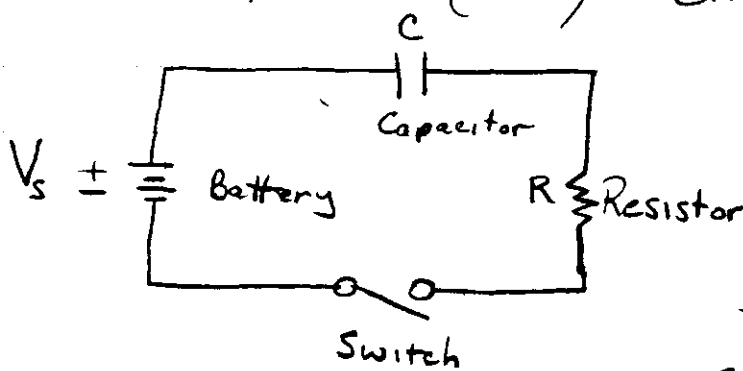


$$I = I_{\max} e^{-t/RC} \quad V = V_0 e^{-t/RC}$$

$$I = I_{\max} (1 - e^{-t/RC}) \quad V = V_0 (1 - e^{-t/RC})$$

(DC) CIRCUIT



WHEN THE SWITCH IS OPEN THERE IS NO CURRENT THROUGH THE CIRCUIT. CLOSING THE SWITCH CAUSES CHARGES TO FLOW, SETTING UP A CURRENT. CHARGES WILL NOT

FLOW ACROSS THE INSULATOR OF THE CAPACITOR. TIME TO ACHIEVE MAXIMUM CHARGE DEPENDS UPON THE CURRENT IN THE CIRCUIT. A HIGH  $\Omega$  RESISTOR IS USED TO LOWER THE CURRENT. THE AMOUNT OF CHARGE DEPENDS UPON THE VALUE OF THE CAPACITOR AND THE emf (VOLTAGE) OF THE SOURCE.

- DERIVATION OF  $q$  vs  $t$  AND  $I$  vs  $t$

RESISTOR AND CAPACITOR IN SERIES

$$V_s = V_R + V_C \quad V_R = IR \quad V_C = \frac{q}{C}$$

$$V_s = IR + \frac{q}{C}$$

AT MAX CHARGE  $I=0$  SO  $V_s = \frac{q}{C}$  OR  $Q_{\max} = V_s C$

$$V_s = IR + \frac{q}{C}$$

$$I = \frac{dq}{dt}$$

$$V_s = \frac{dq}{dt} R + \frac{q}{C} \rightarrow \frac{V_s - \frac{q}{C}}{R} = \frac{dq}{dt} \rightarrow C V_s - q = RC \frac{dq}{dt}$$

$$\frac{dq}{C V_s - q} = \frac{dt}{RC}$$

$$\int \frac{dq}{C V_s - q} = \int \frac{dt}{RC}$$

NOW THE FUN BEGINS!

# RC CIRCUIT

$$\int \frac{dq}{CV_s - q} = \int \frac{dt}{RC}$$

$$u = CV_s - q \quad - \int \frac{du}{u} = \frac{1}{RC} \int dt$$

$$du = -dq$$

$$-\ln|u| = \frac{1}{RC} t + C$$

$$-\ln|CV_s - q| = \frac{t}{RC} + C \quad \text{INITIALLY } t=0 \quad C=0$$

$$-\ln|CV_s| = C$$

$$-\ln|CV_s - q| = \frac{t}{RC} - \ln|CV_s|$$

$$\ln|CV_s| - \ln|CV_s - q| = \frac{t}{RC}$$

$$\ln \left| \frac{CV_s}{CV_s - q} \right| = \frac{t}{RC}$$

$$\frac{CV_s}{CV_s - q} = e^{t/RC}$$

$$\rightarrow CV_s e^{-t/RC} = CV_s - q$$

$$q = CV_s - CV_s e^{-t/RC}$$

$$q = CV_s (1 - e^{-t/RC}) \quad \text{this is it!}$$

$$I = \frac{dq}{dt} = \frac{d(CV_s(1 - e^{-t/RC}))}{dt}$$

$$I = CV_s \frac{d(-e^{-t/RC})}{dt}$$

$$\frac{d e^u}{dt} = e^u du$$

$$u = -t/RC \quad du = -\frac{dt}{RC}$$

$$I = \frac{CV_s}{RC} e^{-t/RC}$$

$$I = \frac{V_s}{R} e^{-t/RC} \quad \text{this too!}$$

THIS IS THE EQUATION FOR SHAPE OF  
I vs t FOR A CHARGING CAPACITOR.

# CHARGING AND DISCHARGING A CAPACITOR

A capacitor is a device for storing electrical charge. You might find a capacitor in the flash lamp of a camera, a car ignition system, or in pulsed lasers. A capacitor usually consists of two sheets of metal separated by a thin layer of insulating material known as a dielectric. To conserve space, the layers are often rolled together and covered with a protective coating.

Consider a capacitor placed in a circuit with a resistor, a battery, and a switch. When the switch is closed, the battery supplies electrical energy to move positive charges to one plate of the capacitor and negative charges to the other. This energy is stored in the capacitor. Note that no current flows through the capacitor; charges cannot move through the insulating material. If the battery is removed and the circuit closed, the capacitor discharges, and the energy is returned to the circuit.

## Equipment

- 6 6-volt DC source
- DC ammeter, 0-1.0 mA
- knife switch
- connecting wires
- stopwatch or watch with second hand
- 2200  $\mu$ F capacitor
- 30 k $\Omega$  and 15 k $\Omega$  resistors
- voltmeter

22  $\mu$ F CAPACITOR

1 M  $\Omega$  AND

TWO 220 k $\Omega$  RESISTORS IN SERIES

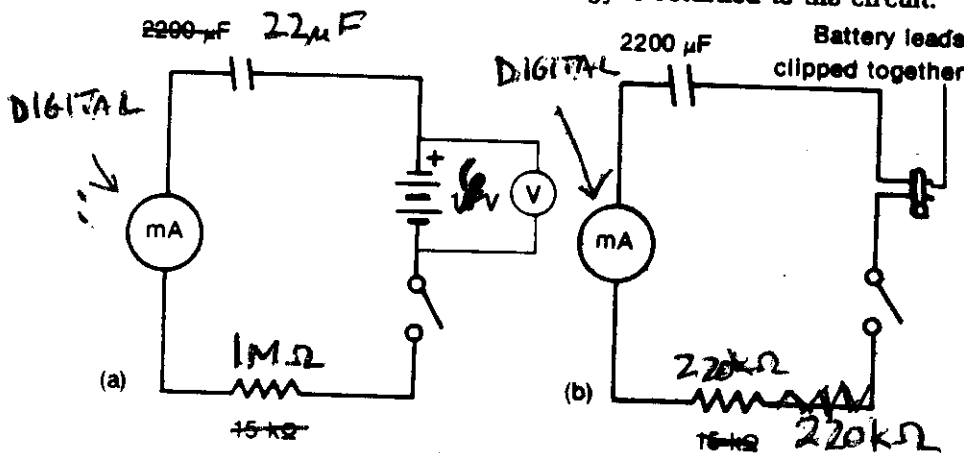


Figure 39-1. It is essential that you follow the circuit diagram (a) carefully. Be sure that the positive terminal of the battery is connected to the positive plate of the capacitor (b). After the capacitor is charged, open the switch and clip the leads together.

## Objective

During this investigation you will study the relationship of current to time as a capacitor is charged and discharged.

\* Reverse polarity of Ammeter

## Procedure

You will need to work with a partner for this investigation. One person will signal the time intervals, the other will read the meter.

1. Set up the circuit as shown in Figure 39-1(a) using the 15-k $\Omega$  resistor. Be sure to connect the positive terminal of the power source to the positive plate of the capacitor. If the leads are switched, the capacitor will be destroyed. CAUTION: Capacitors such as these contain caustic chemicals. Connect only as shown in diagrams.
2. Have your partner signal when to start. Close the switch and immediately read the value of the current and voltage. Take a current reading every 5 seconds until the current is too small to measure. Record all readings in Table 39-1.



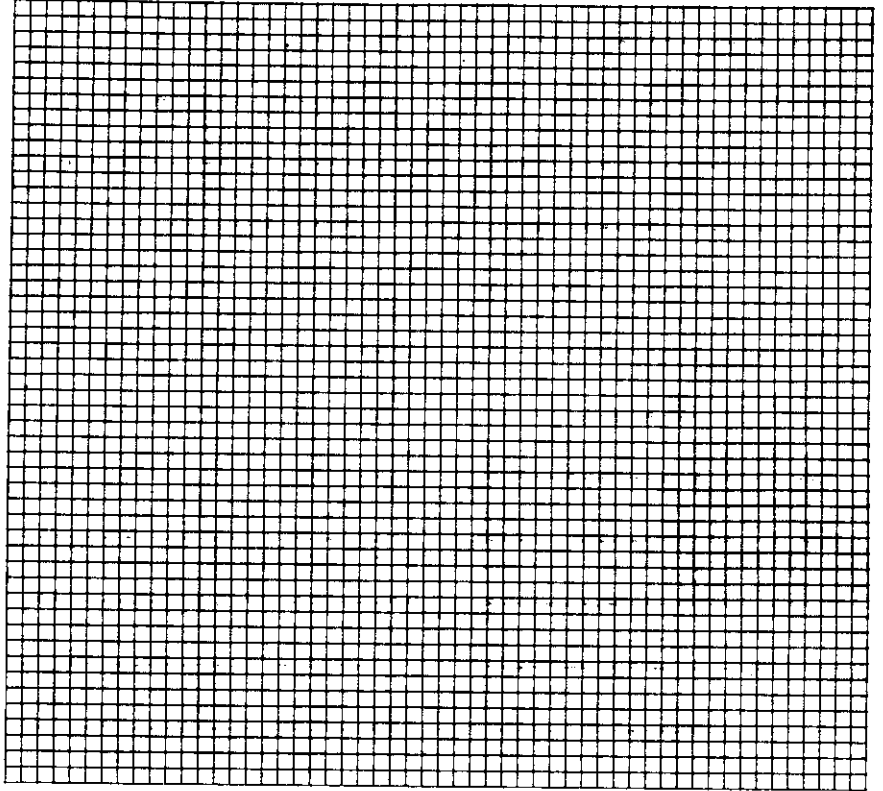


3. What is the purpose of the resistor in the circuit? Explain.

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4. Using the data from Tables 39-1 and 39-2, plot graphs of current as a function of time for charging and discharging the capacitor. Plot both curves of the same set of axes, labeling each curve carefully.



Stored charge \_\_\_\_\_

5. The area between the curve of your graph and the time axis represents the charge stored on the capacitor plates. Estimate the area under the charging curve by sketching a triangle that approximates this area and finding the area of the triangle. Record.
6. Capacitance is the ratio of the charge stored to the potential difference across the capacitor,  $C = Q/V$ .
- Calculate the capacitance of your capacitor using your approximation of charge from Question 5 and the voltage of your power source.

b. How else might  $V$  have been measured? Explain.

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- e. How close does your value come to the manufacturer's value?  
(There may be a large difference since the manufacturer's tolerance is large in capacitors of this type.)

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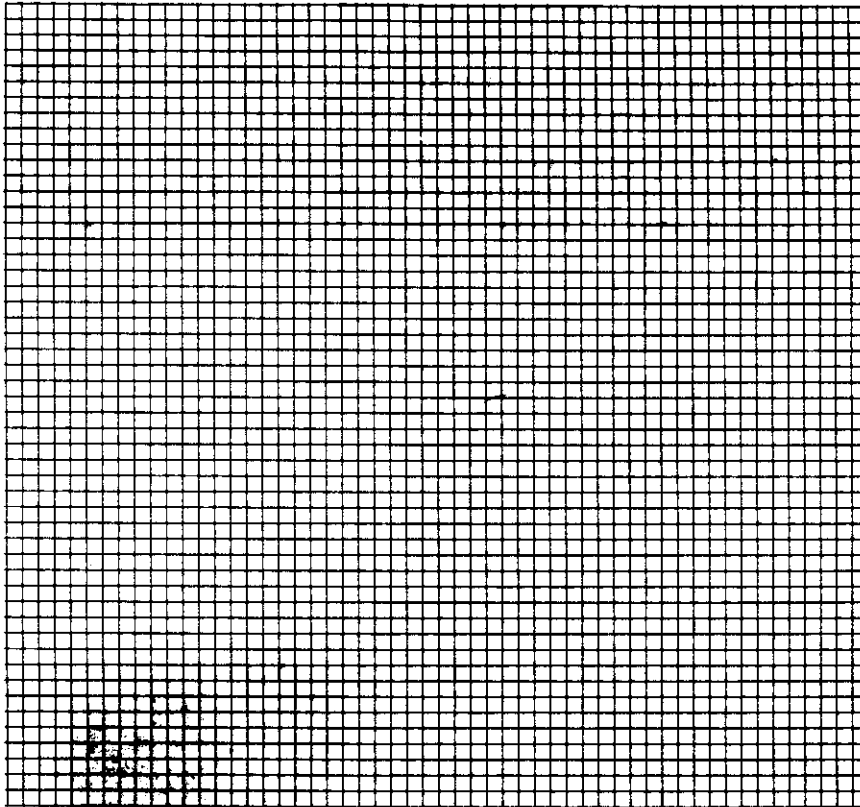
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7. To compare the time of charging with the time of discharging, find the time it takes the current to fall to 37% of the maximum value on each curve. This interval is used because the current does not go to zero at a defined time.

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8. Plot the data using the ~~30 k~~ resistor, Tables 39-3 and 39-4, as in Question 3. Determine the stored charge as in Question 5.



Stored charge \_\_\_\_\_

9. Compare the values for the stored charge and 37% discharge time you obtained from the ~~15 k~~ circuit with those you obtained from the ~~30 k~~ circuit. Explain your observations.

*1MΩ vs 220kΩ*

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10. Describe and explain a current vs time graph for the circuit without the

a. resistor \_\_\_\_\_  
\_\_\_\_\_

b. capacitor \_\_\_\_\_  
\_\_\_\_\_

### Extensions $1M\Omega$

- DO THIS →
- \* 1. Obtain another capacitor similar to the one you used above. Using the ~~1M $\Omega$~~  resistor, repeat Procedure Steps 1-4 with the two capacitors placed first in series and then in parallel.
    - a. Analyze your data as in Interpretation Questions 3 and 4.
    - b. Calculate the effective capacitance of the circuits using the values for Q obtained from your graphs.
    - c. Make a general statement concerning the effect of placing capacitors in series and in parallel.
  - \* 2. Look up the formulas for calculating the effective capacitance of capacitors in series and in parallel. Determine the theoretical values for your circuits and compare them with your results.
  - ec → 3. Camera flash lamps and car ignition systems use capacitor circuits to deliver large bursts (surges) of current that last a very short time. Design a capacitor circuit that could produce such a current.
- 5pts