(i) to calculate the energy stored by the capacitor. [1]

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(iii) Calculate the electric field strength ( $E$ ) between the plates. [2]

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(b) After the capacitor is charged it is isolated from the power supply so that the charge stored **remains constant**. Then the plates are pulled further apart.

(i) Explain what happens to the capacitance of the capacitor and hence the energy stored by the capacitor. [2]

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(ii) Explain how energy is conserved in this case. [2]

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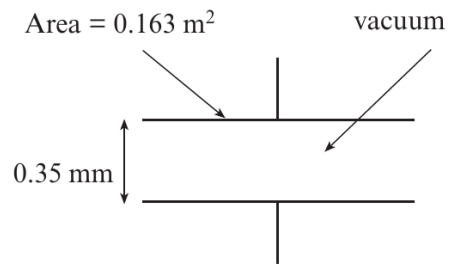
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A3. (a) Calculate the capacitance of the capacitor shown. [2]



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(b) The capacitor is charged so that there is a p.d. of 1.2 kV across the plates. Calculate

(i) the charge stored, [1]

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(ii) the energy stored in the capacitor. [1]

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(c) The capacitor is discharged through a 670 kΩ resistor. Calculate the time the capacitor takes to lose half its charge. [3]

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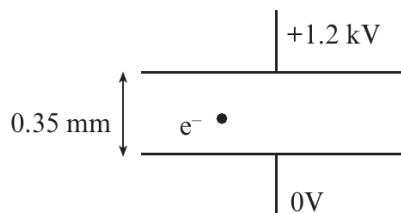
(d) Explain briefly whether or not the time the capacitor takes to lose half its energy is longer or shorter than your answer to (c). [2]

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- (e) An electron is located between the plates of the charged capacitor. Show that the acceleration experienced by the electron is approximately  $6 \times 10^{17} \text{ ms}^{-2}$ . [3]



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- (f) The electron starts from rest halfway between the plates.
- (i) Use the acceleration ( $6 \times 10^{17} \text{ ms}^{-2}$ ) to calculate the speed of the electron when it strikes the upper plate of the capacitor. [2]

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- (ii) Show that the speed of the electron (when it strikes the upper plate of the capacitor) corresponds to a kinetic energy of 0.6 keV and explain briefly another method for obtaining this answer of K.E. = 0.6 keV. [3]

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- (iii) Calculate the time the electron takes to travel to the upper plate. [3]

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# SECTION B

## *Combinations, RC analysis & graphs*

Questions 5 - 7 · 32 marks

3. (a) (i) A capacitor has plates of area  $8.2 \times 10^{-4} \text{ m}^2$  and a separation of 0.77 mm. Calculate the capacitance of the capacitor assuming that there is air (or a vacuum) between the plates. [2]

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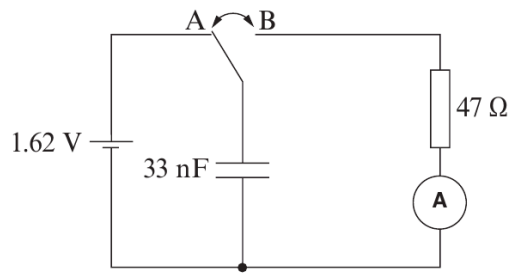
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- (ii) Keeping the dimensions of the capacitor the same, how could you increase its capacitance? [1]

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- (b) Another capacitor is charged and discharged using the following circuit.



- (i) Calculate the charge stored by the capacitor when fully charged. [2]

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- (ii) The fully charged capacitor is now discharged through the  $47\ \Omega$  resistor by moving the switch to B. Calculate the charge still remaining on the capacitor after it has been discharging for  $50.0\ \mu\text{s}$  and comment on the magnitude of your answer. [3]

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- (iii) The capacitor is charged and discharged a total of 20 000 times per second. Calculate the average current through the ammeter. [2]

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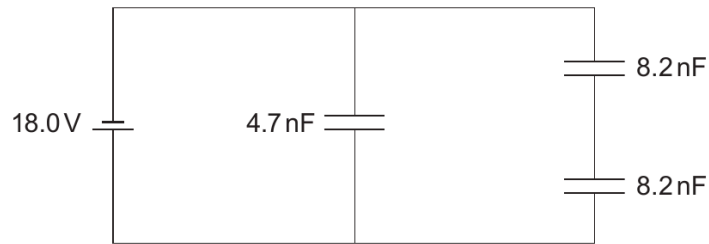


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**SECTION A**

Answer **all** questions.

1. This question is about capacitors in the following circuit.



(a) (i) Calculate the charge stored by each of the capacitors. [2]

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(ii) Calculate the total energy stored by all three capacitors. [2]

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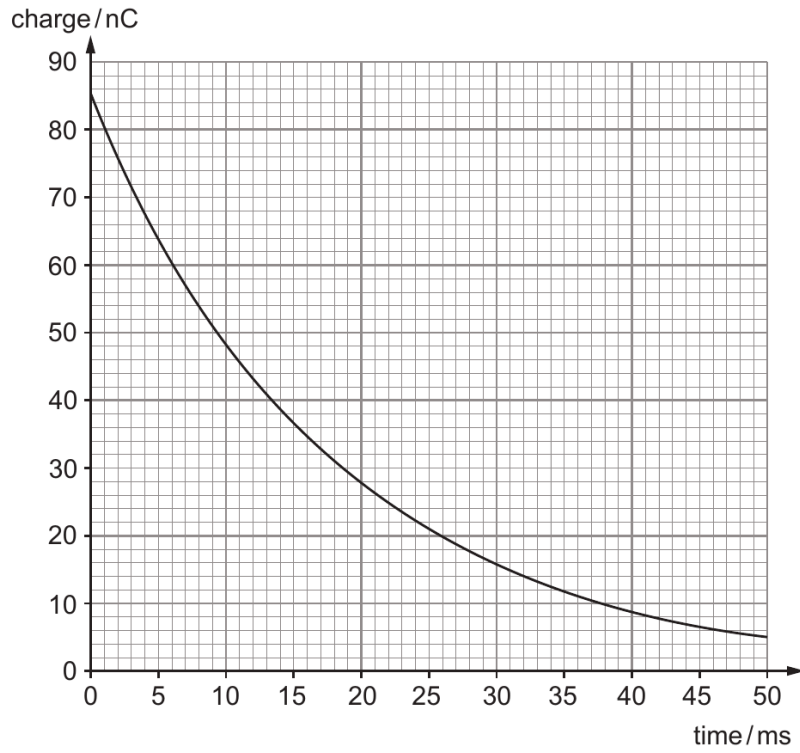
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(b) The 4.7 nF capacitor is discharged through an unknown resistor and the following graph is obtained.



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(i) Calculate the resistance of the resistor. [3]

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(ii) Calculate the current when  $t = 0$  s. [2]

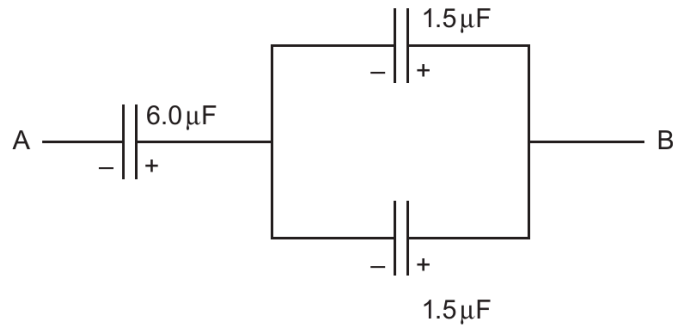
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3. (a) Calculate the capacitance of the combination of capacitors shown. [3]

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(b) Explain why the  $6.0\ \mu\text{F}$  capacitor stores the same amount of energy as one of the  $1.5\ \mu\text{F}$  capacitors. [2]

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(c) When the  $6.0\mu\text{F}$  capacitor is discharged through an unknown resistor, its charge drops from  $74.4\mu\text{C}$  to  $37.2\mu\text{C}$  in a time of  $35\text{ms}$ . Calculate:

(i) the unknown resistance; [3]

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(ii) the initial current in the circuit as the  $6.0\mu\text{F}$  capacitor discharges. [3]

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## END OF QUESTION PACK

***7 questions · 82 marks · ~1 h 45 min***

Mark schemes available from WJEC and Physics & Maths Tutor.