**AC CIRCUITS**

Electricity and Light

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**Theory:**

The capacitive reactance and the inductive reactance of a capacitor and an inductor,   
respectively, are defined as:  
  
*XC = 1/(ωC)* and *XL = ωL*,  
 where *ω = 2πf* is the angular frequency in rad/s, and *f* is the frequency in Hertz (Hz).

If the current in the RC circuit is *I(t) = Iosin(ωt)*, then the maximum voltage across each element and the entire circuit is:  
  
 *VRo = IoXR* , *VCo = IoXC* , and *Vo = IoZ* ,  
 where *XR* is simply the resistance *R* of the resistor, and *Z =* sqrt (*R2+XC2*) is the impedance of the circuit. The relation between the maximum voltage across each element and the entire circuit is:  *Vo =* sqrt(*VoR2 +VoC2*) ….. (1)

For an RL circuit, the voltage across the elements and the entire circuit is:

*VRo = IoXR* , *VCo = IoXL* , and *Vo = IoZ* ,

with the impedance of the circuit being *Z =* sqrt (*R2 +XL2)*

The relation between the voltages then is:  *Vo =* sqrt (*VoR2+VoL* 2) …… (2)

In the case of a resistor, an inductor, and a capacitor connected in series to an AC source (RLC circuit), as shown on the diagram below, the impedance of the circuit is equal to:

*Z =* sqrt (*R2 +(XL-XC)2)*  …… (3)

If the current in the circuit is given by *I(t) = Iosin(ωt)*, the voltage across the circuit as a function of time is then given by *V(t) = Vosin(ωt+φ)*, where *φ* is called a phase angle and for the RLC circuit is equal to:

*tan(φ) = (XL-XC)/(XR)*  …… (4)

Experimentally, the phase angle between the current and the voltage in the circuit, can be determined by measuring the voltage value at the time when the current is zero. If the current *I(t) = Iosin(ωt)* = *0* at some time *t*, then *sin(ωt) = 0* at that time. Using the trigonometric relation for *sin (A + B)*, we can write down for the voltage:

*V(t) = Vo( sin(ωt) cos(φ) + cos(ωt) sin(φ) ) = Vo sin(φ)* The phase angle *φ,* then, can be determined as: *φ=arccos(V(t)/Vo )*  ….. (5)

**A picture containing object, clock

Description automatically generatedA close up of a clock

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**You can refer to the course book on AC Circuits to complete the following questions**

**Please type all your answers in Blue**

This pre-lab is worth 15 points.

1. AC current through a perfect inductor or capacitor is \_\_\_\_\_\_\_\_\_\_\_\_\_ out of phase with the AC voltage across the inductor or capacitor.

-1 90 Degrees

1. What is reactance? What is impedance? What are their units?

-4 Reactance is the opposition of a component to change in a current. This is usually a capacitor or

an inductor. Impedance is the measure of the combined effect of capacitive reactance and

inductive reactance.

1. What is the name for the units of an inductor and capacitor and the symbols which represent them?

The unit for inductors is the ohm (Ω) and the unit for capacitors is the farad (F).

-4

1. For an inductor, the current and voltage is out of phase by an angle φ. How can this angle be determined theoretically?

You can determine the theoretical phase angle of a circuit by getting the equation for voltage and solving for the angle instead. This equation works out to φ = tan^-1((XL-XC)/(XR))

-2

1. What are the equations for the time constants, τ, for a RL and a RC circuit?

The time constant for an RC circuit is τ=RC and the time constant for a RL circuit is τ=L/R

-4

**This lab uses simulation kit in Phet Labs.**

<https://phet.colorado.edu/sims/html/circuit-construction-kit-ac/latest/circuit-construction-kit-ac_en.html>

There are 3 choices, open the “Lab”

**Activity 1: Voltage across the elements in RC circuit.**

1. Connect a resistor and a capacitor in series and connect them to an AC source.
   1. Click on a resistor, a capacitor and an AC source and drag them into the circuit board.
   2. Drag wires and connect the elements in series to form an RC circuit. Two elements are connected when their ends overlap. To disconnect two elements, right-click on the joint and select "split junction".
   3. To change the values for an element, right-click over that element and select change value.

* Put a checkmark in “values” to turn it on. How does A/C voltage differ from DC voltage? The voltage across the voltage source is changing in the A/C circuit while a DC circuit would have a consistent voltage.
* Change the component values to those in Table 1, then paste a screen shot of your circuit below.

**Table 1**

|  |  |  |  |
| --- | --- | --- | --- |
| R(Ω) | C (F) | Eo (V) | f (Hz) |
| 4.0 | 0.06 | 12 | 1.0 |

Diagram

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1. Perform the experiment:
   1. **Measuring the maximum voltage using the voltmeter.** 
      1. Use the voltmeter to measure the maximum voltage across the A/C voltage source. Note\* Use the pause button to pause the simulation. What value did you obtain?

🡪 12V

* 1. **Measuring the maximum voltage on the Voltage Chart.** 
     1. Use the Voltage Chart to measure the amplitude of the voltage on the chart (it's half the height from a trough to a crest). What value did you obtain?

🡪 ~12V

* 1. **Taking measurements.** Measure the maximum voltage across the resistor, VR, the capacitor, VC, and across both elements, VRC. Note\* you can use the Voltage chart in combination with the voltmeter to judge when to pause the simulation to obtain a max value. Complete Table 2.

Table 2

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Frequency (Hz) | VR (V) | VC (V) | VRC (V) | VRC2 (V) | VR2 + VC2 (V) | % difference |
| 1 Hz | ~10V | 6.63V | 12V | 144V | 143.95V | .034% |

Results: Is the sum of the square of the maximum voltages across R and C, VR2 + VC2, equal to the square of voltage across both elements, VRC2 in agreement with Eq.1?

**🡪** Yes. The percent difference is practically 0.

**Activity 2: Voltage across the elements in RL circuit**

1. Connect a resistor and an inductor in series and connect them to an AC source.
   1. Click on a resistor, inductor and AC source and drag them into the circuit board.
   2. Drag wires and connect the elements in series to form an RL circuit. Two elements are connected when their ends overlap. To disconnect two elements, right-click on the joint and select "split junction".
   3. To change the values for an element, right-click over that element and select change value.

Change the component values to those in Table 3, turn on “values” by placing a checkmark, then paste a screen shot of your circuit below.

Table 3

|  |  |  |  |
| --- | --- | --- | --- |
| R (Ω) | L (H) | Eo (V) | f (Hz) |
| 50 | 10 | 10 | 1.0 |

Shape

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Perform the experiment:  
**Taking measurements.** Measure the maximum voltage across the resistor, VR, the inductor, VL, and across both elements, VRL.

Complete Table 4.

Table 4

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Frequency (Hz) | VR (V) | VL (V) | VRL (V) | VRL2 (V) | VR2 + VL2 (V) | % difference |
| 1 Hz | 6.5 | 7.5 | 10V | 100V | 98.5 | 1.5% |

Results: Is the sum of the square of the maximum voltages across R and L, VR2+VL2, equal to the square of voltage across both elements, VRL2 in accordance with Eq.2?

🡪 Yes. The percent difference is close enough to 0. This difference is probably due to measurement errors.

**Activity 3: Impedance of an RLC circuit.**

1. Set up the RLC circuit.
   1. Click on a resistor, an inductor, a capacitor, and an AC source and drag them into the circuit board.
   2. Select an ammeter and voltmeter from the Tools Menu on the right. Connect the Ammeter in series to the RLC circuit.
   3. Drag wires and connect the elements in series to form an RLC circuit with an ammeter and AC source.

Change the component values to those in Table 5, turn on “values” by placing a checkmark, then paste a screen shot of your circuit below.

Diagram

Description automatically generated

**Table 5**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| R (Ω) | L (H) | Eo (V) | f (Hz) | C (F) |
| 10 | 10 | 10 | 0.1 | 0.1 |

1. Perform the experiment:
   1. Measure the maximum voltage across the entire RLC circuit, Vo.
   2. Measure the maximum current in the circuit, Io
   3. Measure the value for the voltage when the current in the circuit is zero, VI=0
2. Data and Results.
   1. For the experimental values of the impedance and the phase angle, use the relation *Z=Vo/Io*, and Eq.5, respectively.
   2. For the theoretical value of the impedance and the phase angle, use Eqs.3-4.
   3. Complete Table 6.

Table 6

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Vo (V) | Io (A) | VI=0 (V) | Zexp (Ω) | Zth (Ω) | % difference in Z | φexpin (deg.) | φthin (deg.) | % difference in φ |
| 10V | .72A | 6.85V | 13.88 | 13.884 | 0.028% | 46.75 | 46.07 | 1.454% |