SI Physics - Full Discipline Demo

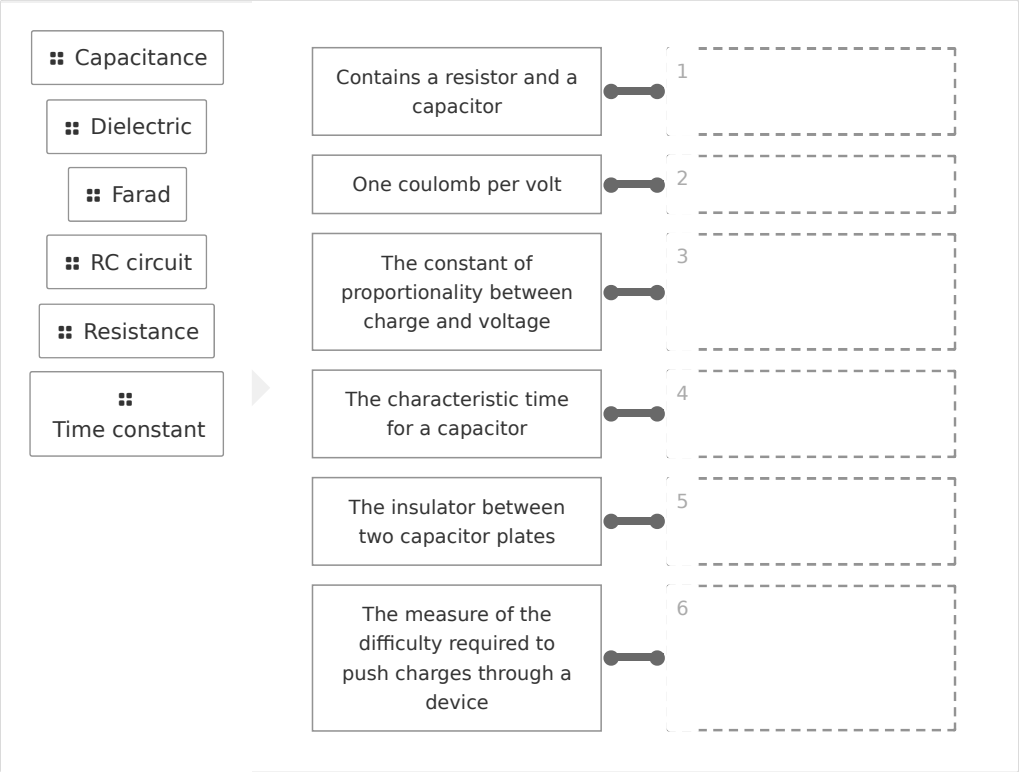
Discharge of a Capacitor

Final Report - Answer Guide

Institution	Science Interactive University
Session	SI Physics - Full Discipline Demo
Course	SI Physics - Full Discipline Demo
Instructor	Sales SI Demo

Test Your Knowledge

Match each term with the best description.



Correct answers:

1 RC circuit 2 Farad 3 Capacitance 4 Time constant

5 Dielectric 6 Resistance

Categorize each statement as true or false.

- A cylindrical capacitor is essentially a parallel-plate capacitor rolled into a tube.
- The dielectric constant indicates the distance by which the two plates of a capacitor are separated.
- The charge on a capacitor increases quickly at first, then much more slowly as the capacitor charges.
- The voltage across a capacitor in an RC circuit increases linearly during charging.
- One of the principle purposes of a capacitor is to store electric potential energy.
- A capacitor charges rapidly when connected to an RC circuit with a battery.

True	False
1	2

Correct answers:

1

A cylindrical capacitor is essentially a parallel-plate capacitor rolled into a tube.

The charge on a capacitor increases quickly at first, then much more slowly as the capacitor charges.

One of the principle purposes of a capacitor is to store electric potential energy.

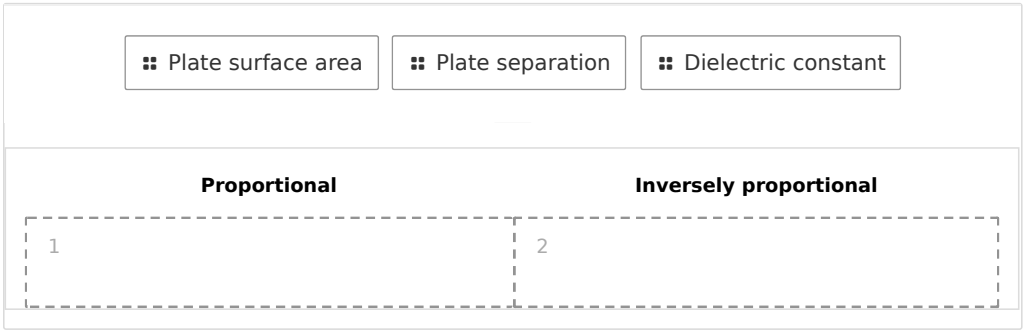
A capacitor charges rapidly when connected to an RC circuit with a battery.

2

The dielectric constant indicates the distance by which the two plates of a capacitor are separated.

The voltage across a capacitor in an RC circuit increases linearly during charging.

Categorize each factor as proportional or inversely proportional to capacitance.



Correct answers:

1 Plate surface area Dielectric constant 2 Plate separation

Exploration

The constant of proportionality between charge and voltage is the _____.

- capacitor
- capacitance ✔
- farad
- None of the above

The unit of capacitance is the _____.

- coulomb
- volt
- farad ✔
- None of the above

The insulator between the two plates of a capacitor is a ____.

- polarizer
- dielectric ✔
- electric field
- None of the above

A dielectric ____ the electric field between the two plates of a capacitor.

- decreases ✔
- increases
- does not affect
- None of the above

The amount of work required to separate the last two charges on a capacitor as it charges is ____ that of the first two charges.

- the same as
- less than
- greater than ✔
- None of the above

The larger the resistance of a resistor, the ____ the current that will pass through the resistor for a given voltage.

- smaller ✔
- larger
- faster
- None of the above

An ideal voltmeter has a resistance of _____ ohms.

- zero
- infinite ✔
- fifty
- None of the above

A charged capacitor in an open circuit will remain charged indefinitely.

- True ✔
- False

There is current in an RC circuit when the capacitor is fully charged.

- True
- False ✔

After one time constant, a discharging capacitor will have _____ percent of its initial charge.

- 63
- 37 ✔
- 0
- None of the above

After _____ time constant(s), a discharging capacitor is fully discharged.

- one
- three
- five ✔
- None of the above

Exercise 1

Why can the internal resistance of the DMM can be determined without taking into account the 100 Ω resistor? Could this be done for a resistor of any resistance value? Explain your answer.

The internal resistance of the DMM can be determined without accounting for the 100 Ω resistor because the resistance of the DMM is so much higher than that of the resistor – the 100 Ω resistance is essentially negligible due to the relative magnitude of the resistances (10^6 vs. 100). This cannot be done for all resistors; it can only be done with resistors with resistance values much lower than the internal resistance of the DMM.

How did the current change when the circuit was initially closed in Part 2 of this exercise? Explain your answer by referencing Panel 1 and the definitions of a capacitor and of current.

When the circuit was connected in Part 2, there was immediately current in the circuit and it quickly returned to zero. When the circuit is completed, charge begins to flow. The charge then builds up on the capacitor, limiting the number of charges moving and decreasing the current. Mathematically, this comes from the exponential time dependence of the charge build up (and thus current, which is the time-derivative of charge) for a charging capacitor.

A 500 µF capacitor is wired in series with a 5 V battery and a 20 kΩ resistor. What is the voltage across the capacitor after 20 seconds of closing the circuit? Show all calculations in your answer.

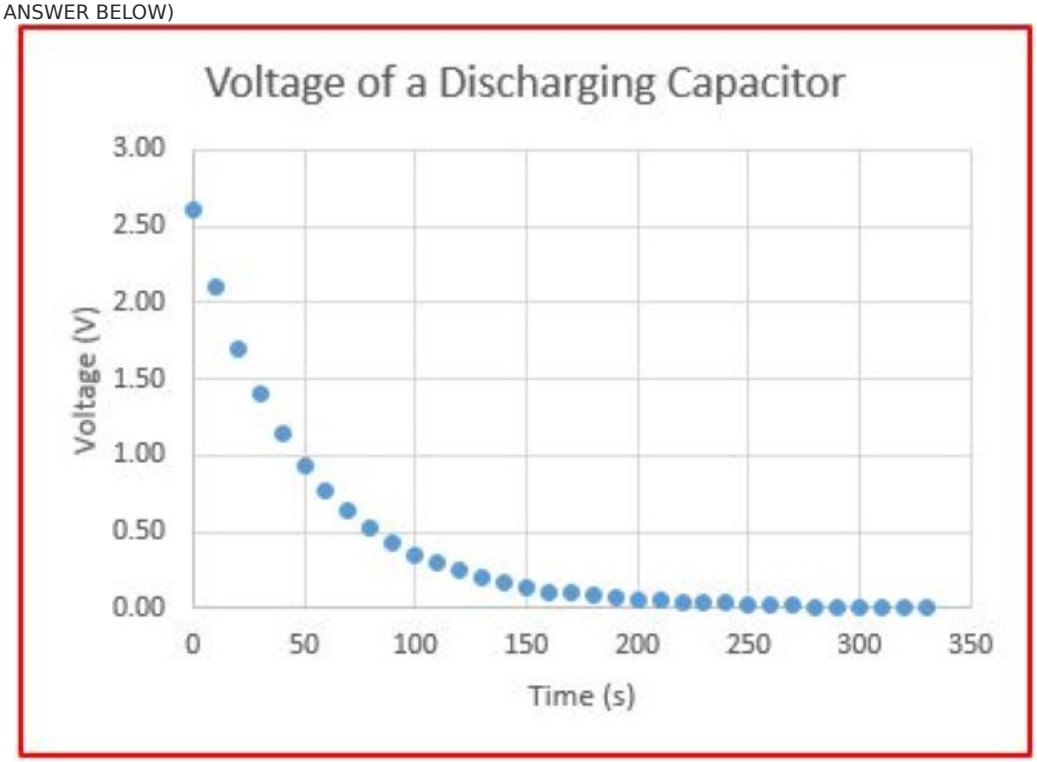
The voltage can be found using the equation: $V(t)=V_0(1-e^{(-t/\tau)})$. The time constant τ can be found using $\tau = RC = (20*10^3\ \Omega)*(500*10^{-6}\ F) = 10$ s. Thus, the voltage at t=20 s is: $V(20\ s)=5\ V(1-e^{(-20/10)}) = 4.32$ V.

Data Table 1: Voltage and Time for Discharging Capacitor
(SAMPLE ANSWER BELOW)

Time (s)	Voltage (V)	Time (s))	Voltage (V)
0	2.61	170	0.10
10	2.10	180	0.08

20	1.70	190	0.07
30	1.40	200	0.06
40	1.14	210	0.05
50	0.93	220	0.04
60	0.77	230	0.03
70	0.64	240	0.03
80	0.52	250	0.02
90	0.43	260	0.02
100	0.35	270	0.02
110	0.30	280	0.01
120	0.25	290	0.01
130	0.20	300	0.01
140	0.17	310	0.01
150	0.14	320	0.01
160	0.11	330	0.00

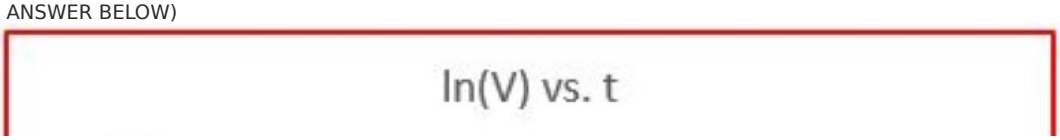
Graph 1: Voltage versus Time
(SAMPLE ANSWER BELOW)

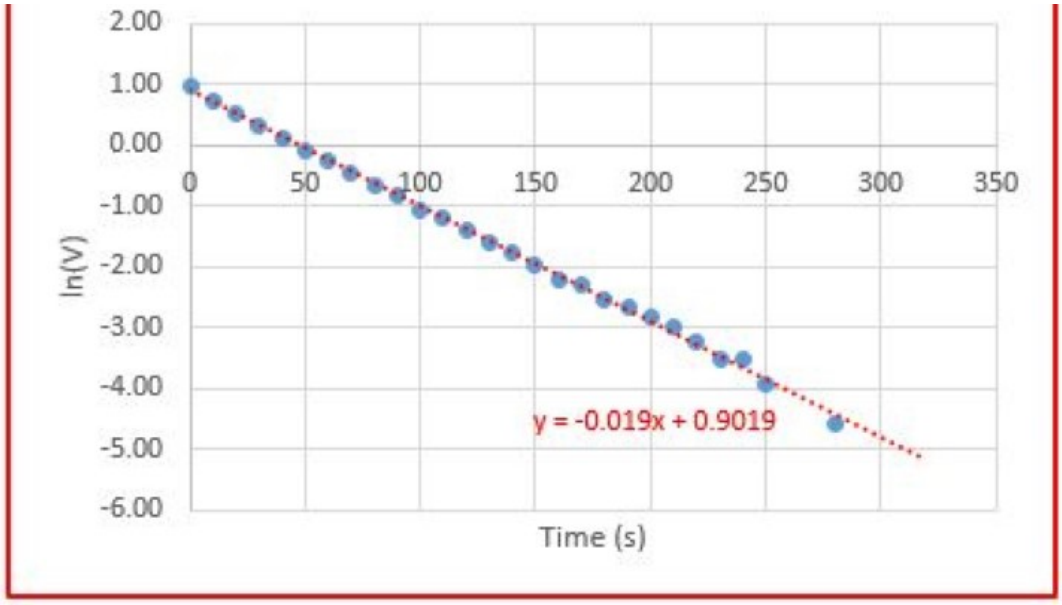


Data Table 2: Natural Log of Voltage for Discharging Capacitor
(SAMPLE ANSWER BELOW)

Time (s)	Voltage (V)	Time (s))	Voltage (V)
0	0.96	170	-2.30
10	0.74	180	-2.53
20	0.53	190	-2.66
30	0.34	200	-2.81
40	0.13	210	-3.00
50	-0.07	220	-3.22
60	-0.26	230	-3.51
70	-0.45	240	-3.51
80	-0.65	250	-3.91
90	-0.84	260	-3.91
100	-1.05	270	-3.91
110	-1.20	280	-4.61
120	-1.39	290	-4.61
130	-1.61	300	-4.61
140	-1.77	310	-4.61
150	-1.97	320	-4.61
160	-2.21	330	NA

Graph 2: Natural Log of Voltage versus Time
(SAMPLE ANSWER BELOW)





Data Table 3: Calculations

(SAMPLE ANSWER BELOW)

Capacitance (μF)	Initial Voltage (V)	Slope (s^{-1})	τ (s)	DMM Resistance (MΩ)	Initial Charge on Capacitor (μC)
47	2.61	-0.0191	52.4	1.11	123

Panel 1: Observations of Current Through a Capacitor

(SAMPLE ANSWER BELOW)

The LED briefly lights up when the circuit is completed but quickly dims. The current jumps immediately after the circuit is completed but quickly decreases to zero exponentially.

Exercise 2

What is the relationship between capacitance, plate separation, and plate area? Refer to Data Tables 4 and 5 and Graphs 3-6 in your answer.

As plate separation increases, the capacitance decreases nonlinearly. As plate area increases, the capacitance increases linearly.

What is the relationship between charge and capacitance? What does the value of the slope represent in Graphs 4 and 6?

Charge and capacitance are directly related. As capacitance increases, the charge on the plates increases. The slope of **Graphs 4** and **6** are equal to the battery voltage, which is equal to the voltage across the capacitor.

What qualitative values of plate separation and plate area (e.g., large or small) maximize capacitance? Refer to Graphs 3 and 5.

Small plate separation and large plate area will maximize capacitance.

How does the electric field strength between capacitor plates change as capacitance increases?

As capacitance increase, the electric field between the capacitor plates becomes stronger. The charge density increases with increasing capacitance and, as was described in **Panel 2**, electric field strength increases as the charge density increases.

Panel 2: Electric Field and Charge Density of a Capacitor
(SAMPLE ANSWER BELOW)

As the battery voltage increases, the charge density on the capacitor plates increases. The electric field between the plates becomes stronger as the voltage increases, as indicated by the increasing density of field lines.

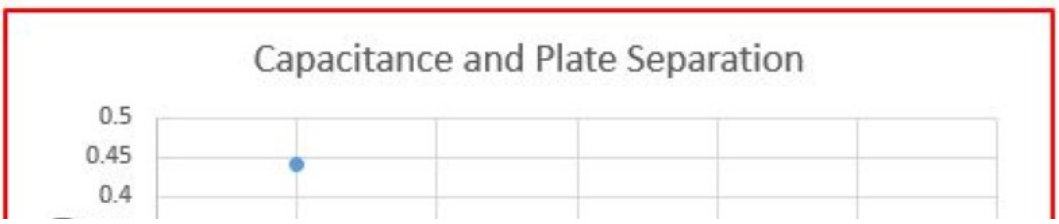
Panel 3: Voltage and Bulb Brightness Using a Capacitor
(SAMPLE ANSWER BELOW)

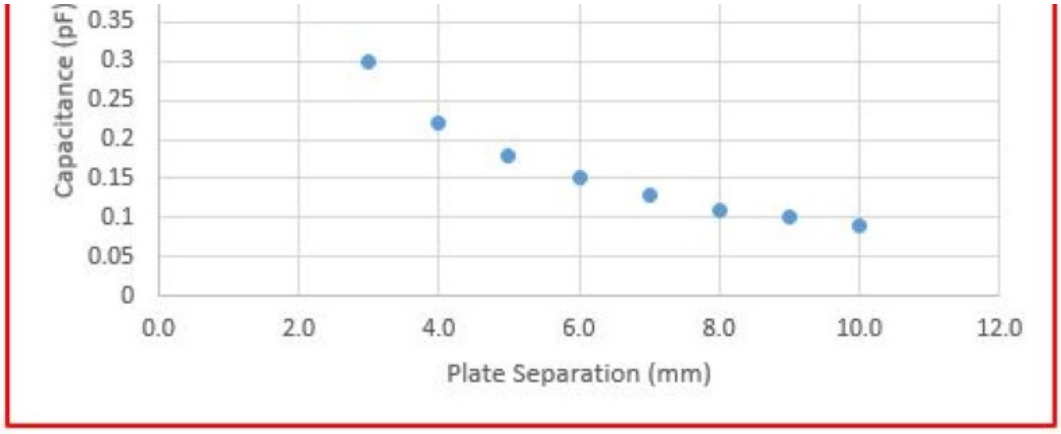
The bulb is initially very bright when the capacitor is connected to the bulb: the voltage is at 1.5 V. As time goes on, the brightness of the bulb and the voltage decreases. The rate of this decrease slows - the brightness and voltage decrease quickly at first but slow near the end.

Data Table 4: Effects of Plate Separation on Capacitance and Stored Charge
(SAMPLE ANSWER BELOW)

Plate Separation (mm)	Capacitance (pF)	Top Plate Charge (pC)
10.0	0.09	0.13
9.0	0.10	0.15
8.0	0.11	0.17
7.0	0.13	0.19
6.0	0.15	0.22
5.0	0.18	0.27
4.0	0.22	0.33
3.0	0.30	0.44
2.0	0.44	0.66

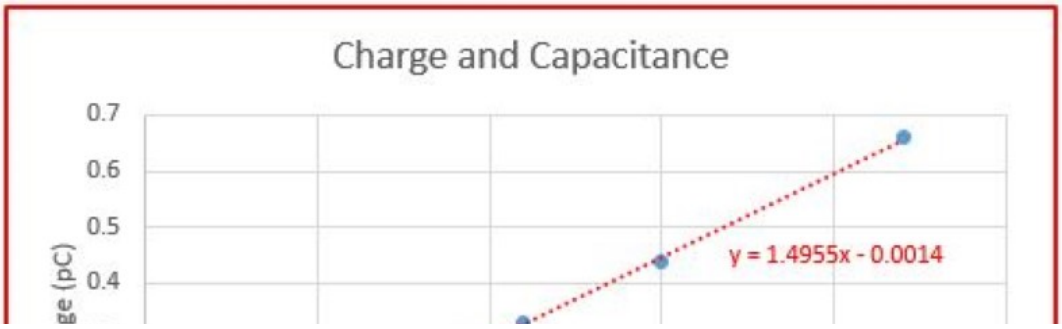
Graph 3: Capacitance as a Function of Plate Separation
(SAMPLE ANSWER BELOW)

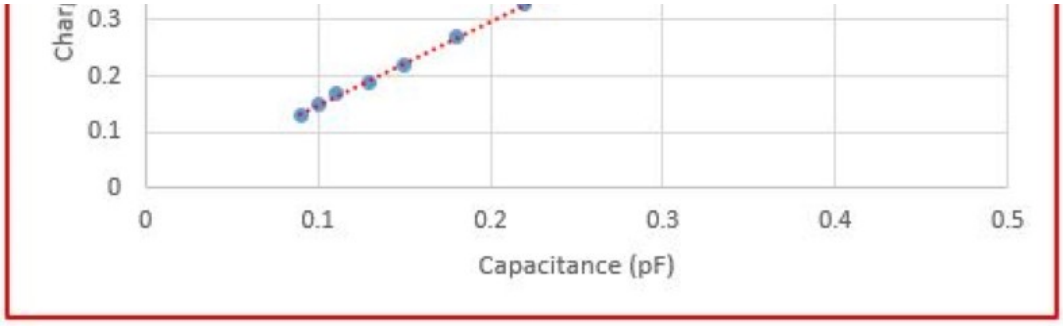




Graph 4: Charge and Capacitance: Varied Plate Separation

(SAMPLE ANSWER BELOW)



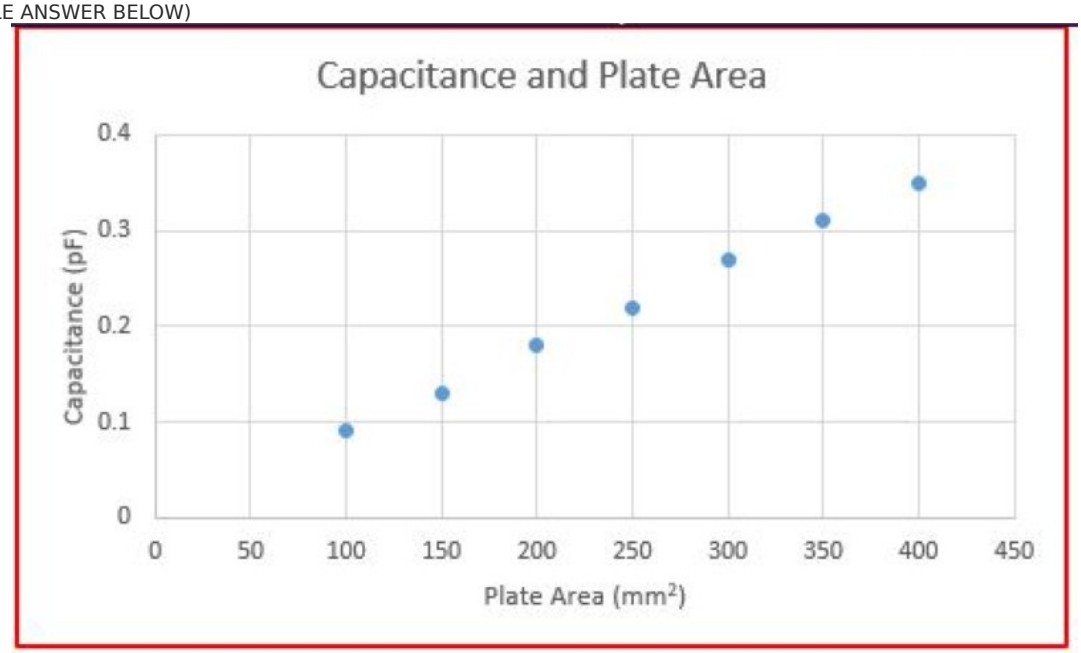


Data Table 5: Effects of Plate Area on Capacitance and Stored Charge

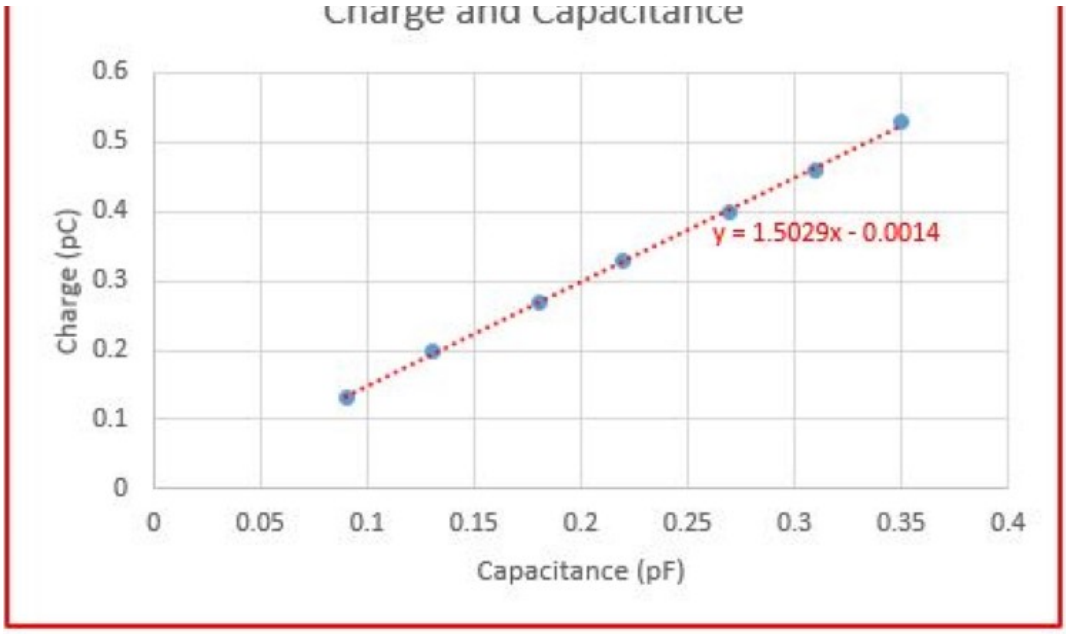
(SAMPLE ANSWER BELOW)

Plate Area (mm^2)	Capacitance (pF)	Top Plate Charge (pC)
100	0.09	0.13
150	0.13	0.2
200	0.18	0.27
250	0.22	0.33
300	0.27	0.4
350	0.31	0.46
400	0.354	0.53

Graph 5: Capacitance as a Function of Plate Area
(SAMPLE ANSWER BELOW)



Graph 6: Charge and Capacitance: Varied Plate Area
(SAMPLE ANSWER BELOW)



Competency Review

A ____ is a device consisting of two conductors that can be charged with equal and opposite charges, separated by a thin insulator.

- RC circuit
- resistor
- capacitor ✔
- None of the above

The capacitance of a capacitor depends on the ____ the capacitor.

- surface area of ✔
- charge on
- voltage across
- All of the above

The capacitance of a capacitor is ____ the plate separation of the capacitor.

- proportional to
- inversely proportional to ✔
- not dependent on
- None of the above

The presence of a dielectric in a capacitor ____ the capacitance of a capacitor.

- increases ✔
- decreases
- stabilizes
- None of the above

Lightning is the result of electrical breakdown in the air when the _____ between the earth and a thundercloud exceeds that which the air can support.

- dielectric
- capacitance
- potential difference ✔
- None of the above

The way charge changes in time in an RC circuit is more important than the final charge on the capacitor.

- True ✔
- False

When an RC circuit is closed without the battery, the capacitor _____.

- remains fully charged
- begins charging
- begins discharging ✔
- None of the above

The voltage in an RC circuit behaves like a(n) _____ function as the capacitor discharges.

- exponential ✔
- linear
- quadratic
- None of the above

During _____, 37% of the maximum charge on a capacitor is present after one time constant.

- charging
- discharging ✔
- both charging and discharging
- None of the above

The time constant of a capacitor in an RC circuit can be found by graphing the _____ against time.

- voltage
- charge
- natural log of voltage ✔
- None of the above

The total charge on a capacitor is equal to capacitance _____ voltage.

- divided by
- multiplied by ✔
- plus
- None of the above

The internal resistance of the DMM is found by creating an RC circuit with a charged capacitor and the DMM set as a voltmeter.

- True ✔
- False

The current in a charging capacitor in an RC circuit is present for a long time.

- True
- False ✔

The capacitance of a capacitor is _____ to the plate area.

- proportional ✔
- inversely proportional
- unrelated
- None of the above

As capacitance increases, the amount of charge the capacitor can hold _____.

- remains constant
- decreases
- increases ✔
- None of the above

Extension Questions

Explain why the two plates of a capacitor are charged to the same magnitude when a battery is connected to the capacitor. (SAMPLE ANSWER BELOW)

The battery does work to separate the charges already on the capacitor. Charges cannot be created or destroyed, so the total number of positive and negative charges must be the same before and after charging, so the charges on the two plates are equal and opposite.

A flashing light is controlled by a charging and discharging of an RC circuit. If the light is flashing too rapidly, describe two changes that you could make to the circuit to reduce the flash rate. (SAMPLE ANSWER BELOW)

The capacitance of the capacitor could be increased, or the resistance of the resistor could be increased. Both these changes would increase the time constant, which would increase the charging and discharging times, thus slowing the flashing. The capacitance could be increased by decreasing the plate separation, adding a dielectric with a larger dielectric constant, or by increasing the surface area of the plates.