1. An oscilloscope can display a graph of voltage vs. *current*, instead of voltage vs time. To see how that is accomplished, draw a small box labelled "Y" to represent the device being investigated. Draw a resistor connected in series with that device, with the pair connected to a *sine wave generator*. "Sinusoidal" is an adjective which means "having a graph like a sine or cosine curve". We studied sinusoidal motion in chapter VIII. A "sine wave generator" makes a sinusoidally alternating emf.
   a. Draw an oscilloscope above that diagram. Then draw three wires connecting it to three points in the circuit so that the spot's vertical displacement will be proportional to the voltage across "Y", and the spot's horizontal displacement will be proportional to the resistor voltage, and hence to the current.
   b. To make this scheme work, you must turn off the oscilloscope's sawtooth generator, as explained in #4 on page 105. Be sure to say how that will be done. *Keep a copy of your plan for use on page 111.*
   * c Suppose "Y" is just another resistor: What pattern will appear on the screen? To figure out the answer, recall that the current -time graph is a sine curve and that Ohm's equation enables you to calculate the resistor voltage. Set up a data table with "time" measured in twelvths of a cycle, and use it to make the graph. Then use the oscilloscope (as in 2a & b) to find out if your prediction is correct.
   * d. Now replace resistor "Y" with a small *capacitor*. Use a moderately low frequency and use a resistor between 1K and 10K. Adjust the height and width of the pattern on the screen until they are equal. Then sketch the pattern and write a clear statement naming its shape. *Don't contradict 1c.*

2. To understand what's happening in 1d, make a larger, neater copy of the voltage vs current graph. Make twelve equally-spaced dots on the curve, and put the origin of a coordinate system at the center.
   a. Choose one of the dots randomly and label it "#1".
   b. Flip a coin to decide whether the rest should be numbered counterclockwise or clockwise.
   c. Number the dots according to that choice. These dot numbers represent *times*, in non-standard units.
   d. Draw the axes for a *current-time* graph and a *capacitor voltage vs time* graph. Label them clearly Make marks for times 1-12 on each time axis. Don't worry about units.
   e. The height of each dot (i.e. its vertical displacement from the axis) tells us the value of the _______ voltage at that time. The horizontal displacement of each dot tells you the value of the _______.
   f. Use the clues in 2d and 2e to plot 12 points on each graph. Describe the graphs and their differences.
   g. Does 2f agree with #3 on RS XI? __ -If not, can we blame the coin? ___

3. Imagine a capacitor connected across a sine wave generator:
   a. Sketch the capacitor's voltage vs. time graph as you did in #9 on page 101.
   b. Using the "second capacitor law" (#6 on RS XI) sketch the capacitor current vs. time graph directly below the first one as you did on pages 33, 73, & 101. Give both graphs the same time scale, and label the axes clearly. Compare these graphs to the ones you sketched in #2.
   c. The capacitor law tells us that *IF* the capacitor voltage vs time graph is sinusoidal, then its current vs time graph must have a shape that is similar, but shifted ____ of a cycle to the ______.
   d. Does 2f agree with that prediction? ____ If not, can we blame the coin? _____
   e. If the law is correct, the spot on the screen must have been going around ___________wise.

4. Reduce the generator voltage amplitude to half of its former value by adjusting its "fine" control:
   a. How does that affect the capacitor current amplitude? ______ -The capacitor voltage amplitude? ____
   b. How does that affect the size and shape of the pattern on the screen in 1d?

5. Suppose we double the generator frequency without changing the capacitor voltage amplitude:
   * a. Use the second capacitor law to predict exactly how the capacitor current amplitude will be affected. Express your prediction as a statement that is *always true*. *Include an illustrated explanation.*
   * b. Exactly how will that modification alter the shape of the pattern on the oscilloscope screen in 1d?

6. "Capacitive reactance" is the quotient obtained when you divide a capacitor's voltage amplitude by its current amplitude. This definition should be copied onto the Ch. ___ review sheet.
   a. The frequency change described in #5 causes the reactance of your capacitor to be multiplied by __.
   b. What happens to the capacitive reactance when you adjust the generator voltage amplitude? _____
   * c. Describe what you did in the lab to test those predictions. Also describe what you saw.
   d. Doubling the reactance would cause the height-to-width ratio on the screen to be _______ed.
   * e. What variables does capacitive reactance depend upon, and how does it depend on those variables?
   * f. Explain why I should believe your answer to 6e.

1. You should already have these basic facts recorded for future reference:
   a. The capacitor law says that whenever the capacitor voltage is *increasing*, the capacitor current must be in the ____tive direction. (See #2 on RS XI or #8 on page 97.)
   b. Whenever the capacitor voltage is *decreasing*, the current must be in the ____tive direction.
   c. The capacitor law also tells us that if the capacitor's voltage vs. time graph resembles a **"sine"** curve, then its current vs. time graph must resemble a _______ curve. Do 1a and 1b agree? ___
   d. If a capacitor current vs time graph is sinusoidal then there is a phase difference of ___ degrees between the current vs. time graph and the capacitor's _______ vs. time graph. (See 3b on p. 109.)

2. The *definition* of **"capacitive reactance"** on RS XII says $\mathbf{X_C}$ = (______ _____) ÷ (_____ ____). The symbol **"$\mathbf{X_C}$"** represents capacitive ___________. Does X_C depend upon voltage amplitude? ___ *If so, please show exactly how X_C was affected when the voltage amplitude was doubled on p.109.*

3. In 1d on page 109 we caused a circle appear on the screen of the oscilloscope. We discovered that changing the reactance of the capacitor causes the pattern's height-to-width ratio to change. We found that you can't change one without changing the other.
   a. Find out how the height-to-width ratio depends on generator frequency. Make a data table and a graph to describe your results. Remember to use ranges and error bars.
   b. Find out what kind of equation describes that graph and give convincing evidence, as on page 16R.
   c. Write a conclusion on the graph about the relation between capacitive reactance and frequency.

4. Now find a second capacitor which is identical to the one in your circuit.
   * a. Make a diagram showing how it can be connected to the first one so that the combination has twice as much capacitance as the original. (Use #8 on RS XI.)
   * b. Use that plan to find out how the reactance is affected. Describe what you see.
   * c. Predict what will happen if the capacitance is halved. Then test that prediction, using the other part of #8 on RS XI. Describe your method, your observations, and your conclusion.

5. If we divided a *resistor's* voltage amplitude by its current amplitude the quotient would be called _________ (name) and would be expressed in _______s (Copy from RS X.) --Does that quotient (for resistors) depend on frequency? ___ **If so, describe that relationship and give evidence.*

6. Find the frequency at which your capacitor's voltage amplitude is equal to the resistor's voltage amplitude. Convince your teacher that they are equal. Then record the the special frequency and the resistance. Show how the capacitance is calculated from the other measured quantities, as on p. 107.

7. We now know that a capacitor's reactance depends on two variables:
   a. In 3c we saw that X_C is proportional to ______. In #4 we found that X_C is proportional to _______.
   b. In #4 on page 109 we found that X_C does *not* depend on ________________. -Does #2 agree? ___
   c. Summarize those discoveries with a simple equation: $\mathbf{X_C}$ = ______
   d. The letter "___" in that equation represents a proportionality constant, and the other three symbols represent *variables*. What do we know about the units of that constant? _________
   e. Show how the value of that constant can be calculated from the data in #6. Express the uncertainty of that result as a percentage, and explain which measurement contributed most to that uncertainty.

8. Now let's figure out *why* the constant has the value found in 7e: Begin by sketching a capacitor voltage vs time graph resembling a cosine curve. Draw the steepest tangent line on that graph.
   a. How can the current amplitude be calculated from the slope of that line? (Use the capacitor law.)
   b. How can the reactance be calculated from the voltage amplitude and that current amplitude?
   c. Combining 8a and 8b gives you an equation relating the reactance to the capacitance, the voltage amplitude, and the slope. Which symbol in that equation represents the slope? ___
   d. In #10 on RS VIII you recorded an exact formula for that slope. Copy it here: ___ = ________
   e. Use 8d to eliminate the slope symbol from equation 8c.
   f. Compare the result with 7c and make a conclusion about the exact value of the unknown constant.

* 9. Explain how your experiment does or does not agree with the theory developed in #8.