Access Tuition

A-Level Physics

Capacitance

Question Paper

Time available: 71 minutes
Marks available: 48 marks

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1. A capacitor of capacitance 63 pF is made from two parallel metal plates separated by an air gap. The capacitor is charged so that it stores a charge of 7.6×10^{-10} C; it is then isolated.

A sheet of mica of dielectric constant 6.0 is inserted between the plates so that it completely fills the space between them. The mica does not discharge the capacitor and does not change the separation of the plates.

(a) Explain what is meant by a dielectric constant of 6.0

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(1)

(b) Mica is made up of polar molecules. As the mica is inserted, the capacitance of the capacitor changes.

Explain how the polar molecules cause this change in capacitance.

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(3)

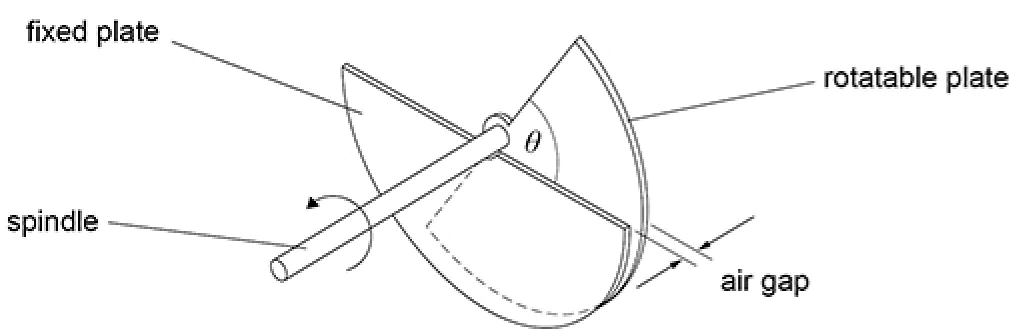
(c) Calculate the difference between the initial energy stored by the capacitor and the energy stored when the mica has been fully inserted.

energy difference = _______________ J

(3)

Figure 1 shows the structure of a variable capacitor used for measuring angular movement. The capacitor consists of two semicircular metal plates. These plates are parallel and are separated by an air gap.

Figure 1

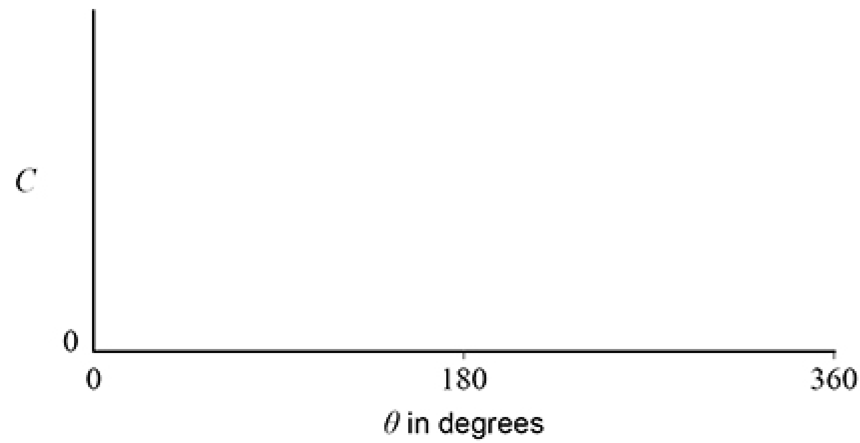


To vary the capacitance, one of the plates is rotated through an angle θ using the spindle. The other plate remains fixed.

(d) Sketch a graph on **Figure 2** to show how the capacitance C varies with θ as the spindle is turned through 360°.

When θ is 0°, the plates completely overlap.

Figure 2



(2)

(e) In one situation, the variable capacitor is too large for the available space.

The same maximum capacitance is required using plates that have half the diameter of the original capacitor.

Explain, with numerical detail, **two** ways in which this can be achieved.

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2 ____

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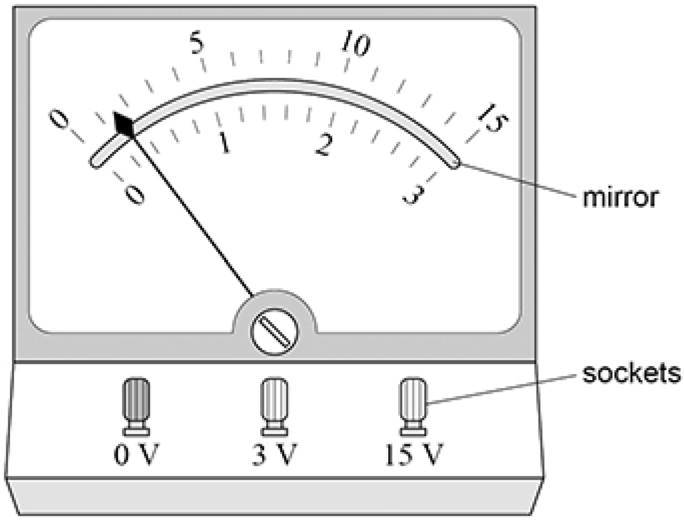
(3)

(Total 12 marks)

2. An analogue voltmeter has a resistance that is much less than that of a modern digital voltmeter.
Analogue meters can be damaged if the full-scale reading is exceeded.
Figure 1 shows a dual-range analogue voltmeter with a zero error.

Figure 1



(a) The voltmeter is set to the **more sensitive** range and then used in a circuit.

What is the potential difference (pd) between the terminals of the voltmeter when a full-scale reading is indicated?

Tick (✓) **one** box.

2.7 V	☐
3.3 V	☐
13.5 V	☐
16.5 V	☐

(1)

(b) Explain the use of the mirror when reading the meter.

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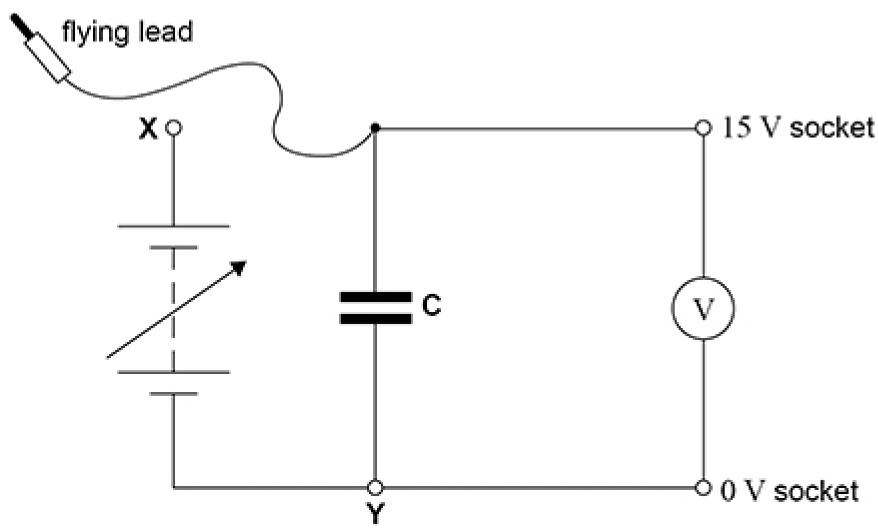
(2)

A student corrects the zero error on the meter and then assembles the circuit shown in **Figure 2**.
The capacitance of the capacitor **C** is not known.

Figure 2



The output pd of the power supply is set to zero.
The student connects the flying lead to socket **X** and adjusts the output pd until the voltmeter reading is full scale (15 V).
She disconnects the flying lead from socket **X** so that **C** discharges through the voltmeter.

She measures the time $T_{½}$ for the voltmeter reading V to fall from 10 V to 5 V.

She repeats this process several times.

Table 1 shows the student's results, **none** of which is anomalous.

Table 1

$T_{½}$ **/ s**	12.00	11.94	12.06	12.04	12.16

(c) Determine the percentage uncertainty in $T_{½}$.

percentage uncertainty = ________________ %

(2)

(d) Show that the time constant for the discharge circuit is about 17 s.

(1)

(e) The student thinks that the time constant of the circuit in **Figure 2** is directly proportional to the range of the meter.
To test her theory, she repeats the experiment with the voltmeter set to the 3 V range.
She expects $T_{½}$ to be about 2.5 s.

Explain:

- what the student should do, before connecting capacitor **C** to the 0 V and 3 V sockets, to avoid exceeding the full-scale reading on the voltmeter
- how she should develop her procedure to get an accurate result for the time constant
- how she should use her result to check whether her theory is correct.

(4)

The student wants to find the resistance of the voltmeter when it is set to the 15 V range.
She replaces **C** with an 820 μF capacitor and charges it to 15 V.
She discharges the capacitor through the voltmeter, starting a stopwatch when V is 14 V.
She records the stopwatch reading T at other values of V as the capacitor discharges.

Table 2 shows her results.

Table 2

***V* / V**	14	11	8	6	4	3	2
***t* / s**	0.0	3.1	7.2	11.0	16.2	19.9	25.2

(f) Suggest **two** reasons why the student selected the values of V shown in **Table 2**.
Explain each of your answers.

1 ____

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2 ____

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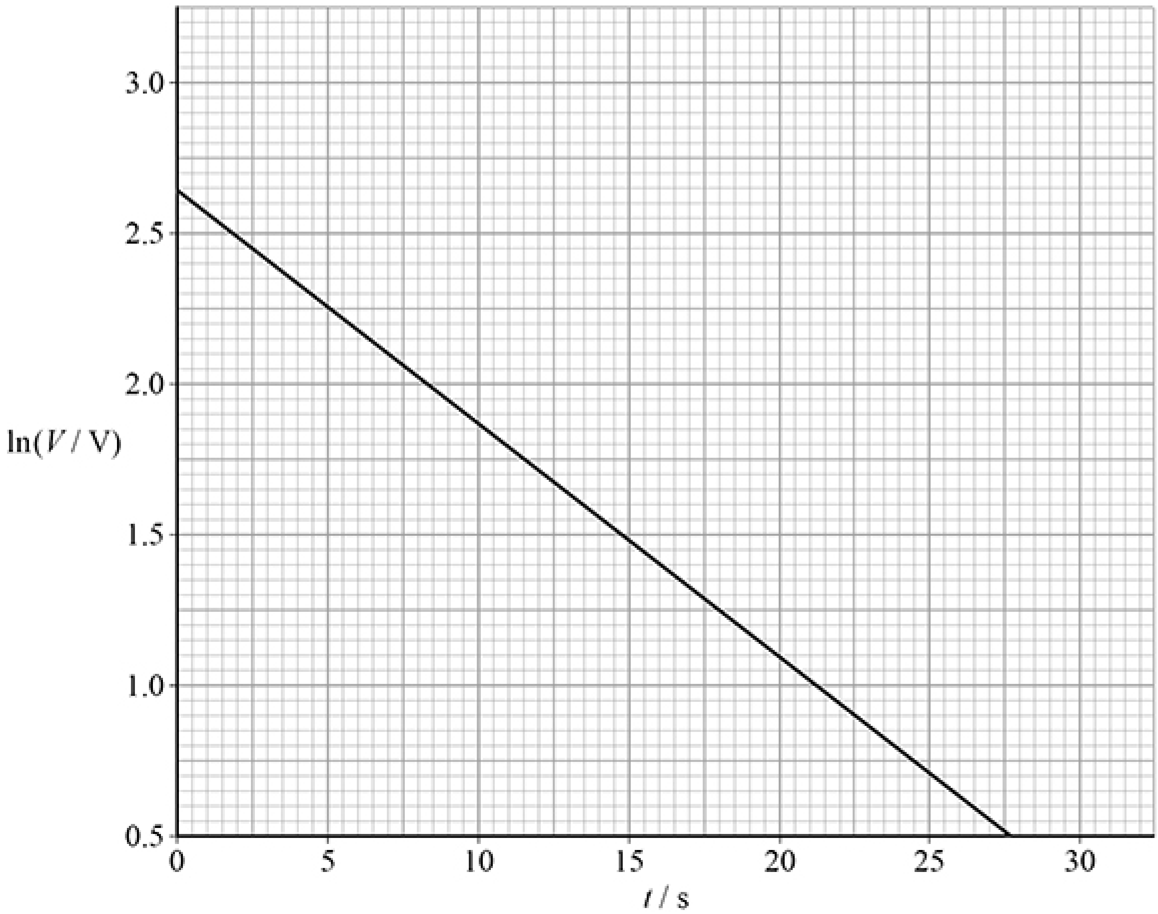
(4)

Figure 3 shows a graph of the experimental data.

Figure 3



(g) Show, using **Figure 3**, that the resistance of the voltmeter is about 16 kΩ.

(3)

(h) Determine the current in the voltmeter at t = 10 s.

current = _______________ A

(2)

(Total 19 marks)

3. (a) State what is meant by a capacitance of 370 μF

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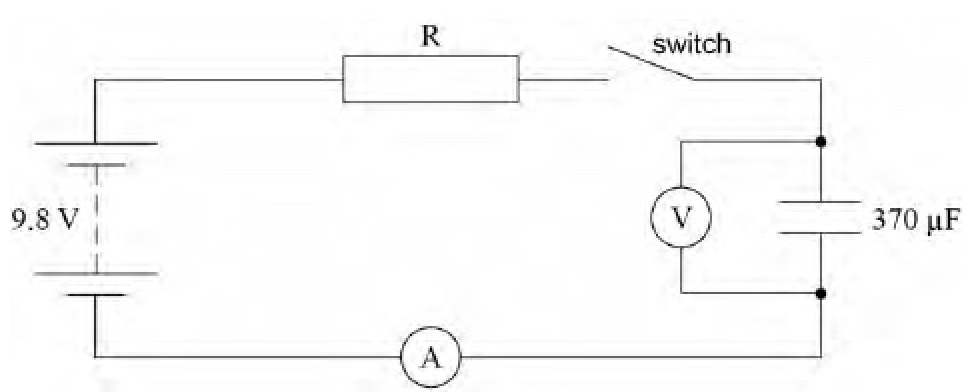
(2)

(b) The charging of a 370 μF capacitor is investigated using the circuit shown in **Figure 1**. Both meters in the circuit are ideal.

Figure 1



The power supply of emf 9.8V has a negligible internal resistance. The capacitor is initially uncharged. When the switch is closed at time t = 0 charge begins to flow through resistor R. The time constant of the charging circuit is 1.0 s

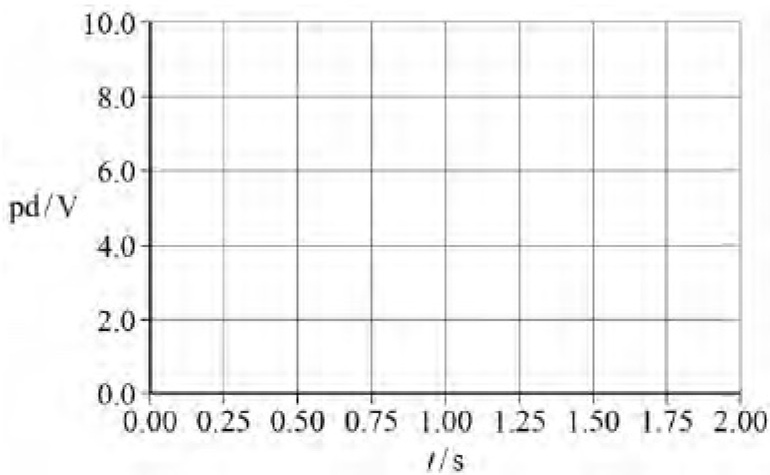
Calculate the resistance of R.

resistance of R = ____________________ Ω

(1)

(c) Identify, with the symbol X on **Figure 2**, the potential difference (pd) across the capacitor when the switch has been closed for 2.0 s
Sketch the graph that shows how the pd varies from t = 0 to t = 2.0 s

Figure 2



(2)

(d) Calculate the time taken for the charging current to fall to half its initial value.

time = ____________________ s

(1)

(e) Calculate the time taken for the charge on the capacitor to reach 3.0 mC

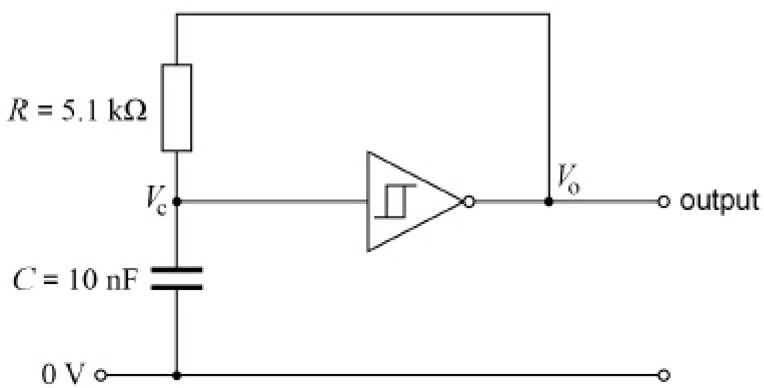
time = ____________________ s

(3)

(Total 9 marks)

4. (a) **Figure 1** shows an astable circuit based on a NOT logic gate. The symbol in the centre of the logic gate means that the output V_o changes at two different input values of V_c depending on whether the input voltage is rising or falling.

Figure 1



The pulse repetition frequency (PRF) for this particular circuit is given by:

$$\frac{1}{1.4\,RC}$$

Calculate the PRF in kHz

PRF = ____________________ kHz

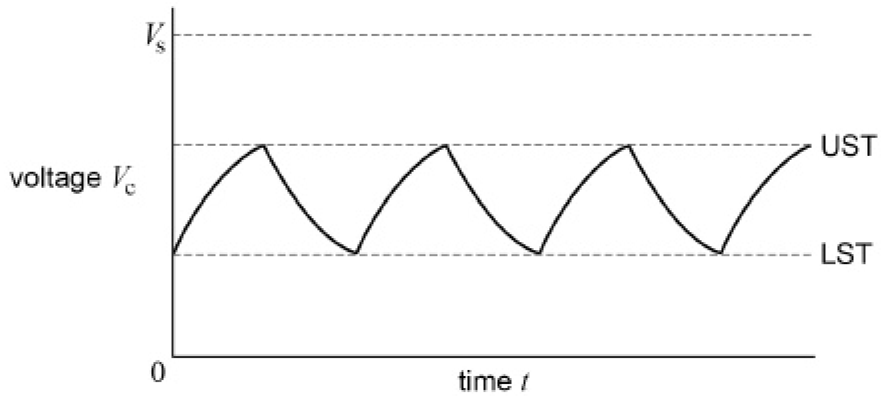
(1)

(b) The supply voltage to the NOT gate is V_s

- When V_c increases and reaches the upper switching threshold (UST), the output of the NOT gate will switch from V_s to 0 V
- When V_c decreases and reaches the lower switching threshold (LST), the output of the NOT gate will switch from 0 V to V_s

The graph in **Figure 2** shows V_c constantly changing as the capacitor charges and discharges.

Figure 2



Draw on **Figure 2** the output voltage V_o for the astable circuit.

(1)

(c) The circuit in **Figure 1** can be modified by the addition of a resistor to vary the PRF.

The astable is to be modified so that it produces a frequency 4 times that of the original.

Calculate the value of the resistor that should be added to the circuit and explain where in the circuit this additional resistor should be placed.

value of resistor = ____________________ kΩ

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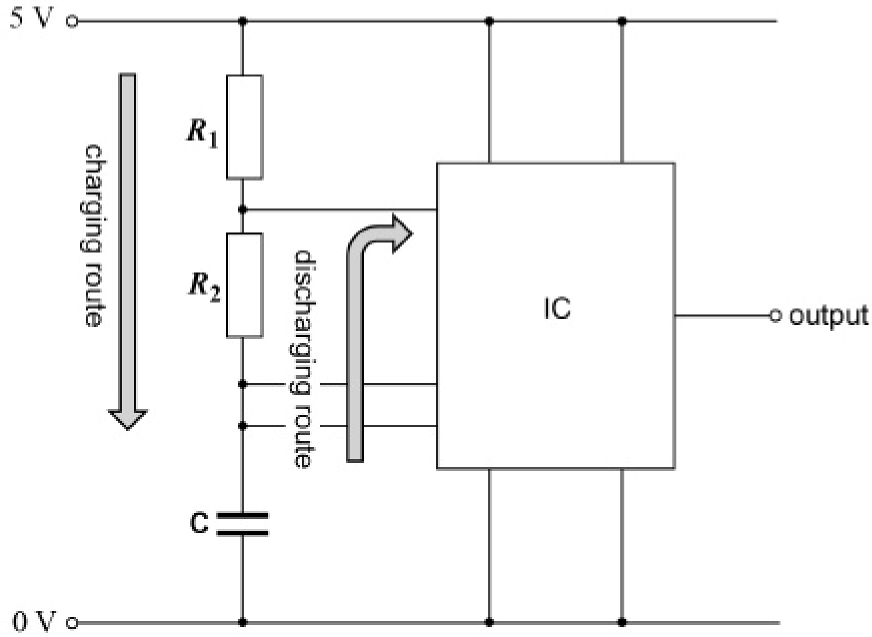
(2)

(d) In another astable, two resistors (R_1 and R_2) and a capacitor **C** form a timing chain to control the mark and space times for a square wave produced at the output of the integrated circuit (IC) shown in **Figure 3**.

Figure 3



The charging time for the capacitor **C** is: $t_C = 0.7 \times (R_1 + R_2) \times C$

The discharging time for the capacitor **C** is: $t_D = 0.7 \times R_2 \times C$

Calculate, in kΩ, values for R_1 and R_2 needed to produce a 5 kHz signal with 75% duty cycle given that the capacitor **C** has a value of 10 nF

R_1 = ____________________ kΩ

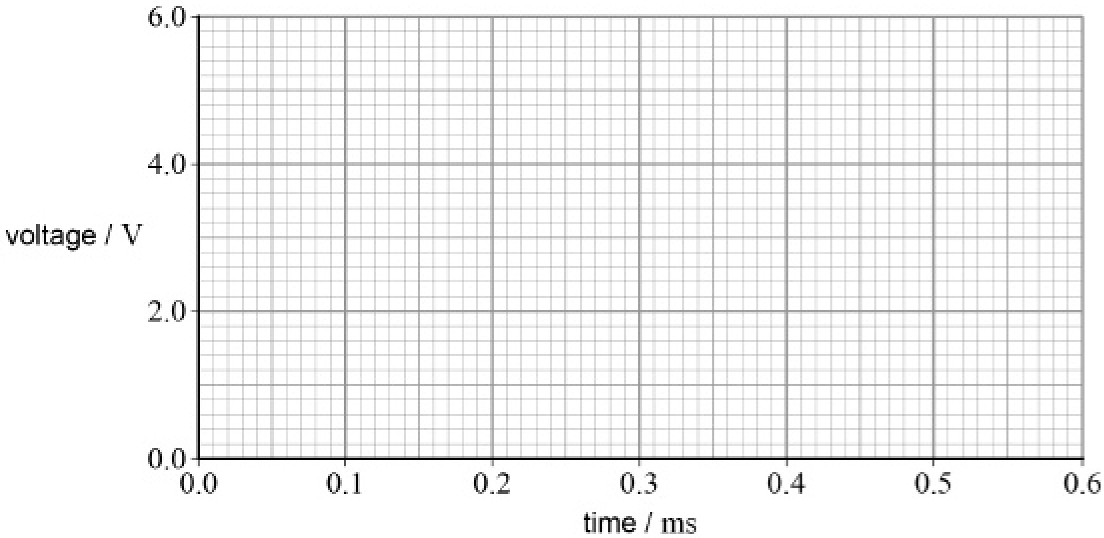
R_2 = ____________________ kΩ

(2)

(e) The output of the IC in **Figure 3** is 5 V during the charging period and 0 V during the discharging period.

Draw on **Figure 4** the wave pattern that represents this signal.

Figure 4



(2)
(Total 8 marks)