

1. Measure the resistance of a 0-5V voltmeter as precisely as you can. (See #6 on page 90.) Show how you obtain your data, and record the meter readings (with SDC's) beside your circuit diagram. Also show how you calculate the resistance and its uncertainty. Round off the final result properly. (Do *NOT* round off the original data.) Ask for help if necessary, but use only words that you understand.
2. Use the *same* voltmeter to measure and record the power supply emf, as on page 84. Use it to predict the capacitor voltage and resistor voltage that will exist immediately after you complete a resistor-capacitor series circuit with an *uncharged* capacitor. Use 4c & 5 on p. 96, and #1 on p. 97, where we decided to use a _____ as a resistor. *Explain your predictions, starting with a circuit diagram.*
3. Prepare the circuit after your plan has been checked. Use the *same* power supply outlet as in #2, and *USE THE SIGN RULE*. Use a light bulb to discharge the capacitor, as in #5 on page 97.
 - a. By connecting the bulb you ensured that the initial capacitor voltage and charge would each be ____.
 - b. Remove the bulb at time "zero" to begin the charging process, as in 6b on page 95.)
 - c. Record the MLV of the resistor voltage at the moment when the bulb is removed.
 - d. Record it again at thirty-second intervals. Make a graph of resistor voltage vs. time *while* the measurements are in progress. Stop when the resistor voltage is less than 20% of its initial value.
 - e. Unplug the circuit *immediately* when that last voltage reading has been taken. Then write it down.
4. You already know how the three voltages in this circuit are related. (See #5 on RS IX or #1 on 99R.)
 - a. Use that relation to *calculate* the initial resistor voltage. -Does it agree with your data table?
 - b. Use that relation to calculate the MLV of the *last capacitor voltage in 3d*. *Do NOT measure it.*
 - * c. Explain those calculations concisely.
5. Dismantle the circuit *WITHOUT* discharging the capacitor. Immediately connect the voltmeter across the capacitor, using the sign rules. Record and plot the voltages at 30-second intervals as in 3d. Continue until the voltage is less than 1/5 of its initial value. Between measurements do 5a-5c.
 - a. Draw a diagram of this new circuit (*with no battery*) and indicate the direction of electron flow.
 - b. Explain how the TWO voltages in this "*discharging*" circuit must be related. (Use 5a and #2.)
 - * c. Does the initial voltage for the discharging process agree with the one predicted in #4b?
If not, explain what we can conclude from that discrepancy. Give both voltages in range form.
6. Set up two data tables: one for the charging process, and one for the discharging process. Let each table have columns for "Time", "Resistor Voltage", "Capacitor Voltage", "Current", "Average Current", "Charge Increment", and "Charge". (The "Average Current" is the current averaged over the 30-second interval just *ending*, as explained on page 99R. The "charge increment" means the charge *delivered to or from* a capacitor plate during that interval. "Charge" means the charge present on one plate at that time.) Remember to write appropriate units in parentheses under the column headings.
7. Figure out how to use the data already collected and the laws and formulas already known to fill in the tables. *If you need help, use page 99R*. Notice that a set of plans like this is almost the same as a computer program or spreadsheet. If you have a computer this would be a good time to use it.
8. Use the plans in #7 to fill in the *first three MLV's in each column of each data table*. Bring the results to the next class session and *show them to your teacher*. If you need help, use page 99R.
9. You need to see the shapes of the following graphs for the charging *and* discharging circuits:
 - a. Resistor Voltage vs Time. (You made these while the experiment was in progress.)
Keep them for future work and hand in sketches with this report.
 - b. Capacitor voltage vs time. *If your sketches contradict your data or page 98 you must explain.*
 - c. Current vs time. (sketches) *Use the sign convention in #2 on RS XI. Do not ignore your data!*
 - d. Capacitor charge vs capacitor voltage, *plotted carefully, using data. Do not ignore 5c.*
10. Is it ever possible for an uncharged capacitor to have a non-zero voltage? ____ -Is it possible for a graph of charge vs. voltage to pass above or below the origin if made correctly? ____ -Do *both* of your linear graphs agree with those facts? ____ If they do not, did you explain why in 5c? ____
11. If any of your graphs are linear, then draw straight lines that fit the data and calculate their slopes in range form, as usual. Write those slopes on the graphs. Remember to give the GLV, SLV, and *units* of those slopes *in sentence form*. Keep copies for future work. Hand in the *linear* graphs with this report, along with *sketches* of the others. *Keep the data tables and curved graphs for future work.*

- How are the three voltages in the charging circuit related? (Use #5 on RS IX or #5 on page 96.)
 - Solve for the unknown capacitor voltage. $\underline{\hspace{2cm}} = \underline{\hspace{2cm}}$
 - Use equation 1a to fill in the FIRST THREE " V_c " values in your "charging" data table. (Also use 2 & 5 on p. 99.) The rest will be done later with a computer.
- The discharging circuit is *simpler* than the charging circuit because the $\underline{\hspace{2cm}}$ has been removed. The new circuit is identical to the old one except the battery's emf is now $\underline{\hspace{2cm}}$ instead of $\underline{\hspace{2cm}}$ s.
 - If you look at it that way, you can use the same equation that you wrote for #1 except that the $\underline{\hspace{2cm}}$ voltage should be replaced with a $\underline{\hspace{2cm}}$, so that it says $\underline{\hspace{2cm}} = \underline{\hspace{2cm}}$.
 - The V_c values will therefore be equal in magnitude to the $\underline{\hspace{2cm}}$ values. (See 5b on page 99.)
 - Use those clues to fill in the first three " V_r " and " V_c " values in your "discharging" data table.
- In #1 on p. 99 you re-measured the resistance of your voltmeter. It was found to be $\underline{\hspace{2cm}} \pm \underline{\hspace{2cm}}$ ohms. According to #2 on RS IX, the current through that voltmeter is always equal to the voltage across the $\underline{\hspace{2cm}}$ divided by the resistance of the $\underline{\hspace{2cm}}$.
 - Use that equation to fill in the first *three* currents in *EACH* data table. The rest will be done for you.
 - The voltages have $\underline{\hspace{2cm}}$ significant digits. The currents must have $\underline{\hspace{2cm}}$ digits because we keep one bogus digit to avoid roundoff error.
 - On page 97 you decided that a current in the charging direction could be represented by a *positive* number. What sign must the current have when the capacitor is discharging? $\underline{\hspace{2cm}}$
 - Do the numbers in your data tables agree with that sign convention? $\underline{\hspace{2cm}}$
- Recall that the "average current" is the current averaged over the 30-second time interval just *ending*, as explained in #8 on page 99.
 - How much current was there during the 30 seconds *BEFORE* you completed the circuit? $\underline{\hspace{2cm}}$
 - What was the average current for that 30-second interval? $\underline{\hspace{2cm}}$
 - Which entry in your "time" column corresponds to the *END* of that interval? $\underline{\hspace{2cm}}$
 - Use those facts to fill in the first "average current" value in *EACH* data table.
- Suppose I deliver 5 bananas on Monday, 4 bananas on Tuesday, and 3 bananas on Wednesday. My *average* delivery rate was $\underline{\hspace{2cm}}$ bananas per day. My *initial* delivery rate was $\underline{\hspace{2cm}}$, and my *final* rate was $\underline{\hspace{2cm}}$. The average delivery rate can be calculated by averaging the initial and final rates *IF AND ONLY IF* the graph of delivery rate vs. time has a $\underline{\hspace{2cm}}$ shape.
 - Use similar reasoning to fill in the second and third "average current" values in *EACH* table.
 - Do the signs of those average currents agree with 3c? $\underline{\hspace{2cm}}$
 - Write an equation for calculating the rest: $\underline{\hspace{2cm}} = \underline{\hspace{2cm}}$
 - To figure out how many bananas were delivered during the entire 3-day period you could multiply:

$$(\underline{\hspace{2cm}} \text{ bananas per day})(3 \text{ days}) = \underline{\hspace{2cm}} \text{ bananas.}$$
- On Review Sheet IX you defined the standard unit of current in this way: One " $\underline{\hspace{2cm}}$ " is equal to one $\underline{\hspace{2cm}}$ per $\underline{\hspace{2cm}}$. You also wrote that the standard unit of electric *charge* is the " $\underline{\hspace{2cm}}$ ".
 - As in 5d, the amount of charge delivered to one plate during a given time interval can be calculated by $\underline{\hspace{2cm}}$ ing the $\underline{\hspace{2cm}}$ (in $\underline{\hspace{2cm}}$ s per $\underline{\hspace{2cm}}$) by the number of $\underline{\hspace{2cm}}$ s in that interval.
 - Do the units check when you do that? $\underline{\hspace{2cm}}$
 - Should the first factor in 6a be an initial value, a final value, or average value? $\underline{\hspace{2cm}}$ (Use #5.)
 - Use 6b and 6c to fill in the first three "charge increments" in *EACH* table. Remember to find out what "increment" means (#8 on p. 99) and to be careful with signs.
- Suppose you know the amount of charge present on a capacitor plate at one time and you also know how much charge is delivered during the next time interval. What must you do with those two numbers to determine the amount present at the end of that interval? $\underline{\hspace{2cm}}$
 - In #3 on page 99 you made sure that the *initial* charge value was $\underline{\hspace{2cm}}$. Did you record that value in your "charging" data table? $\underline{\hspace{2cm}}$
 - The amount of charge *delivered* during the first 30-second interval is in row $\underline{\hspace{2cm}}$ of the $\underline{\hspace{2cm}}$ column of the data table.
 - The amount of charge delivered during the *next* interval should be recorded in row $\underline{\hspace{2cm}}$.
 - Use the plan described above to fill in the second and third entries in the "Charge" column.
 - You can use similar logic to fill in the second and third charge values in the "discharging" table, but first you will need one additional piece of information. What is it and where will you find it?

For the *charging* process:

Time (sec.)	Resistor Voltage	Capacitor Voltage	Current (in Amps)	Average Current	Charge Increment	Charge (in C)
0	Copy from #3 on p. 99	Use #1 on page 99R.	Use #3 on page 99R.	Use #4 on 99R	Use #6 on 99R	Use 7a on 99R
30	"	"	"	Use #5 on 99R	"	Use #7 on 99R
60	"	"	"	"	"	"
90	"	"	"	"	"	"

For the *discharging* process:

Time (sec.)	Resistor Voltage	Capacitor Voltage	Current (in Amps)	Average Current	Charge Increment	Charge (in C)
0	Copy from #5 on p.99	Use #2 on page 99R.	Use #3 on page 99R.	Use #4 on 99R	Use #6 on 99R	Use 7e on 99R
30	"	"	on 99R	Use #5	" on 99R	Use #7
60	"	"	"	"	"	"
90	"	"	"	"	"	"