Mark schemes

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*

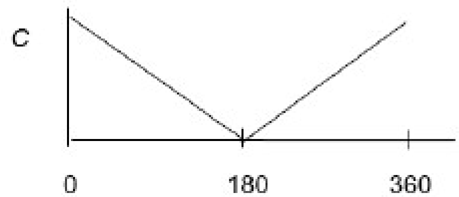
Condone a negative final answer

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 quantitative answer for air gap or dielectric or both.

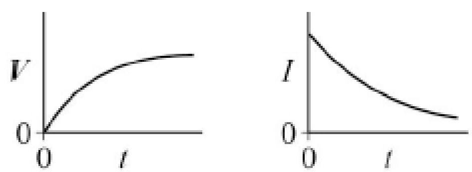
(Allow: more plates when explained)

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

3

[12]

2. D



[1]

3. C

[1]

4. A

[1]

5. (a) $V_{rms}\left(=\frac{V_{peak}}{\sqrt{2}}=\frac{15}{\sqrt{2}}\right)=10.6\text{ (V)}$ ✓

{allow 11 V to 2 sig figs}

1

(b) (Peak voltage 3 divisions corresponding to 15 V)

y-voltage gain = 5 (V div^{-1}) ✓

1

(c) A horizontal line drawn at 10.6 V ✓

Tolerance – must be between 10 and 11 up from the centre

Allow ecf from (a)

1

(d) (Period T = corresponds to 8 divisions
$T = 8 \times 5.0 \times 10^{-4}$ s = 0.0040 s
Frequency = $1/T$ = 1/0.0040) = 250 (Hz) ✓

Answer only gains the mark.

1

(e) Time constant = 4×10^{-4} (s) ✓$_1$ {only needs 1 sig fig}

The second and third mark can come from the following alternatives.
Note the mark is for the method so allow arithmetic slips and imprecise measurements.

To use a number of small divisions rather than grid divisions is not an arithmetic error. This error comes from not knowing how the oscilloscope is used.
Full marks can be awarded from consideration of the charging part of the cycle.

The equation can be presented in a number of variations using RC or τ for example.

Make use of the equation $V_t = V_0 e^{-\frac{t}{\text{time constant}}}$ ✓$_{2a}$

Substitute values for V_t and V_0 (confirmed by the graph) and calculate the (unknown) time constant. ✓$_{3a}$

Typical calculation might be:

$\frac{V_t}{V_0} = \frac{1}{12}$ *in 2 time divisions. Substitution into the equation will give τ*

V_t and V_o both need to be defined in relation to the graph

OR

Ln2 (= 0.69) $= \frac{t_{\frac{1}{2}}}{\text{time constant}}$ ✓$_{2b}$

Substitute time for V to decrease to half its value (confirmed by the graph) and calculate the time constant ✓$_{3b}$

OR

V halves its value in 0.5 time divisions.

Substituting gives τ

$t_{\frac{1}{2}}$ needs to be defined in relation to the graph

OR

The voltage falls to 1/*e* or 37% in a time constant ✓$_{2c}$ {owtte}
Find the time that corresponds to this fall in voltage confirmed by the graph (normally the start of the discharge This gives the τ directly) ✓$_{3c}$

OR
37% of 3 divisions is 1.1 divisions which occurs in time ¾ time divisions giving τ

3

(f) Reduce the time-base setting ✓$_{1a}$

Uncertainty is due to the smallness of the divisions and this action means the waveform/trace stretched horizontally/in x-direction. ✓$_{2a}$ {owtte}

OR

Increase the y-gain ✓$_{1b}$

Uncertainty is due to the smallness of the divisions and this action means the waveform/trace stretched vertically/in y-direction. (The trace will need to be moved vertically to fit on the screen) ✓$_{2b}$ {owtte}

$_1$ Stated answer must be a practicable change

$_2$ Explanation must refer to both the trace and its relation to uncertainty and follow a correct change.

2

[9]

6. **A**

[1]

7. **A**

[1]

8. **A**

[1]

9. (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 $t = RC$ $\therefore V = 0.37V_0 = 5.2$ 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 $\frac{\text{their } V_{10}}{\text{their voltmeter resistance}}$

1

[19]

10. **C**

[1]

11. **C**

[1]

12. **B**

[1]

13. (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})

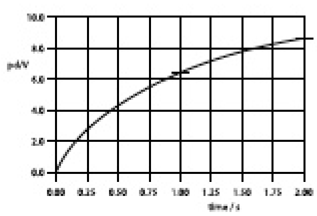
R = 2.7 × 10^3 (Ω) ✓

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]

14. **B**

[1]

15. **C**

[1]

16. **C**

[1]

17. (a) peak (to peak) voltage = 6.3(0) (V) ✓

accept any answer that rounds to 6.3 V

do not allow power of ten errors, eg 0.0063 V

1

(b) period = 8 divisions

(= $8 \times 0.5 \times 10^{-3}$ (s))

= 4 ms $_1$ ✓

$$\left(f = \frac{1}{T} = \frac{1}{0.004}\right)$$

= 250 (Hz) $_2$ ✓

award both marks if 250 Hz seen

accept 4.0(0) ms for $_1$ ✓ but reject 4.05, 3.95 etc

ecf$_2$ ✓ for wrong period

2

(c) any valid approach leading to *RC* in range

2.1×10^{-4} to 3.4×10^{-4} or 3×10^{-4} (s)

OR

their *T* in 02.2 × 0.069 ± 10 % $_{12}$ ✓ ✓

1 mark can be awarded for use of any valid approach in which *RC* is seen with substitutions or with rearranged equations, eg

$0.5 = 6.3e^{\frac{-6\times10^{-3}}{RC}}$ or $RC = \frac{-t}{\ln\left(\frac{V}{V_0}\right)}$ or

$RC = \frac{t}{\ln\left(\frac{V_0}{V}\right)}$

OR

$1.75 \times 10^{-4} = RC \times \ln 2$

OR

$RC = \frac{t_{0.5}}{\ln(2)}$

valid approaches;
reads off t when C starts to discharge and t at a lower value of V:

rearranges $V = V_0 e^{\frac{-\Delta t}{RC}}$ *to calculate RC*

for ecf $_2$ ✓ *Δt used must correspond to interpretation of time base used in determining the frequency in (b); there is no ecf for misinterpretation of the voltage scale*
OR
reads off t when C starts to charge and t at a higher value of V:

rearranges $V = V_0\left(1 - e^{\frac{-\Delta t}{RC}}\right)$ *to calculate RC etc*

OR

determines half-life $t_{0.5}$ *and finds RC from* $\frac{t_{0.5}}{\ln(2)}$

for ecf $_2$ ✓ $t_{0.5}$ *used must correspond to etc*
OR
uses idea that during discharge V falls to $0.37V_0$ *in one time constant: determines suitable V and reads off RC directly*

for ecf $_2$ ✓ *time interval used must correspond to etc*
OR

uses idea that during charging V rises to $0.63V_0$ *in one time constant: determines suitable V and reads off RC directly*

reject idea that V falls to zero in 5RC

2

(d) qualitative comment

idea that the waveform will stretch horizontally $_1$ ✓

quantitative comment

by a factor of $\left(\frac{0.5}{0.2} = \right) 2.5$ $_2$ ✓

OR

half a cycle now covers 10 (horizontal) divisions on the screen $_2$ ✓
(and also earns $_1$ ✓)

(so the) resolution of the time axis has increased $_3$ ✓ (and also earns $_1$ ✓)

measuring larger distance / across more divisions from the screen reduces (percentage) uncertainty in reading the time (constant / interval / half life) $_4$ ✓

for $_1$ ✓ look for reference to time axis or direction waveform is re-scaled

accept 'graph is longer/stretched' or 'will not see whole cycle' or 'fewer cycles shown' or 'period takes more space' or 'distance being measured is larger' or 'time per division is less' or 'larger in x direction' or 'time is stretched'

reject 'waveform becomes larger' or 'may not see whole cycle' or 'measuring larger time'

for $_2$ ✓ there needs to be valid quantitative detail

award $_{12}$ ✓✓ for 'half a cycle now fills the screen' or 'half a cycle is displayed' as these clearly recognise the stretching is along the time axis and 'half' is quantitative

accept 'new distance (on screen corresponding to half life or time constant) is 2.5 × answer shown in working for (c)'

the candidate who realises that half a wave now covers the complete width of the screen cannot claim this is a disadvantage; they would still be able to bring either half cycle into view by using the X-shift and find RC for $_3$ ✓ uses technical language correctly

ignore (but do not penalise) 'times are more precise' or 'more accurate'

reject 'smaller resolution' or 'lower resolution'

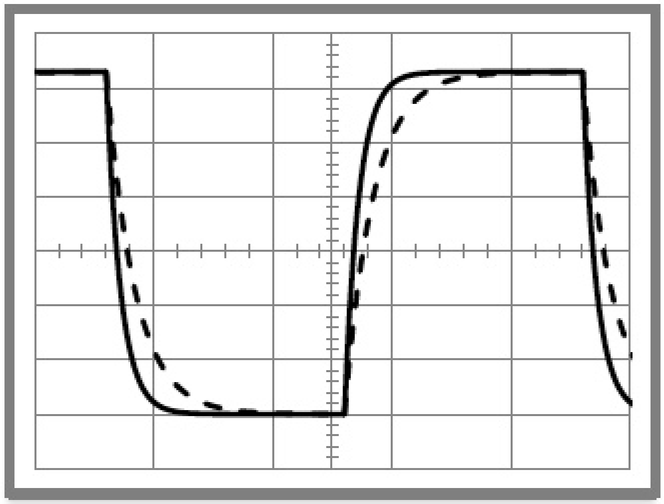
for 4 ✓ there needs to be a qualifying explanation for the comment about uncertainty

reject 'advantage because the (time) scale is easier to read'

3 MAX

(e) valid sketch on **Figure 7** showing discharge time to 0 V reduced and charging time to peak voltage reduced (see below) 1 ✓

connecting resistor in parallel with R halves [reduces by 50%] circuit [total] resistance [time constant] 2 ✓



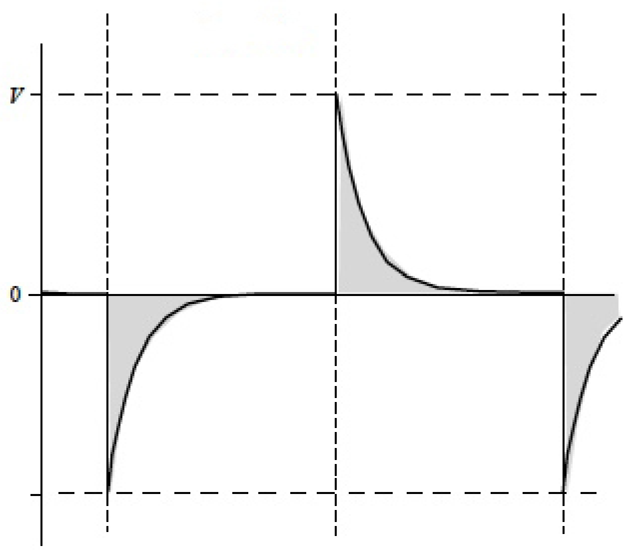
do not insist on seeing second discharge although if shown this must look correct

2

(f) amendment to **Figure 8** showing waveform across R with approximately the correct shape, amplitude ± *V* and the correct phase

correct waveform shown while signal generator output is low (0 V): only the complete negative half cycle needs to be shown but if second negative half cycle is included it must be correct 1 ✓

correct waveform shown while voltage across signal generator output is high; condone no signal or signal = 0 V before going to –V for the first time 2 ✓



don't insist on seeing vertical lines

2

(g) <u>reduce</u> the (sensitivity of) (Y-voltage)) <u>gain</u> $_1$ ✓

(change) to <u>2 V</u> division^{-1} $_2$ ✓ (and earns $_1$ ✓)

adjust the <u>Y</u> (vertical) <u>shift</u> $_3$ ✓

'make (Y-) gain smaller' or 'increase the volts per division' or 'reduce the Y-resolution' are acceptable substitutes for 'reduce the (Y-)gain'

<u>increase</u> the (Y-) gain to 2 V division^{-1} $_2$ ✓ not $_1$ ✓

<u>reduce</u> the (Y-) gain to 0.5 V division^{-1} $_1$ ✓ not $_2$ ✓

ignore any comment about time base or 'X-gain'

if all positive waveform is given for (f) allow sensible comment about triggering/stability control, eg

waveform may not be stable $_1$ ✓; adjust triggering $_2$ ✓

2 MAX

[14]

18. A **[1]**

19. D **[1]**

20. C **[1]**