LAB 10 - ALTERNATING CURRENT RC CIRCUITS

This experiment concludes CP2 lab experience. At this end of the class time please give your instructor the Data/Question Sheet, Rubric, the sketches requested in the Rubric and a brief Analysis of Results. There will be only one lab report per group accompanying this work. All members of your group need to contribute to the report.

Goals:

- **Investigate voltage magnitudes across capacitors and resistors in AC circuits**
- **Investigate phase shifts between the voltages in AC circuits**

Preliminary activity

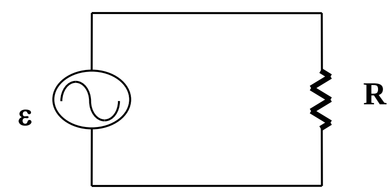
1. You will use an Excel file to make a graph based on the voltage measurements you make, please download **Lab10_AC_RC.XLS** from the lab schedule webpage. Save it under a new name, as a working copy.

Introduction

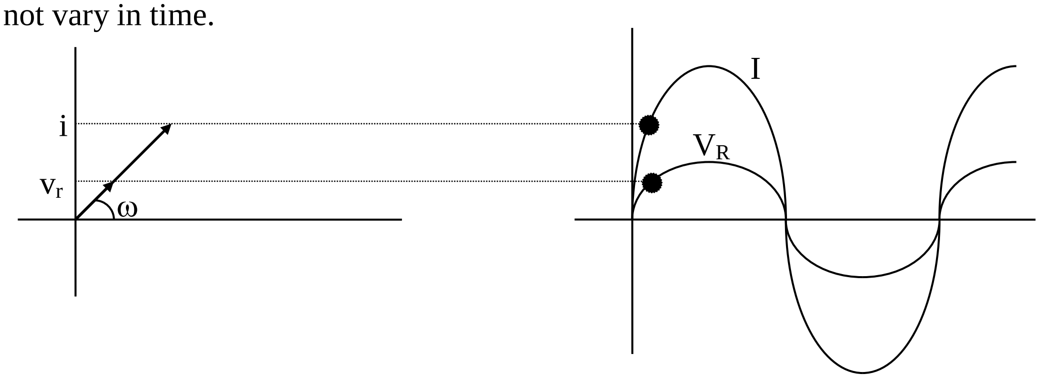
Up until now you have studied DC (direct current) circuits involving a constant current from a battery or a DC power adapter. The electrical circuits that most devices use are AC (alternating current). The voltage in the device (and thus the current through the device) varies sinusoidally with time - with a frequency of 60 Hz (cycles per second). So the current goes from a positive peak (indicating a particular direction in the circuit) to a negative peak 60 times a second.

Resistive AC circuit:

Suppose an AC voltage is applied across a resistor as shown to the left. There will be a current in the circuit that is also sinusoidal. Remembering Ohm's Law, you can see that at any given moment in time, the voltages across all the elements in a circuit loop must sum to zero. In this case, that makes the voltage across the resistor (V_R) the same as the voltage from the generator (ε). The current in this circuit is said to be *in phase* with the voltage across the resistor as indicated in the graph below.



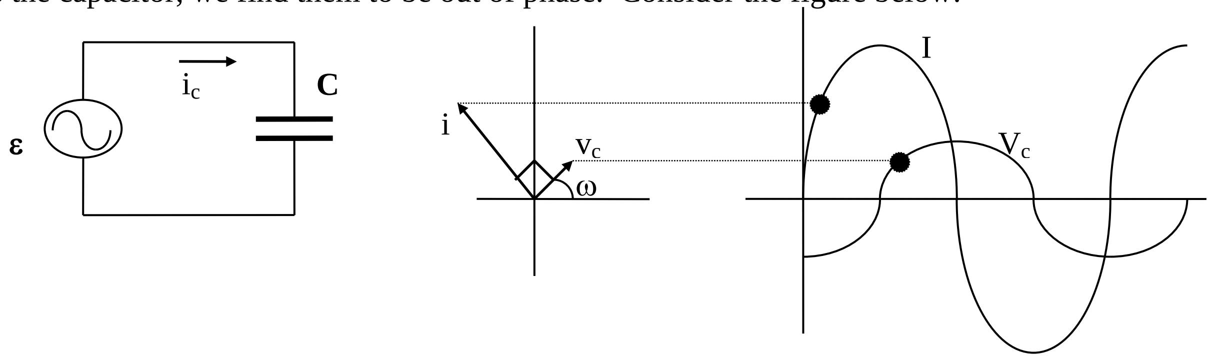
Vectors called *phasors* can represent each the current and the voltage across the resistor. At any given instance, the component of the particular vector along the vertical axis indicates the magnitude (and direction) of the variable at that time. Phasors are physical quantities that vary in time, but whose orientation to each other does not vary in time.



So, the current at that moment in time (i) is the vertical component of the I vector which rotates with an angular frequency ω. The voltage across the resistor (v_r) at that moment is the vertical component of the V_R vector that rotates with an angular frequency ω.

Capacitor AC Circuit

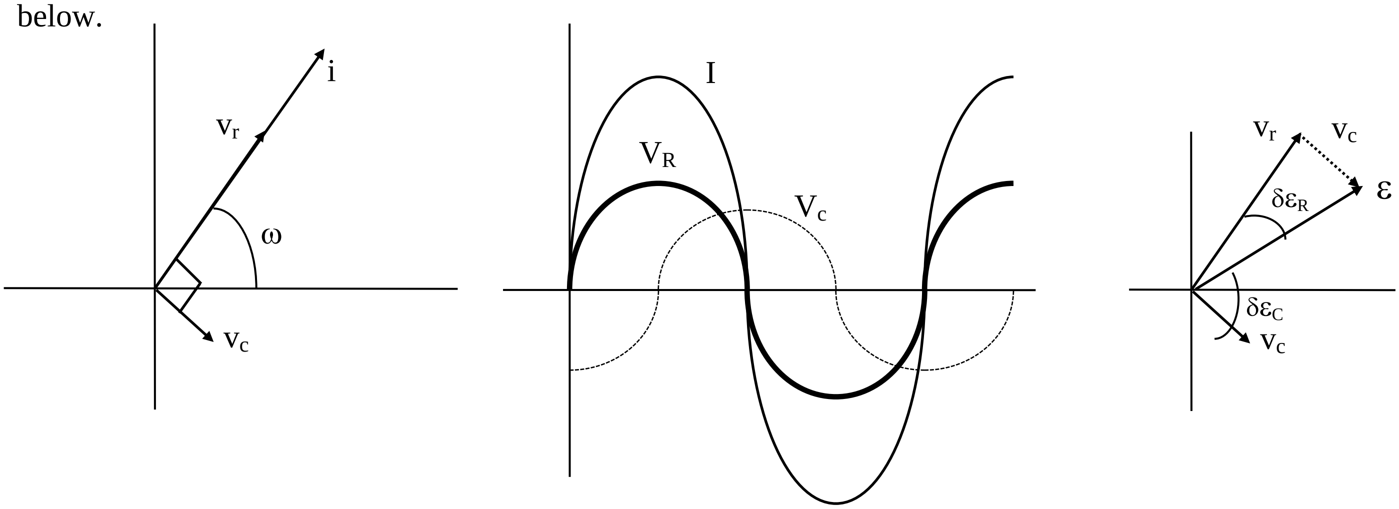
When a current flows in a circuit containing a capacitor, charges will accumulate on the plates and this will create a voltage across the capacitor. But, when we look at the vectors for the current and the voltage across the capacitor, we find them to be out of phase. Consider the figure below:



In this case, the current *leads* the voltage across the capacitor (that is, the current will peak first, and then the voltage across the capacitor will peak). Let's see why that is ... assume that you have an uncharged capacitor and the voltage from the generator is a maximum. Then, there will be a maximum current. But that current will start to charge up the capacitor, so as the current starts to drop off, the voltage across the capacitor starts to rise. When the current reaches zero, the voltage across the capacitor reaches a maximum. Now the current starts to peak in the negative direction, which means the capacitor will start to discharge, thus its voltage starts to drop. This cycle continues like that with the current leading the voltage across the capacitor by 90 degrees or 1/4 cycle. They are out of phase by 90 degrees.

Resistive and Capacitive Circuit

Next put these two cases together. If you have a circuit that has a resistor and a capacitor in series, the current will be in phase with the voltage across the resistor, but out of phase (by 90 degrees or 1/4 cycle) with the voltage across the capacitor. The current (and thus the voltage across the resistor) will lead the voltage across the capacitor by 1/4 cycle. We can put the three vectors (I, V_R, V_C) together as shown on the left below.



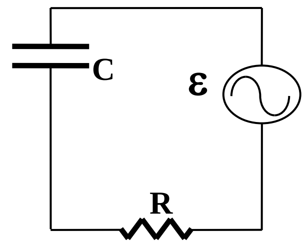
Because of the combination of the resistor and the capacitor in the circuit, a phasor vector ε, as shown in the third figure from left above, can represent the voltage across the entire circuit. Note that this vector is equal to the sum of the two sine waves for the voltage across the capacitor and the voltage across the resistor.

RC Circuit summary

- The voltage across the resistor leads the voltage across the capacitor by 90 degrees.
- There is a phase angle between the main voltage (**ε**) and the voltage across the resistor ($\delta\varepsilon_R$).

- There is a phase angle between the main voltage (**ε**) and the voltage across the capacitor ($\delta\varepsilon_C$).
- The phase angle δ_{ER} and phase angle δ_{EC} add up to 90 degrees or 1/4 cycle (for RC circuits) (δ_{RC}=90^0)
- The voltages in the circuit form a Pythagorean relationship: $\varepsilon^2 = V_R^2 + V_C^2$

Part 1 - Investigating the Voltage Magnitudes



Circuit Connections

There is one main series circuit that we are using. There is a main voltage (**ε**) across the transformer, a voltage across the resistor (V_R), and a voltage across the capacitor (V_C). The circuit should be set up in that clockwise order as shown to the right. Once you have setup this circuit, you will not change the basis connections during the experiment.

1. Prepare the transformers. We will use the household voltage, which is 120V, enough to electrify something. To make the experiment safe, we need to downgrade the voltage to a safe range. **Please refer to the procedures in the online help page** to make the connection, and ask your instructor for help if needed.

2. Prepare the other circuit elements. For the capacitor in the circuit, we will use a **10**-microfarad capacitor. Since we want to be able to change the resistance R in the circuit, we will use a decade resistance box for the resistor. The input voltage comes from the transformer (a step-down transformer to convert the 120 volts of wall voltage to a usable smaller voltage).

3. Measurements. You need to measure the voltages with the multimeter. Set the multimeter dial to AC voltage as shown to the left, and use the two terminals at the bottom to measure AC voltages.
4. Measure the voltage of the power supply (**ε**) first. (You should find this to be basically the same for all the resistances - the transformer supplies a fixed peak voltage to the circuit.) You might notice that the numbers seem to be smaller than what the DataStudio showed as a peak voltage. That's because the meter is giving an "average" value called the root-mean-squared (rms) value - which is the peak voltage divided by $\sqrt{2}$. For our purposes, we will just record this value for the voltage and use it in calculations in the next sections.
5. Use the combination of switches on the decade resistor box to engage the following resistance one at a time, 10 Ω, 20 Ω, 40 Ω, 80 Ω, 160 Ω, 200 Ω, 300 Ω, 400 Ω, 800 Ω, 1600 Ω, 2000Ω, and measure the voltages across the power supply **ε**, the resistor V_R and the capacitor V_C. Record the values in the appropriate columns in the VOLTAGES page in Excel.

You need to check to see if the numbers you have make sense based on the theory presented in the introduction. The squares of the V_C and V_R should equal the square of **ε**. There is a spreadsheet template that will help you make the final comparisons.

6. Data to graphs. As you input the voltage values, the graphs in Excel start filling in automatically.

7. Print graph page. When you are finished inputting the numbers, print the Voltage page to be included with the lab report. (Make sure you try the Print Preview to make sure you have only one page and the graph is sized for easy reading.

Questions Answer on the Data Question sheet:
Pick three rows (near beginning, in middle, and near end) in the chart of Part 1. Show sample calculations to answer the following questions:

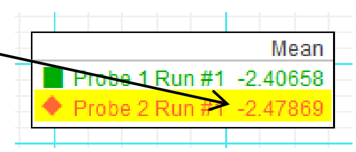
1. Do the resistor and capacitor voltages add up algebraically to the total voltage? If not, why not?
2. How **should** you attempt to add them (hint: should they be considered "vectors"?)? Show that the voltage data in each of your three rows is reasonable, if you "add" them the right way.
3. Observe the graphs. Briefly explain how the change in the V_R graph is related to the change in the V_C graph. Explain some reasons for those changes.

Part 2 - Investigating the Effect of Changing the Resistance on the Phase Angles

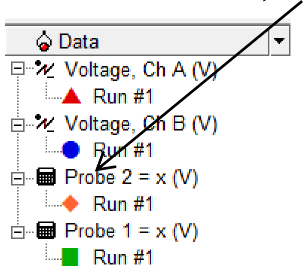
1. Load the experiment file. Download the experiment file **Lab10_AC_RC_2012.ds** from the lab schedule webpage and load it on the desktop of the laboratory computer. **Note: there are important calibration instructions below!**

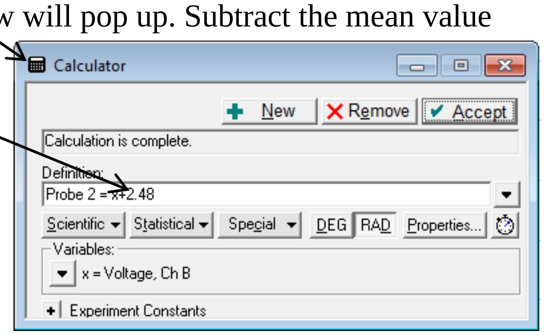
2. Prepare sensors. Two voltage probes are needed. Plug in the voltage probe → analog adapter → USBLink. Start the DataStudio software.

3. Identify and zero the voltage probes. You will use two probes P1 and P2 across various elements in a circuit. You need to know which probe is viewed as P1 by DataStudio, which is P2. You also need to zero both probes. Please follow the procedures below to do this.
   1) Connect the red and black end of one probe together.
   2) Connect another probe to the transformer, and turn it on.
   3) Make a measurement in DataStudio. One probe should read a horizontal data line. Use the color of the data line and the data legend to identify whether this probe is P1 or P2. Use a piece of tape or a Post-it note to label the probe. As an example assume that it's probe P2.
   4) In the data legend, read the mean value of P2 (your value is probably different.)



   5) In the Data window, double click Probe 2, this window will pop up. Subtract the mean value in the formula, and click the Accept button. Now the data line of Probe 2 in DataStudio should line up with the horizontal axis. It is now zeroed.



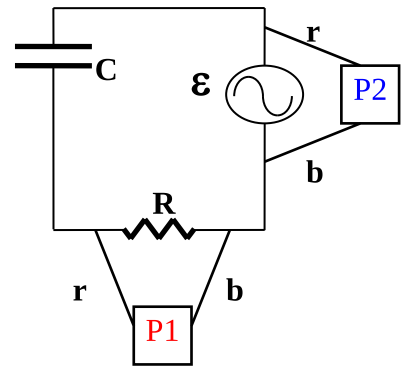


   6) Unplug the other probe from the transformer, and connect its red and black ends together. Repeat steps 3) to 5) to zero this probe as well.

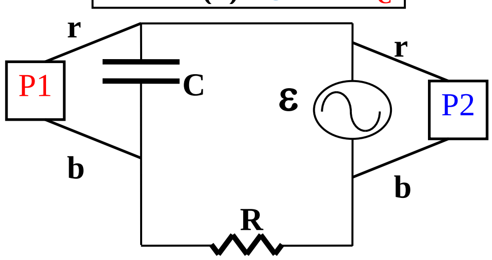
When you should connect a voltage probe to the circuit, you need to connect the red and black sides of the probe in a **VERY particular order** relative to the other elements. Failing to do so, results in useless data. Please refer to the symbol description below. **Note:** This is the same basic circuit that you used in Part 1. The only change is the addition of the voltage sensors.

Symbol in the circuit diagrams:
- C : capacitor
- R : resistor
- P1 : the first probe labeled on the duel channel analyzer
- P2 : the second probe
- r : red probe
- b : black probe

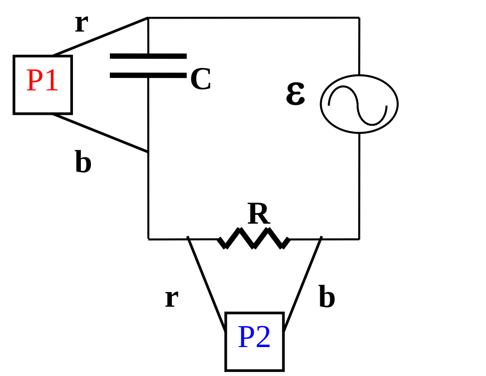
Circuit (1) - ε and V_R



Circuit (2) - ε and V_C



Circuit (3) – V_C and V_R

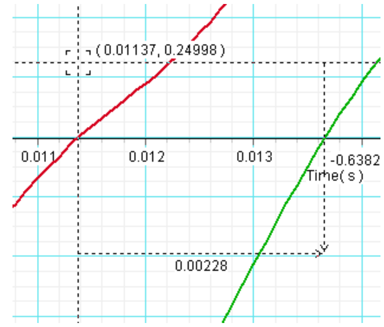


1. <u>The Excel template.</u> In this procedure you will fill in all the data cells in the PHASES Excel sheet. As you fill in the chart, your graphs should start filling in. Be very mindful of the particular order of probe connections that must be made.

2. <u>Set up Circuit (1).</u> Setup the components in the series circuit, and then attach the probes as shown in circuit (1) above. Set the decade box to 0 ohms. DataStudio should be displaying both Voltage Channel A (probe 1, in this case the V_R) and Voltage Channel B (probe 2, in this case **ε**) and the time axis shows 0.03 seconds.

3. <u>Start graphing.</u> Click the START button in DataStudio to start the graphing process. In a moment, the graph should appear on the screen. Both voltages are being measured, but you will probably only see one show up – Voltage Channel B - the voltage across the whole circuit. Since the resistance is zero, there should be no voltage across the resistor.

4. <u>Time relates to phase.</u> To find the phase angle between the two voltage curves, you are going to need to measure the time that occurs between the two curves. You can compare the time difference to the time for one cycle (which should be 1/60 seconds = 0.01666 sec), and from that, find out what the phase angle (the fraction of a cycle would be the fraction of 360 degrees). YOU just need to measure the time difference between the two curves, and Excel will calculate the angle.



5. <u>Measuring the time (to get the phase).</u> Set 400 ohms, and click START to record another graph. Rescale the graph to zoom in on an area where both curves are **rising across** the time axis as show to the left. Use the Smart Tool  and the Delta Tool in DataStudio to measure the difference of time when the two curves **rising cross** the time axis. Record this time on the Excel sheet, and notice that the angle is automatically calculated.

Also, as you are working on a particular Circuit from Part 2 [(1), (2), or (3)] – look at the questions on the Data/Question sheet for each circuit – you should answer them as you go (with the graphs on the screen in front of you). One graph for each circuit (maybe the 400 Ohm graph) should be able to answer the questions for that circuit.

6. <u>Clearing the graph for the next data.</u> Once you record the data, you don't need to store the graph, so you should just clear the data runs each time (note, hiding them will be more trouble than it is worth – there are two channels being graphed, you'd have to hide each run for each channel each time). So, the procedure would be: a) change the resistance, b) record a graph, c) zoom and measure the time difference, d) record in Excel, e) delete all runs in DataStudio and repeat.

7. <u>Trouble graphs?</u> Set 40 ohms (remember to switch the 400 ohms off again), and graph it. You might find a **very jagged graph** for the voltage. The **online help page** shows a "sine fit" technique that would help with those troublesome curves.

8. <u>Other resistances.</u> At this point, you just need to apply this procedure to fill in all the data cells in the PHASES Excel sheet. As you fill in the chart, your graphs should start filling in. Be very mindful of the particular order of probe connections that must be made, based on the information in Part 2.

Questions Answer the questions on the Data/Question sheet for this section.

DATA/QUESTION SHEET FOR LAB 11 - AC - RC CIRCUITS

Part 1 - Investigating the Voltage Magnitudes

Pick three rows (near beginning, in middle, and near end) in the chart of Part 1. Use these measured values to answer the following questions.

1. Do the resistor and capacitor voltages add up algebraically to the total voltage? If not, why not?

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2. How **should** you add them (hint: should they be considered "vectors"?)? **Show** that the voltage data in each of your three rows is reasonable, if you "add" them the right way.

3. Observe the graphs. Briefly explain how the change in the V_R graph is related to the change in the V_C graph. Explain some reasons for those changes and their relationship.

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Part 3 - Investigating the Effect of Changing the Resistance on the Phase Angles

Questions about CIRCUIT (1) (ε and V_R):

a) With the resistance set at 400 ohms, and the graph on the screen ... which graph is "leading" which? ["Leading": as you move along the time axis from left to the right, which graph peaks first, and then which peaks second?] Is this reasonable based on the discussion (and vector graph) in the introduction?

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b) How does the phase (the shift) between the curves seem to vary as you increase the resistance (compare the values in the appropriate column of the excel sheet) - are they getting closer together or farther apart as the resistance increases – is that to be expected? Explain your reasoning

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Questions about CIRCUIT (2) (ε and V_C):

a) With the resistance set at 400 ohms, and the graph on the screen ... which graph is "leading" which? ["Leading": as you move along the time axis from left to the right, which graph peaks first, and then which peaks second?] Is this reasonable based on the discussion (and vector graph) in the introduction?

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b) How does the phase (the shift) between the curves seem to vary as you increase the resistance (compare the values in the appropriate column of the excel sheet) - are they getting closer together or farther apart as the resistance increases – is that to be expected?

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Questions about CIRCUIT (3) (V_R and V_C):

a) With the resistance set at 400 ohms, and the graph on the screen ... which graph is "leading" which? ["Leading": as you move along the time axis from left to the right, which graph peaks first, and then which peaks second?] Is this reasonable based on the discussion (and vector graph) in the introduction?

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b) How does the phase (the shift) between the curves seem to vary as you increase the resistance (compare the values in the appropriate column of the excel sheet) - are they getting closer together or farther apart as the resistance increases – is that to be expected?

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Return equipment to instructor and to the drawer from where you have removed it. Please insure a good experience for the next lab group by cleaning up your lab station.

How do I write up this lab? … **What is required for this lab report?**

Consult the Rubric for this experiment and the "Lab Report Instructions" document (found on the Lab Schedule page).

Questions/Suggestions → Dr. Changgong Zhou czhou@ltu.edu

Portions of this laboratory manual have been adapted from materials originally developed by Priscilla Laws, David Sokoloff and Ronald Thornton for the Tools for Scientific Thinking, RealTime Physics and Workshop Physics curricula. You are free to use (and modify) this laboratory manual only for non-commercial educational uses.

Lawrence Technological University
Department of Physics

College Physics 2 Lab
PHY2431

Rubric - Lab 10 Alternating Current - RC Circuits - 80 points

Cover Page	Student Names	2
8 Points	Course-Section-Station	2
	Lab Title / Instructor's Name	2
	Date	2

Part 1 – Investigating the voltages	Calculations for three rows of data	12
27 Points	Excel Graph (4.5) – both pages – phases and voltages	15
Part 2 – Changing resistance ..	Questions	20
20 Points		

Analysis	Spelling/Grammar	5
20 Points	Analyze the results of this experiment, including a description of how well the measurements of the voltages of the three circuit elements relate to each other supported the AC-RC circuit theories. How did they "add up"? Give some numerical examples to back up your claim (such as one of the "row" calculations). (See "Lab Report Instructions" file for format details.)	20

Also: points will be taken off for the following as appropriate:

Report turned in late (5 points per school day)
Any units missing (if not printed on data table) (1 pt each)
Report not typed/stapled (5 pts)
Decimal point and sig fig errors (1 pt each)
Presentation (i.e. torn edges on papers (5 pts)
Instructor's signature/stamp missing – 5 points
Data/Question sheets missing – 20 points
Rubric not attached to lab report – 5 pts

Revised –04/12/2012