A-Level Physics

Capacitance

Mark Scheme

Time available: 71 minutes
Marks available: 48 marks

1. (a) (Dielectric constant is) $\frac{\text{permittivity of medium}}{\text{permittivity of free space}}$ and is equal to 6 ✓

OR

The permittivity of the dielectric is 6 times the permittivity of free space

Allow: $\frac{C \text{ with dielectric (between plates)}}{C \text{ in a vacuum}}$ *= 6.*

Its not enough to quote relative permittivity = 6

1

(b) (Electric field exists between plates)

Polar molecules align with their positive side facing the negative plate (owtte) ✓$_1$

✓$_1$ or vice versa.

producing a counter electric field/reducing the field between the plates ✓$_2$

The pd V reduces between the capacitor plates but charge Q remains the same so capacitance Q/V increases. ✓$_3$

✓$_3$ This mark may be approached from the idea that more charge would be required to maintain pd hence C increases by referencing $C = Q/V$

3

(c) Q remains the same ✓$_1$

New C is 6 × previous C ✓$_2$

✓$_2$ May be seen in the substitution in the energy difference calculation

Energy difference = 3.8×10^{-9} J ✓$_3$

✓$_3$ Calculates change in energy using $E = ½Q^2\left(\frac{1}{c_2} - \frac{1}{c_1}\right) = 4.58 \times 10^{-9} - 7.64 \times 10^{-10}$

Where $Q = 7.6 \times 10^{-10}$ *C :* $c_1 = 63 \times 10^{-12}$ *F*

and $c_2 = 6 \times 63 \times 10^{-12}$ $E = 378 \times 10^{-12}$ *J*

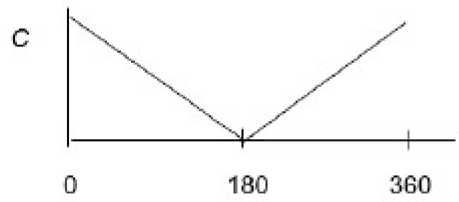
Condone a negative final answer

If no marks given award single mark for the initial energy stored = 4.58×10^{-9} *J*

3

(d) showing a linear decrease and increase ✓

points correct at 0, 180 and 360 degrees ✓



Ignore graph beyond 360 degrees

2

(e) Insert dielectric between plates/attach dielectric to one plate
OR reduce air gap explained ✓

Dielectric has $\varepsilon_r = 4$ ✓

air gap reduced to ¼ ✓

1st mark for <u>quantitative</u> answer for air gap or dielectric or both.

(Allow: more plates when explained)

*2nd and 3rd marks for numerical analysis for air gap **and** dielectric change. Do not allow incorrect physics.*

3

[12]

2. (a) tick in **first** box (2.7 V) ✓

[cao]

1

(b) move position until needle / pointer hides / is aligned with its reflection in the mirror or wtte $_1$✓

for $_1$✓ allow 'view scale so needle / pointer hides reflection';

condone 'there is no reflection'

this reduces / eliminates parallax error

OR

to ensure scale is read from directly above $_2$✓

for $_2$✓ reject 'reduces / eliminates human error'

allow 'reading is made when at right angles' / 'perpendicular to the scale';

reject 'view scale at eye level' / 'so not looking at an angle' / 'so not looking straight at needle'

2

(c) average $T_{½}$ correct

OR

uncertainty in $T_{½}$ correct $_1$✓

for $_1$✓ average $T_{½}$ = 12.04 (s); reject 12.0

allow credit for correct $T_{½}$ seen in working for percentage uncertainty;

uncertainty in $T_{½}$ (from half range) = 0.11 (s)

1

percentage uncertainty in $T_{½}$ correct $_2$✓

for $_2$✓ minimum 2 sf;

correct answer rounds to 0.91(4)%

1

(d) time constant = $\dfrac{\text{their mean } T_{½}}{\ln 2}$

OR

$\dfrac{-(\text{their mean } T_{½})}{\ln 0.5}$ ✓

expect 17.37 (s);

allow minimum 3 sf 17.4 / use of ln 2 = 0.69 for leading to 17.45;

reject use of $T_{½}$ = 12 leading to 17.31;

reject $\dfrac{\text{their mean } T_{½}}{\ln 0.5}$ (ignoring −sign in result)

1

(e) ways ensure pd across **C** doesn't exceed 3 V

before connecting **C** to **X** $_1$✓

as **X** is connected $_2$✓

*for $_1$✓ discharge **C** / connect flying lead to **Y** / 'reset to 0 V' (before reconnecting);*

reject 'reset equipment'

*for $_2$✓ reduce the <u>output pd</u> / socket **X** (or wtte) to ≤ 3 V (then reconnect **C** and adjust pd so meter reads full-scale);*

*reject 'only charge **C** to 3 V'*

idea of adding resistance to limit pd is neutral

Max 3

suggests timing for ΔV > 1.5 V or wtte $_{3a}$✓

OR

take repeated readings (of $T_{½}$ or time constant);

any valid processing eg calculate an average value / reject anomalies / check results are concordant or wtte $_{3b}$✓

check / correct / compensate for any <u>zero error</u> (on the voltmeter) $_4$✓

suggests a valid quantitative test of theory by comparison with the result obtained using the 15 V range $_5$✓

for $_{3a}$✓ accept 'increase timing interval' / time for concurrent half lives or wtte;

*reject 'measure time for **C** to fully discharge'*

for $_{3b}$✓ accept 'repeat the experiment and calculate a mean' only if this refers to

reject 'repeat etc to get more reliable result'

for $_4$✓ accept 'check etc for systematic error'

'student' is repeating previous experiment so reject idea of making V the dependent variable / plot V against t / using data logging

(theory will be correct if) half-life / time constant is one fifth / 20% (of previous value) / about 3.5 s / time constant reduced by 80% / ratio of time constant to range / ratio of half-life to range is same / similar

reject 'plot ln V against t, find ($-$gradient^{-1})'

1

(f) in answer space 1:

any valid comment about the values of V in **Table 2** $_1$✓

corresponding explanation $_2$✓ (contingent on $_1$✓)

give credit for any good physics, eg

V recorded to nearest volt $_1$✓

because of (low) scale resolution / hard to interpolate between markings; reject 'values easier to plot' $_2$✓

in answer space 2:

different valid comment about the values of V in **Table 2** $_3$✓

corresponding explanation $_4$✓ (contingent on $_3$✓)

different / decreasing intervals between values of V / more lower values of V $_3$✓

to make intervals between t readings about the same / or wtte; allow 'to distribute data on graph' or wtte / to allow (convenient interval for) t to be read / recorded $_4$✓

only credit one comment and explanation per answer space

comments about the number of data sets are neutral

no readings for V < 2 V / smallest V = 2 V $_{5}$✓

because difficult to establish exact moment to read stopwatch / needle is moving too slowly / sensible comment about parallax $_{6}$✓

V data over wide range / from 14 to 2 (V) $_{7}$✓

*to maximise evidence available (for graph / **Figure 8**) or wtte* $_{8}$✓

no readings for V > 14 V / largest V = 14 V $_{9}$✓

*can begin discharge **C** before starting stopwatch* $_{10}$✓

4

(g) attempts gradient calculation using $\Delta\ln(V\,/\,\mathrm{V})$ divided by Δt;

use of $|\text{gradient}| = \left|\frac{-1}{R \times C}\right|$ $_{1a}$✓

for $_{1a}$✓ expected gradient is −0.077;

condone one read-off error in gradient calculation or missing sign;

allow any subject / (at least) substitution of their gradient into a valid calculation for R

condone missing / wrong POT for capacitance

OR

reads off ln V_0, ln V and corresponding Δt from **Figure 3**;

use of $V = V_0 e^{-\frac{t}{RC}}$ $_{1b}$✓

for $_{1b}$✓ condone one read off error;

allow any subject / (at least) substitution of all their data into a valid calculation for R

condone missing / wrong POT for capacitance

$_{1b}$✓variation below:

reads off ln $V0$ and finds $V0$ = 14.1 (V);

$V = 0.37V_0$ when $t = RC \therefore V = 0.37V_0 = 5.2\,\mathrm{V}$

reads of ln 5.2 = 1.65; Δt ≈ 13 (s) $\therefore R = \frac{13}{C}$

valid working leading to

voltmeter resistance ≥ 3 sf in range 15.0 kΩ to 16.6 kΩ $_{2}$✓

voltmeter resistance ≥ 3 sf in range 15.5 kΩ to 16.1 kΩ $_{3}$✓

accept > 3 sf that rounds to 3 sf in range

allow $_{23}$✓ = 1 MAX for POT error

*allow $_{123}$✓ = 1 MAX for using **Table 2** data*

3

(h) reads $\ln(V_{10}$ / V) from **Figure 8**;

deduces V_{10} in range 6.36 to 6.69 (V) $_1$✓

for $_1$✓ V_{10} to ≥ 3 sf required;

accept > 3 sf that rounds to 3 sf in range;

accept V_0 from ln V_0 read off and V_{10} deduced

from $V_{10} = V_0 e^{\frac{-10}{CR}}$;

condone use of V_0 = 15(V);

if V_{10} is not recorded allow $_1$✓ for use of $e^{\ln V_{10}}$ in the calculation of I_{10} where $\ln(V_{10}$ / V) is in the range 1.85 to 1.90

1

≥ 2 sf result in range 3.9 to 4.3 × 10^{-4} (A) $_2$✓

for $_2$✓ allow use of resistance = 16 × 10^3 (Ω);

accept ≥ 3 sf result that rounds to 2 sf in range

*allow ECF if V10 is **correctly obtained** from an incorrect $\ln(V_{10}$ / V) read off and I_{10}*

calculated using $\dfrac{\text{their } V_{10}}{\text{their voltmeter resistance}}$

1

[19]

3. (a) (Refers to a capacitor that) stores/holds/changes by 370 μC of charge ✓

For every (1) volt/volt change (of pd across its plates) ✓

OR

Reference to charge to pd OR charge to voltage ratio ✓ includes units C or coulomb and V or volt ✓

"Unit of pd" is no substitute for using volt and "unit of charge" is no substitute for coulomb.

However the alternative marking could give a single mark for 370 × 10^{-6} units of charge per unit of pd.

An equation may contribute towards the first mark but only if the symbols are identified. A second mark can be given if the units are identified.

Ignore poor phrasing like 'per unit volt passing through'.

2

(b) (Using time constant = *R C*)

(R = 1.0 / 370 × 10^{-6})

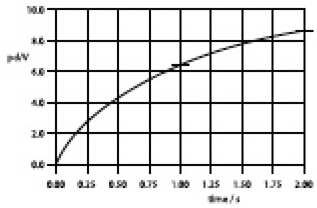
R = 2.7 × 10^3 (Ω) ✓

Check that the unit on answer line has not been altered.

1

(c) First mark for marking a cross at 2 s and 8.5 V (by eye) ✓

Second mark for graph starting at the origin and having a decreasing gradient ie not reaching horizontal ✓



Cross must be in the bottom half but not on the 8.0 V major grid line or exactly half way up (9.0 V).

If a series of plotting crosses are given only consider the one placed at 2 s for the first mark.

2

(d) (Using $T½ = 0.69\,RC = 0.69 \times 1.0$)

$T½ = 0.69$ (s) ✓

1 sig fig is not acceptable

1

(e) (Use of $Q = Q_o(1 - e^{-\frac{t}{RC}}) = CV_o\,(1 - e^{-\frac{t}{RC}})$)

Mark for max charge = CV_o which may come from substitution or seeing $3.6(2) \times 10^{-3}$ C ✓

$3.0 \times 10^{-3} = 370 \times 10^{-6} \times 9.8\,(1 - e^{-t})$ ✓

Mark for substitution ($0.8274 = (1 - e^{-t})$ so $e^{t} = 1/0.173 = 5.79$)

$t = 1.7$ s or 1.8 s ✓

OR

Voltage $V = Q/C = 3 \times 10^{-3} / 370 \times 10^{-6}$
= 8.1(1) V ✓

(Substitute into $V = V_0(1 - e^{-\frac{t}{RC}})$)

$8.1 = 9.8\ (1 - e^{-t})$ ✓

t = 1.7 s or 1.8 s ✓

Alternative mark scheme uses the voltage as proportional to the charge.

Do not allow use of the graph for 2nd mark and 3rd mark.

An answer only gains only the last mark.

Evidence of working must be shown which shows substitution into a $(1 - e^{-t})$ form of the equation.

3

[9]

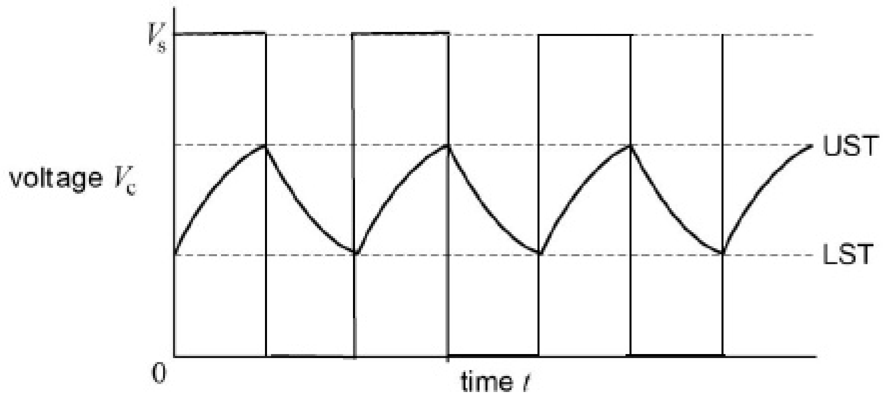
4. (a) PRF = 1 / (1.4 RC)

$= 1 / (1.4 \times 5.1 \times 10^3 \times 10 \times 10^{-9})$

14 kHz ✓

1

(b) Square wave with correct phase and amplitude ✓



1

(c) New resistor calculated and stated to be 1.7 kΩ ✓

New resistor placed in parallel with original resistor ✓

Ecf from part (a)

2

(d) $T = \frac{1}{f} = \frac{1}{5 \times 10^3}$ = 0.2 ms (200 μs)

$t_C = 0.2 \times 10^{-3} \times \frac{3}{4}$ = 150 μs

$t_D = 0.2 \times 10^{-3} \times \frac{1}{4}$ = 50 μs

$R_2 = \frac{t_D}{0.7 \times C} = \frac{50 \times 10^{-6}}{0.7 \times 10 \times 10^{-9}}$ = 7.1 kΩ (Accept 7kΩ)

$R_1 = \frac{t_C}{0.7 \times C}$ – R2 = 14.3 kΩ (Accept 14kΩ)

1 mark for significant calculation
Eg showing $R_1 = 2R_2$
OR
Calculation for t_C or t_D
1 mark for values of R_1 and R_2

2

(e) Two properties per mark – (max mark 2)✔✔

- A square wave
- Amplitude of 0 V to 5 V
- Periodic time of 0.2 ms
- High for 0.15 ms – Low for 0.05 ms

2

[8]