11.3 Capacitance

Question Paper

Course	DP IB Physics
Section	11. Electromagnetic Induction (HL only)
Topic	11.3 Capacitance
Difficulty	Medium

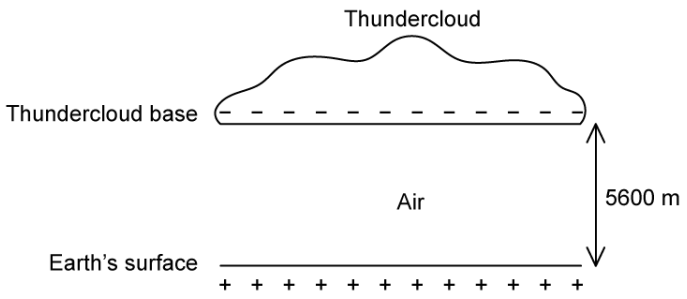
Time allowed: 70

Score: /55

Percentage: /100

Question 1a

A negatively charged thundercloud above the Earth's surface may be modelled by a parallel plate capacitor.



The lower plate of the capacitor is the Earth's surface and the upper plate is the base of the thundercloud.

The following data are available.

$$\text{Area of thunder cloud base} = 4.7 \times 10^{12}\ \text{cm}^2$$

$$\text{Distance of thundercloud base from Earth's surface} = 5600\ \text{m}$$

$$\text{Permittivity of air} = 8.8\ \text{pF m}^{-1}$$

Lightning takes place when the capacitor discharges through the air between the thundercloud and the Earth's surface. The time constant of the system is 48 ms. A lightning strike lasts for 25 ms.

(a)
Show that the capacitance of this arrangement is $C = 740$ nF.

[2]

[2 marks]

Question 1b

The energy stored in the system is 1.2 GJ.

(b)

(i) Calculate in V, the potential difference between the thundercloud and the Earth's surface.

[2]

(ii) Calculate in C, the charge on the thundercloud base.

[2]

[4 marks]

Question 1c

(c)
Calculate, in A, the average current during the discharge.

[4]

[4 marks]

Question 1d

(d)

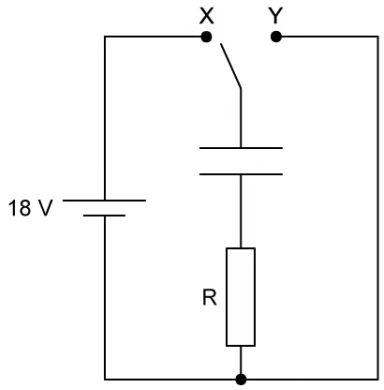
State **two** assumptions that need to be made so that the Earth-thundercloud system may be modelled by a parallel plate capacitor.

[2]

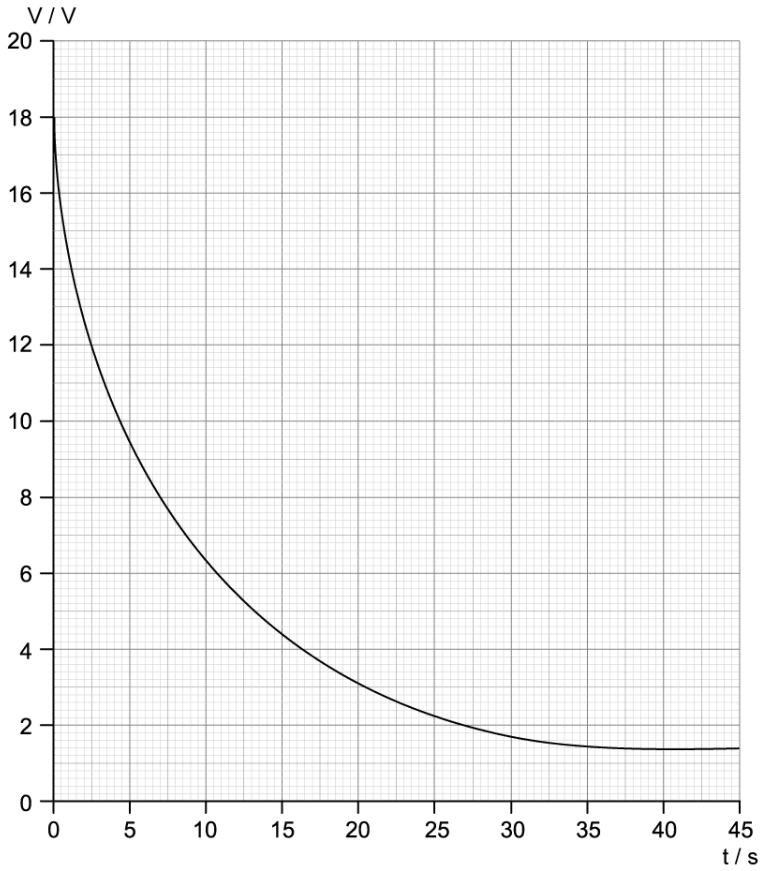
[2 marks]

Question 2a

An uncharged capacitor in a vacuum is connected to a cell of emf 18 V and negligible internal resistance. A resistor of resistance *R* is also connected.



At *t* = 0 the switch is placed at position Y. The graph shows the variation with time *t* of the voltage *V* across the capacitor. The capacitor has capacitance 2.8 μF in a vacuum.



(a)
On the axes, draw a graph to show the variation with time of the voltage across the resistor when the switch is placed at position X.

[2]

[2 marks]

Question 2b

(b)
Show that the resistance *R* is about 3.0 MΩ.

[3]

[3 marks]

Question 2c

(c)
Outline the effects of inserting a dielectric between the plates of the fully charged capacitor.

[2]

[2 marks]

Question 2d

The permittivity of the dielectric material in (c) is 2.5 times that of a vacuum.

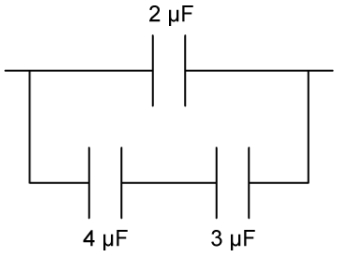
(d)
Show that the energy stored in the capacitor is about 1.1 mJ when it is at position X for some time.

[2]

[2 marks]

Question 3a

Three capacitors are connected below.



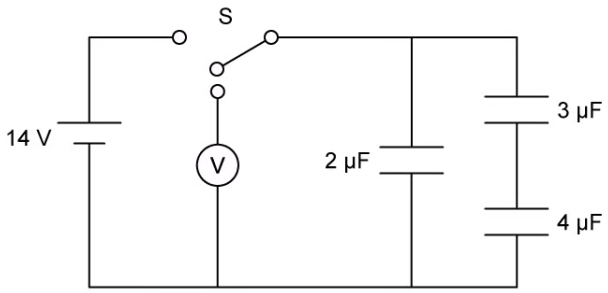
(a)
Calculate the combined capacitance of the capacitors.

[3]

[3 marks]

Question 3b

The capacitors are now connected in a circuit. A two-way switch S can connect the capacitors either to a d.c. supply, of e.m.f. 14 V, or to a voltmeter.



The switch is first connected to the d.c. supply.

(b)
Explain why the energy stored in the 2 μF capacitor is greater than the energy stored by the combined 3 μF and 4 μF capacitors.

[4]

[4 marks]

Question 3c

The switch S is moved to connect the charged capacitors to the voltmeter. The voltmeter has an internal resistance of 25 MΩ.

(c)
State and explain how the capacitors will discharge.

[2]

[2 marks]

Question 3d

(d)
Calculate the time *t* taken for the voltmeter reading to fall to half of its initial reading.

[3]

[3 marks]

Question 4a

A capacitor consists of two parallel square pieces of aluminium separated by a vacuum 1.5 mm apart. The capacitance of the capacitor is 2.9 nF

(a)
Calculate the length of one side of the plates.

[3]

[3 marks]

Question 4b

A sheet of plastic film is placed between the foil which has $\varepsilon = 5\varepsilon_0$.

It begins to conduct when the electric field strength in it exceeds 4.3 MN C^{-1}.

(b)

(i)

Calculate the maximum charge that can be stored on the capacitor.

[3]

(ii)

Explain why the plastic film does not conduct below an electric field strength of 4.3 MN C^{-1}.

[1]

[4 marks]

Question 4c

(c)

Show that the change in maximum potential difference between the capacitor before and after the plastic film was introduced Is 26 kV.

[3]

[3 marks]

Question 4d

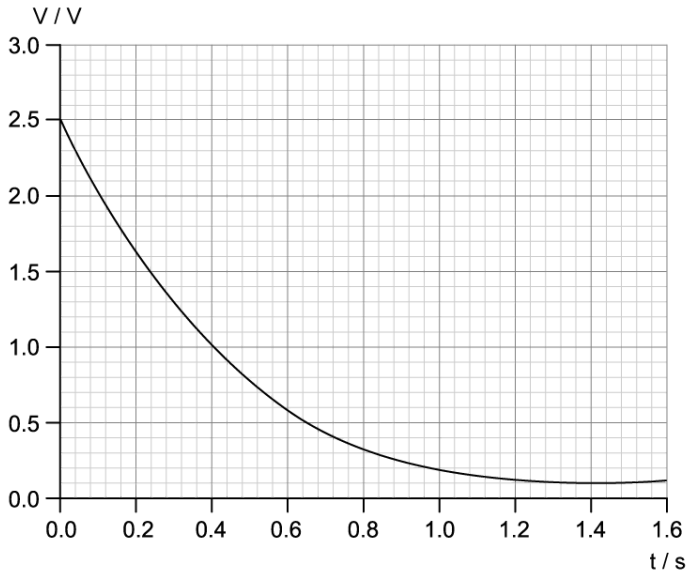
(d)
Explain how the energy stored in the capacitor changes when the plastic film has been added.

[3]

[3 marks]

Question 5a

A capacitor of capacitance C_1 is discharged through a resistor of 550 MΩ. The graph shows the variation with time t of the voltage V across the capacitor.



(a)
Calculate the value of C_1.

[3]

[3 marks]

Question 5b

The capacitor is changed to one of value 2 C_1 and the resistor to one that is 1100 MΩ.

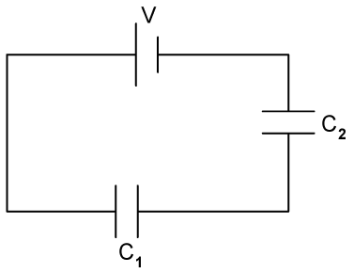
(b) Sketch on the graph the variation with *t* of *V* when the new combination is discharged.

[2]

[2 marks]

Question 5c

The capacitor from part (a) is now connected in series with another capacitor of capacitance, C_2. They are both fully charged by a potential difference *V*. Their combined capacitance is 0.3 nF.



(c)
Calculate the value of C_2.

[2]

[2 marks]

Question 5d

Each capacitor holds a charge of 3.6 nC.

(d)
Calculate the value of *V*.

[2]

[2 marks]