Boğaziçi University

Introductory Phys Labs

ALTERNATING CURRENTS SERIES CIRCUITS

PHYL202

THEORY

AC Current: Current that fluctuates sinusoidally with time at a fixed frequency

AC Voltage: Voltage that fluctuates sinusoidally with time at a fixed frequency

Alternating Current (AC): Flow of electric charge that periodically reverses direction

Resistance: Opposition of a resistance to any current

Capacitive Reactance: Opposition of a capacitor to an alternating current

Inductive Reactance: Opposition of an inductor to an alternating current

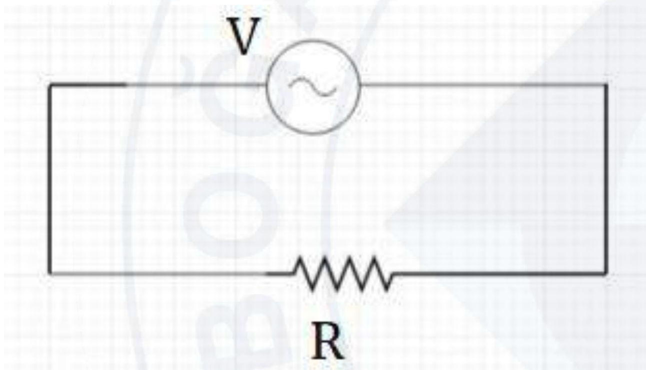
Impedance: AC analog to resistance in a DC circuit, which measures the combined effect of resistance, capacitive reactance and inductive reactance

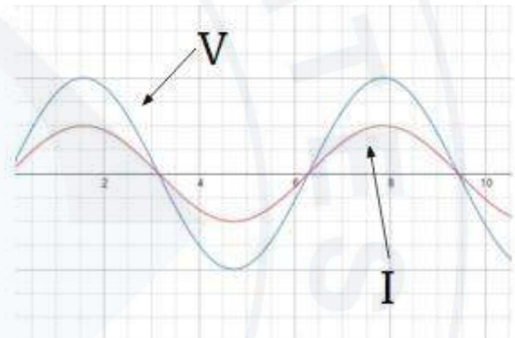
Phase Angle: Amount by which the voltage and current are out of phase with each other in a circuit

Resistor in an AC Circuit:

When the resistive load R is connected across the alternating source shown in the figure below, the current flows through it. The alternating current flows in one direction and then in the opposite direction when the polarity is reversed. Also, we know that according to Ohm's Law, potential drop across a resistor is given by

$V_R = I\,R.$



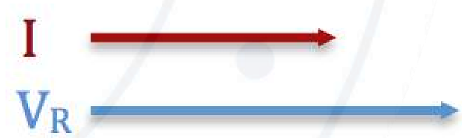


$$V = IR$$

$$V_o \sin(\omega t) = IR$$

$$I = \frac{V_o}{R}\sin(\omega t)$$

$$I = I_o \sin(\omega t),$$

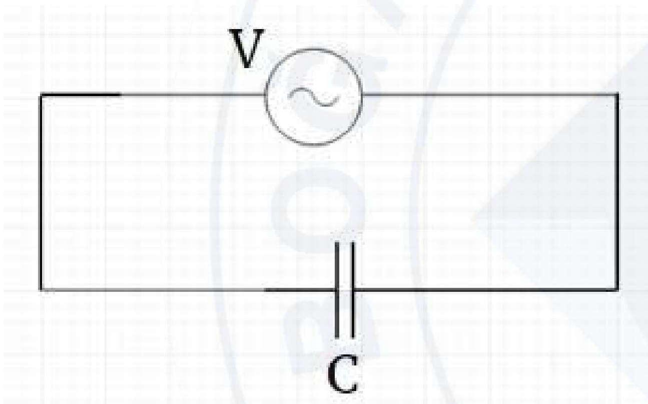


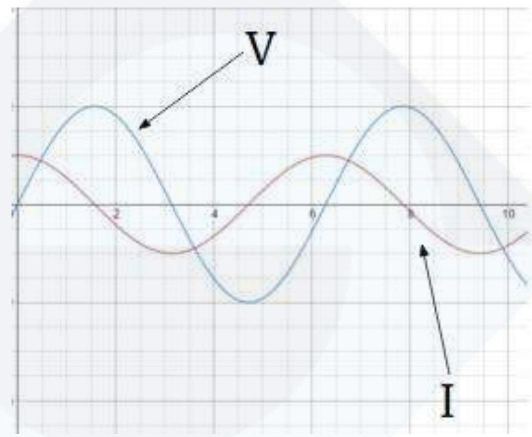
where $I_o = \frac{V_o}{R}$ is the maximum value of current in the circuit.

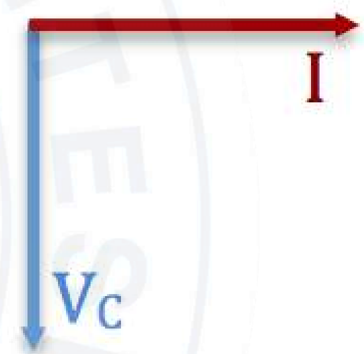
Current in a purely resistive circuit is in phase with the applied voltage

Capacitor in an AC Circuit:

In a <u>purely</u> capacitive circuit, we use the properties of an inductor to show characteristic relations for the circuit. I flows through the following circuit, then by using Kirchoff's law of voltages for closed loops, we get $V = V_C$.







$$V = V_C$$

$$V_o \sin(\omega t) = \frac{Q}{C}$$

$$Q = V_o C \sin(\omega t)$$

$$I = \frac{d}{dt}(Q)$$

$$= V_o C \frac{d}{dt} \sin(\omega t)$$

$$= \frac{V_o}{1/C\omega} \cos(\omega t)$$

$$= I_o \sin\left(\omega t + \frac{\pi}{2}\right)$$

Current in a purely capacitive circuit leads the applied voltage by a phase difference of π/2, i.e. when voltage attains its maxima, current attains its minima, but being ahead of voltage

Capacitor in an AC Circuit:

Here, I_0 is the peak current during a complete cycle. This current is given by

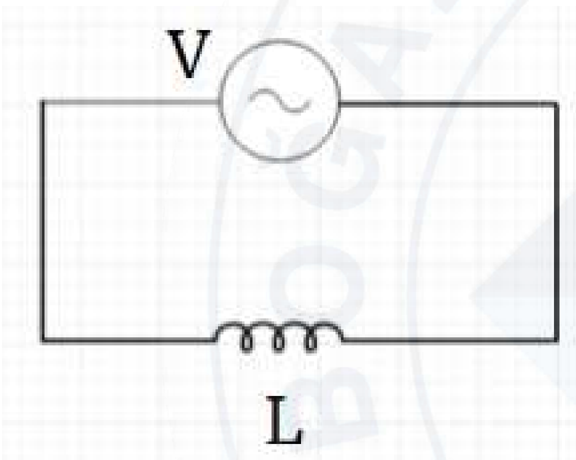
$$\frac{V_o}{1/C\omega}$$

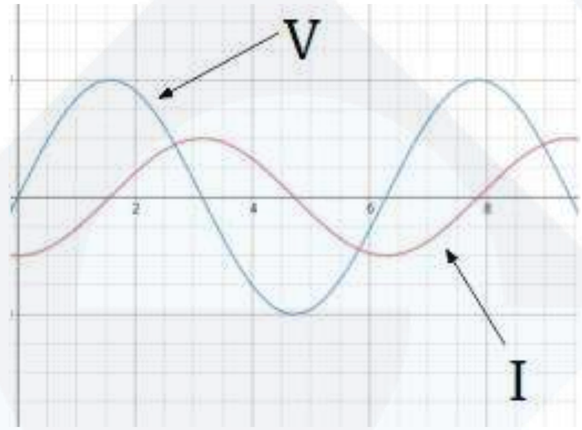
Now, look at the term in the denominator. It acts as resistance in this circuit and is denoted by X_C and is known as capacitive reactance. So,

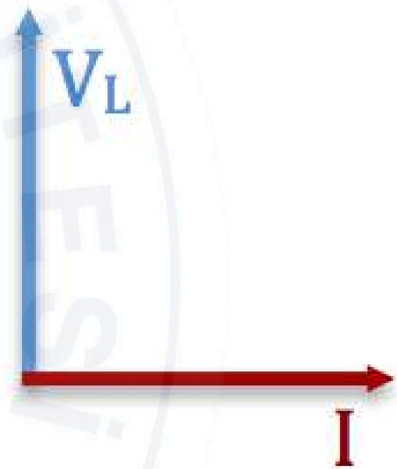
$$X_C = \frac{1}{C\omega},$$

Inductor in an AC Circuit:

In a <u>purely</u> inductive circuit, we use the properties of an inductor to show characteristic relations for the circuit. According to Kirchoff's voltage law for closed loops, we get $V = V_L$







$$V = L\frac{d}{dt}(I)$$

$$V_o \sin(\omega t) = L\frac{d}{dt}(I)$$

$$dI = \frac{V_o}{L}\sin(\omega t)\,dt$$

$$\int dI = \int \frac{V_o}{L}\sin(\omega t)\,dt$$

$$I = \frac{V_o}{L\omega}\left(-\cos(\omega t)\right)$$

$$= \frac{V_o}{L\omega}\sin\left(\omega t - \frac{\pi}{2}\right)$$

Current lags the applied potential difference by a phase of π/2

Inductor in an AC Circuit:

Here, I_0 is the peak current in the circuit. This current is given by

$$I_o = \frac{V_o}{L\omega}$$

Now, look at the term in the denominator. It acts as resistance in this circuit and is denoted by X_L and is known as Inductive reactance. So,

$$X_L = L\omega$$

RC CIRCUIT

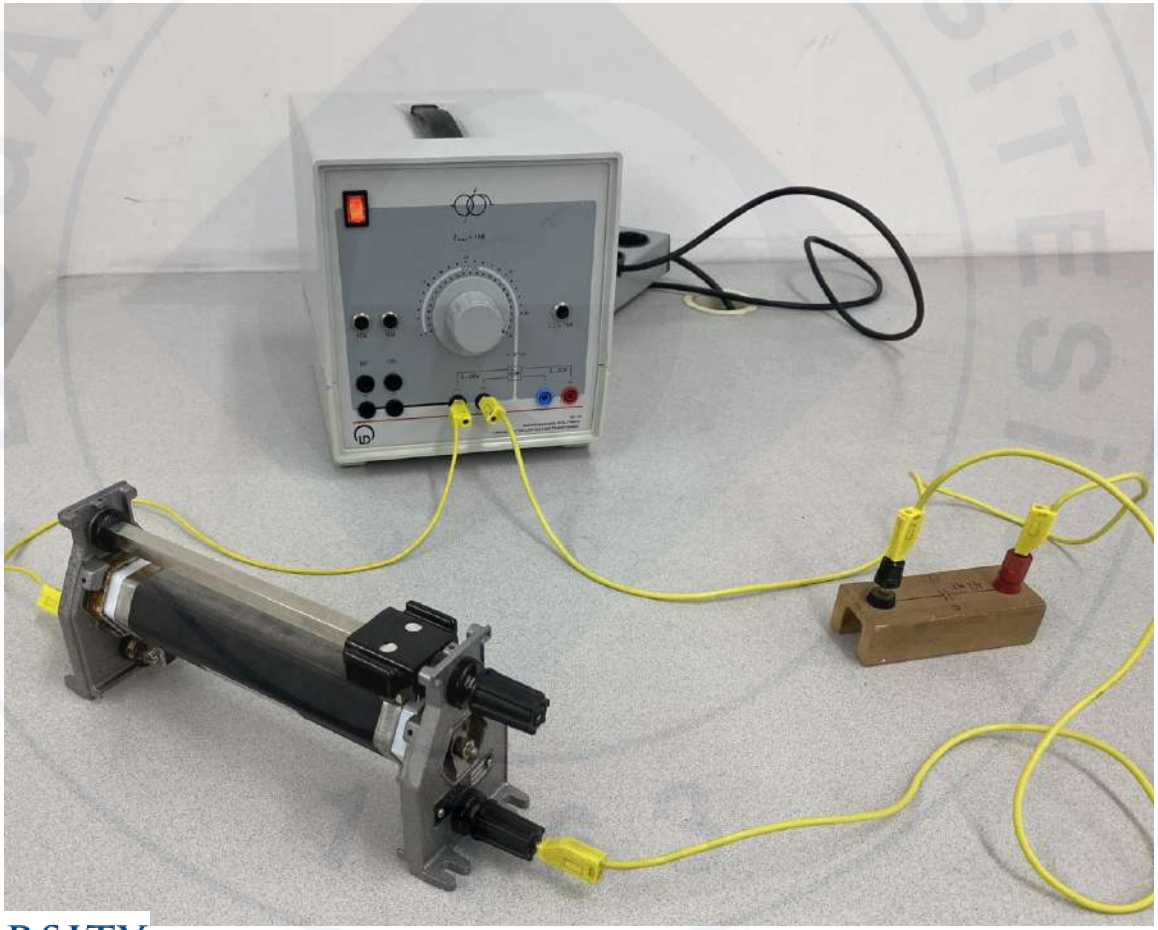
When you connect a capacitor and a resistor in series to an alternating voltage source, the phase of the current through the capacitor will be 90° ahead of the voltage. If we were to take the current as our reference for the phase, then the voltage across the capacitor will be 90° behind the current hence the voltage across the resistor. The total voltage across the RC series combination will be equal to the applied voltage:

$$V_{app} = \sqrt{\left(V_R^2 + V_C^2\right)}$$

EXPERIMENT

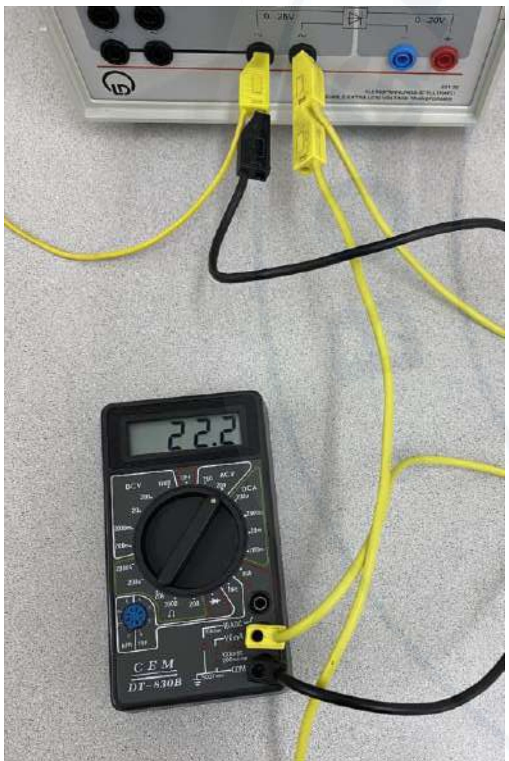
RC CIRCUIT

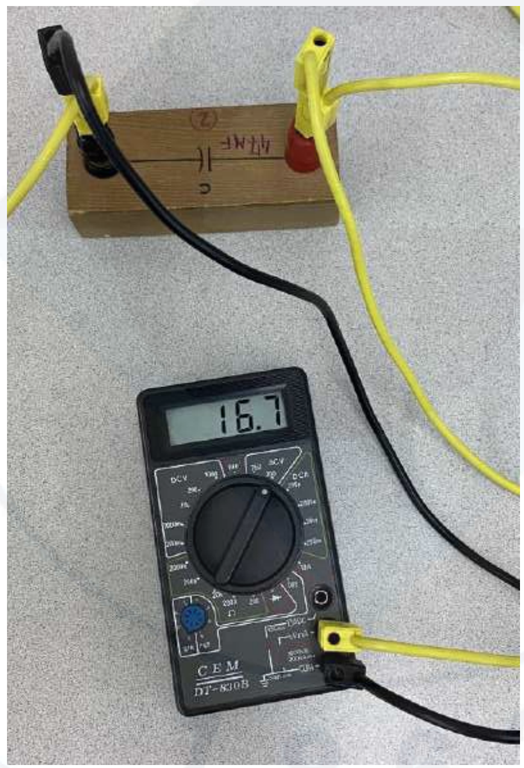
- Construct an RC circuit.

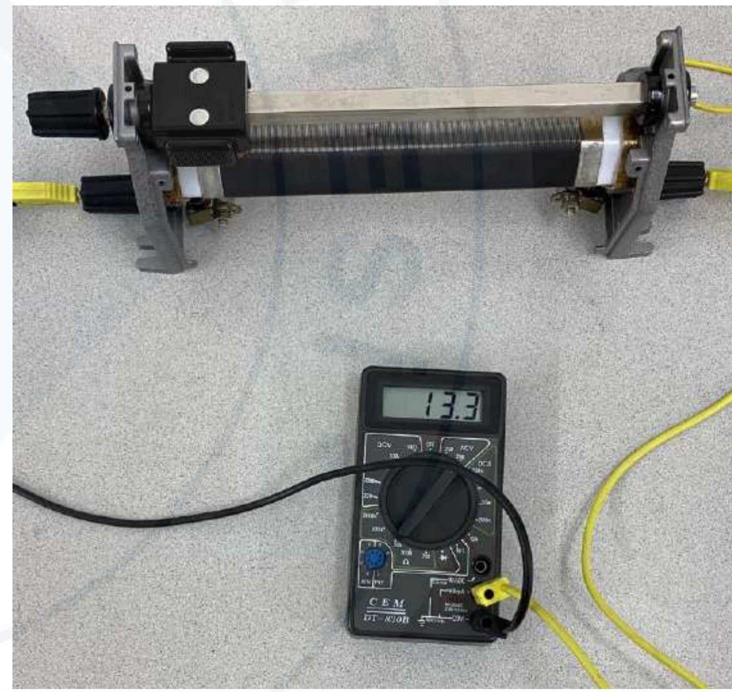


RC CIRCUIT

- **Measure the voltage across each element.**







RC CIRCUIT

Description / Notation			Value & Unit
Potential difference across the resistance	V_R	=	....
Potential difference across the capacitor	V_C	=	....
Applied potential	V_{app}	=	....

Phasor Diagram of the RC Circuit: **Scaling Factor:**

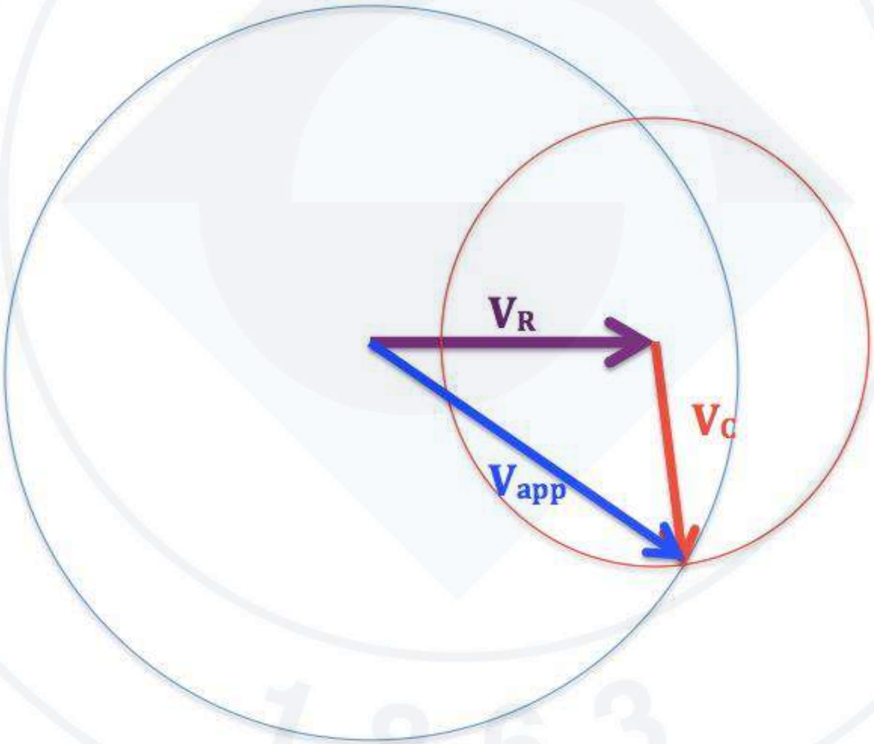
RC CIRCUIT

- Then draw the phasor diagram by taking the current (i.e. the voltage across the resistor) as the reference.

- Then draw two circles by using compasses with radii equal to V_C from the tip and V_{app} from the beginning of the phasor corresponding to the voltage across the resistor.

RC CIRCUIT

- **Phasors for V_C and V_{app} will meet each other at the point where the circles intersect. Determine the angle between V_C and V_R.**



RL CIRCUIT

When you connect an inductor and a resistor in series to an alternating voltage source, the current through the inductor will be 90° behind the voltage. If we were to take the current as our reference for the phase, then the voltage across the inductor will be 90° ahead of the current hence the voltage across the resistor. The total voltage across the RL series combination will be equal to the applied voltage:

$$V_{app} = \sqrt{V_R^2 + V_L^2}$$

RL CIRCUIT

However, the inductor also has some internal resistance, R_L. Because of its internal resistance, the voltage across the inductor will not be exactly 90° ahead but at an angle calculated from:

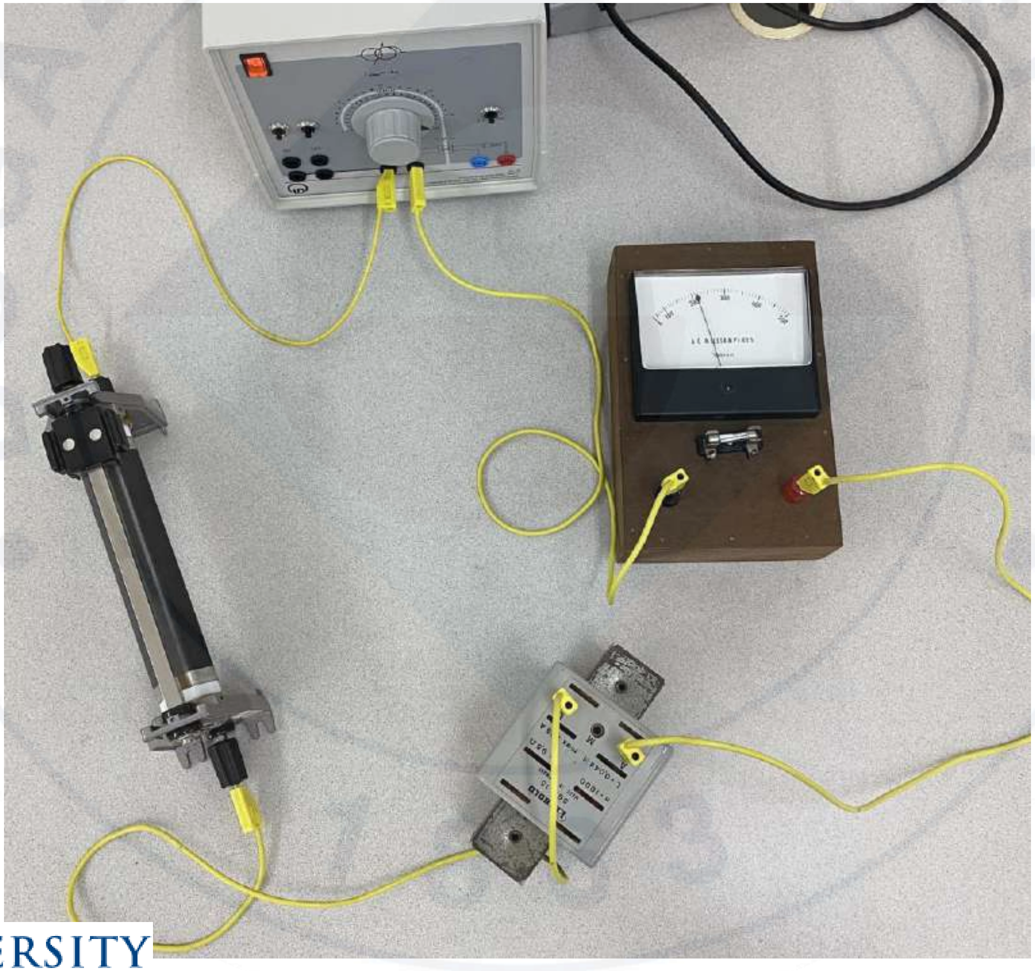
$$\tan\theta = \frac{2\pi f L}{R_L}$$

We should also modify Equation (5) accordingly:

$$V_{app} = I\sqrt{(R + R_L)^2 + X_L^2}$$

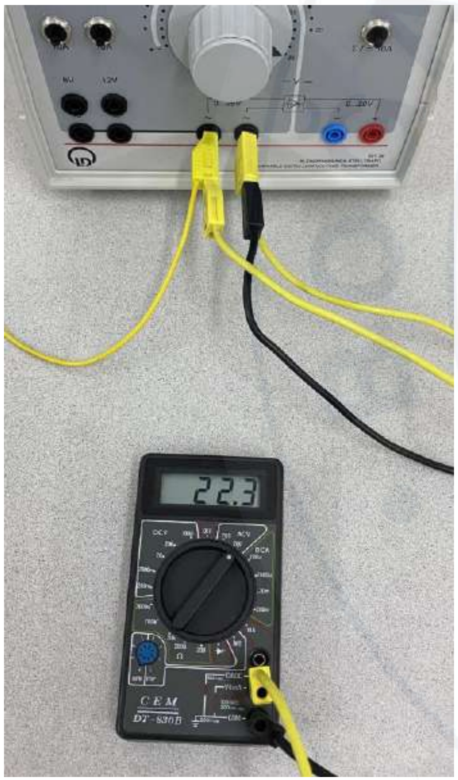
RL CIRCUIT

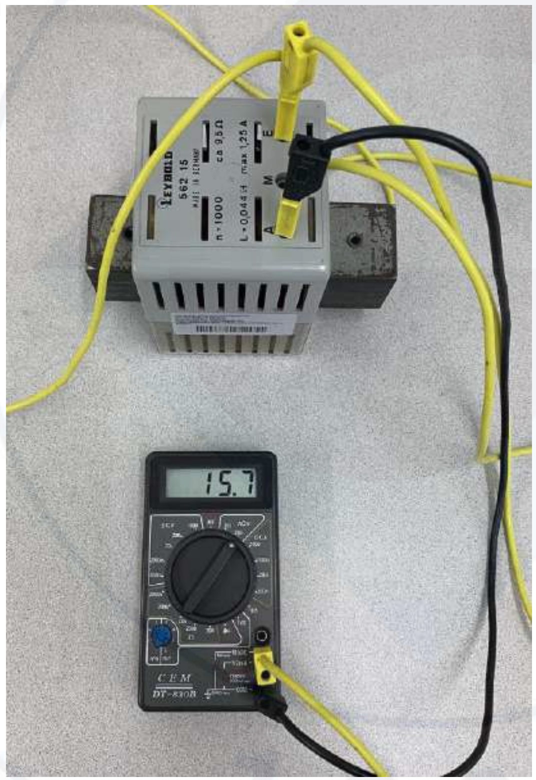
- **Construct an RL circuit.**

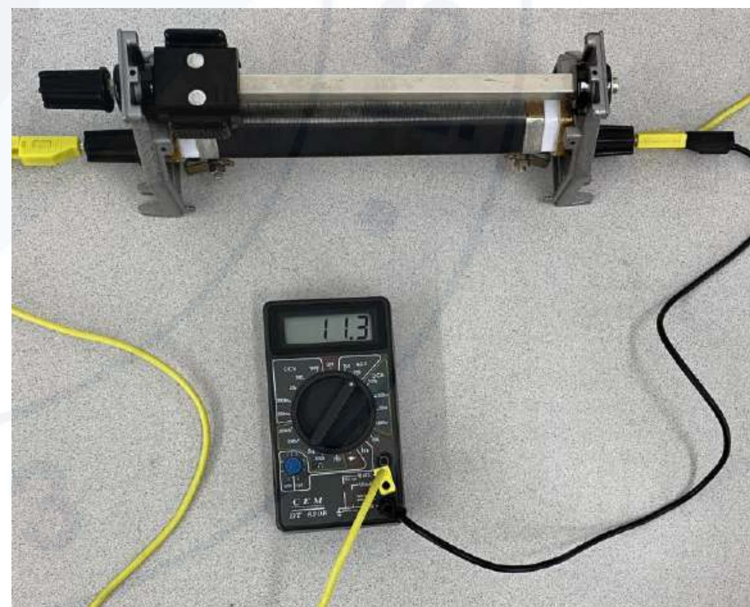


RL CIRCUIT

- **Measure the voltage across each element.**







RL CIRCUIT

Description / Notation		Value & Unit
Current in the circuit I	=	....
Potential difference across the resistance V_R	=	....
Potential difference across the inductor V_L	=	....
Applied potential V_{app}	=	....

Phasor Diagram of the RL Circuit:

Scaling factor:

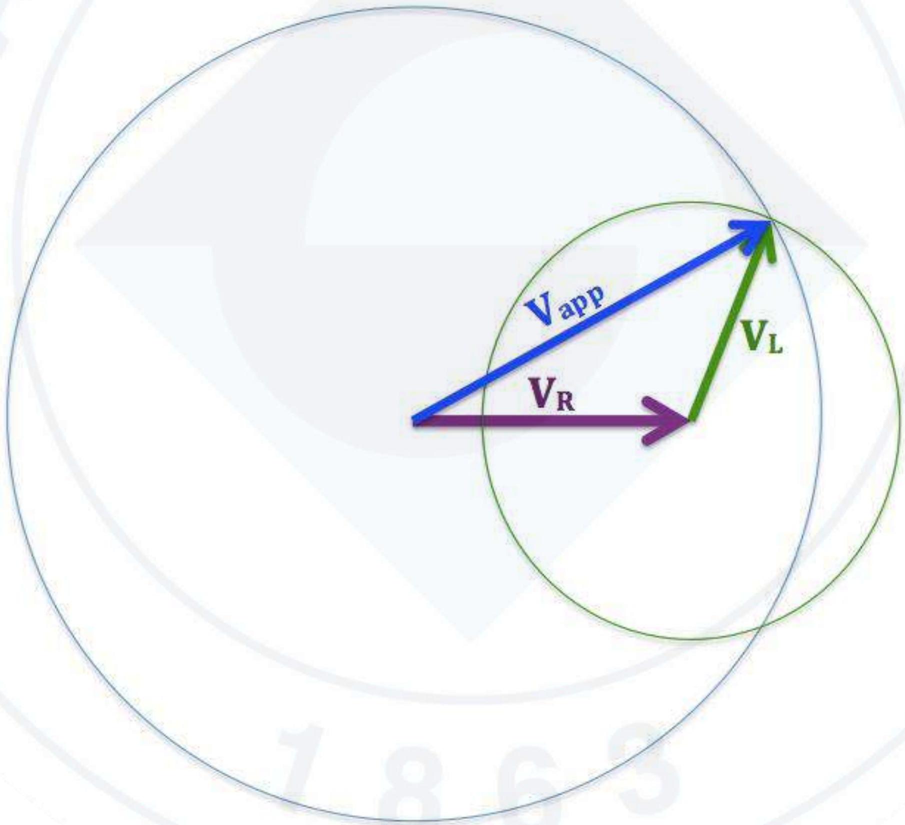
RL CIRCUIT

- **Then draw the phasor diagram by taking the current (i.e. the voltage across the resistor) as the reference.**

- **Then draw two circles by using compasses with radii equal to V_L from the tip and V_{app} from the beginning of the phasor corresponding to the voltage across the resistor.**

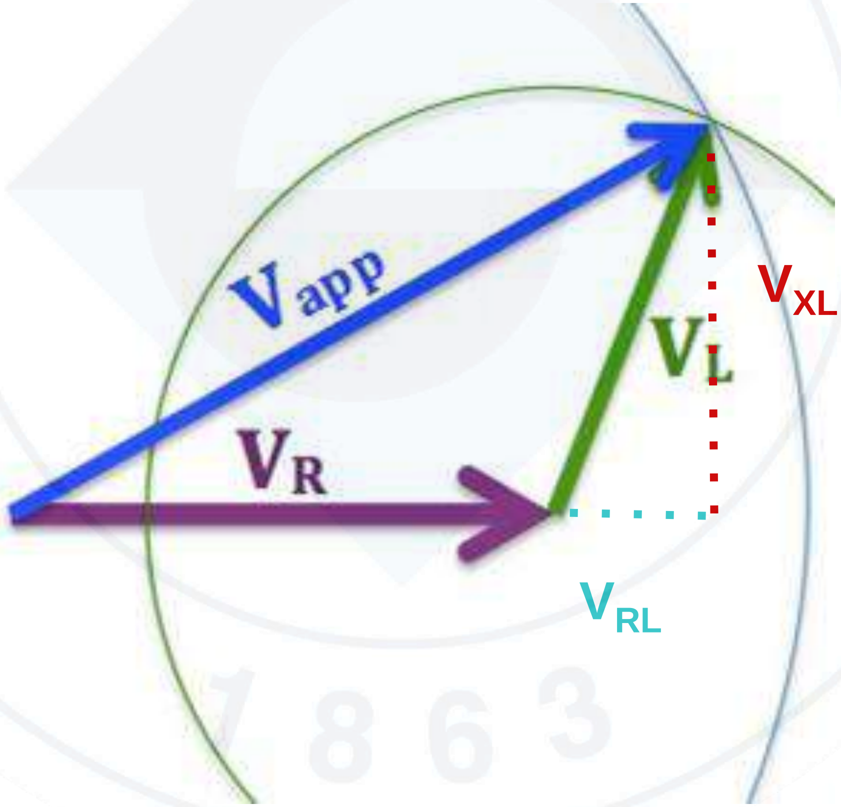
RL CIRCUIT

- **Phasors for V_L and V_{app} will meet each other at the point where the circles intersect.**



RL CIRCUIT

- **Determine the internal resistance of the inductor by measuring the current through the circuit and the horizontal component of V_L from your phasor diagram.**



RL CIRCUIT

Description / Symbol	Value / Calculation	Result
Potential difference due to the internal resistance of the inductor V_{r_L} =	....	....
Internal resistance of the inductor r_L =	....	....

RLC CIRCUIT

When you connect an inductor, a capacitor, and a resistor in series to an alternating voltage source, the current through the inductor and the capacitor will be 90° behind and ahead of the voltage, respectively. If we were to take the current as our reference for the phase, then the voltage across the inductor and the capacitor will be 90° ahead of and behind the current (hence the voltage across the resistor), respectively. The total voltage across the RLC series combination will be equal to the applied voltage:

$$V_{app} = \sqrt{(V_L - V_C)^2 + V_R^2}$$

RLC CIRCUIT

However, the inductor also has some internal resistance, R_L. Because of its internal resistance, the voltage across the inductor will not be exactly 90° ahead but at an angle calculated from:

$$\tan\theta = \frac{2\pi f L}{R_L}$$

Applied Potential: $$V_{app} = I\sqrt{(R+R_L)^2 + (X_L - X_C)^2} = IZ$$

Total Impedance: $$Z = \sqrt{(R+R_L)^2 + (X_L - X_C)^2}$$

RLC CIRCUIT

Now the phase difference between the current and the voltage is more complex and given by:

$$\tan\Phi = \frac{(X_L - X_C)}{R_{total}}$$

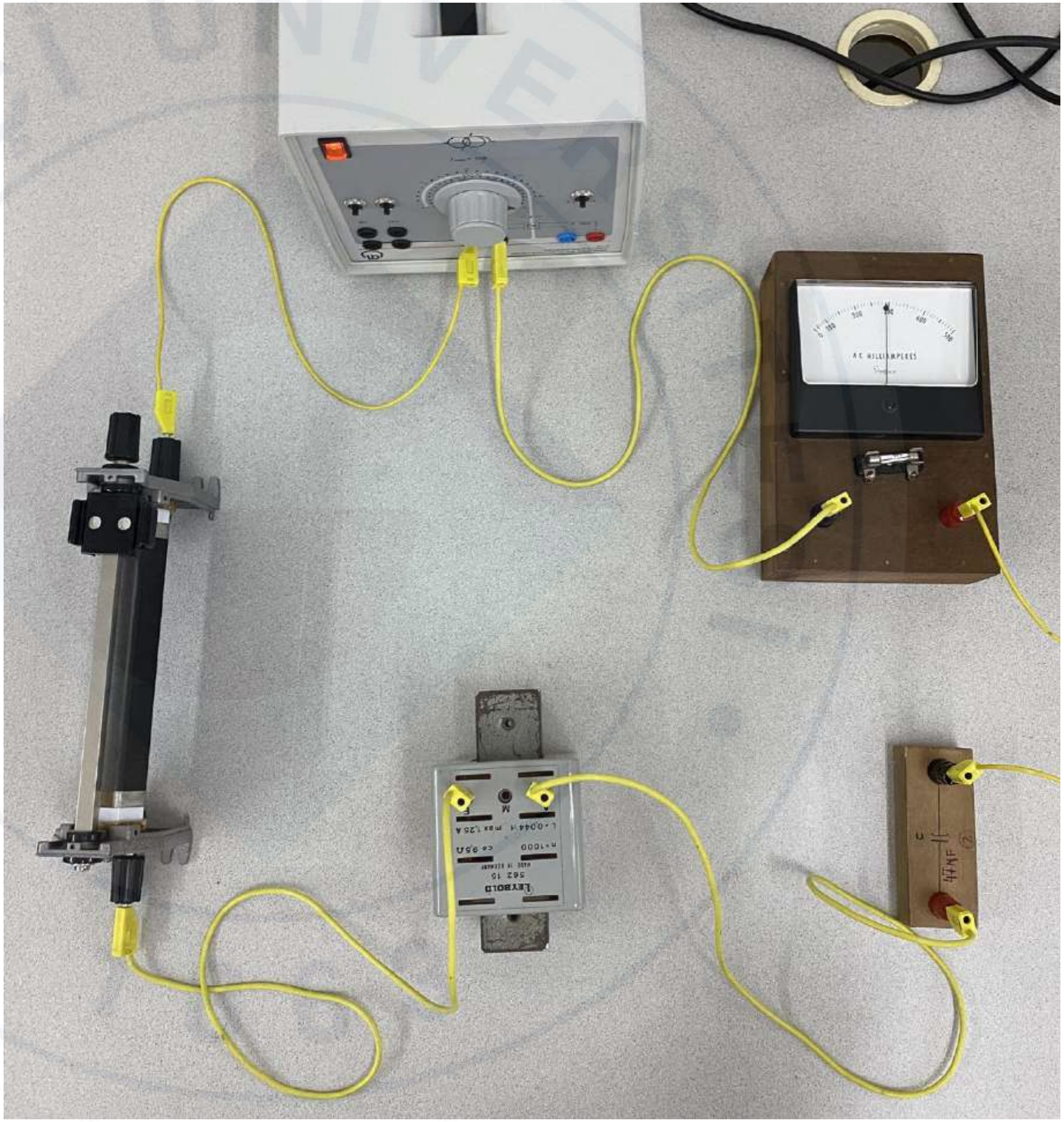
This Φ angle is the angle between the applied voltage and the resulting current phasors. It determines the total average power used in an RLC circuit:

$$\overline{P} = V_{rms} I_{rms} \cos\Phi$$

We should remember that the values measured by instruments like voltmeters, ammeters, etc. are root-mean-squared values and not the peak values.

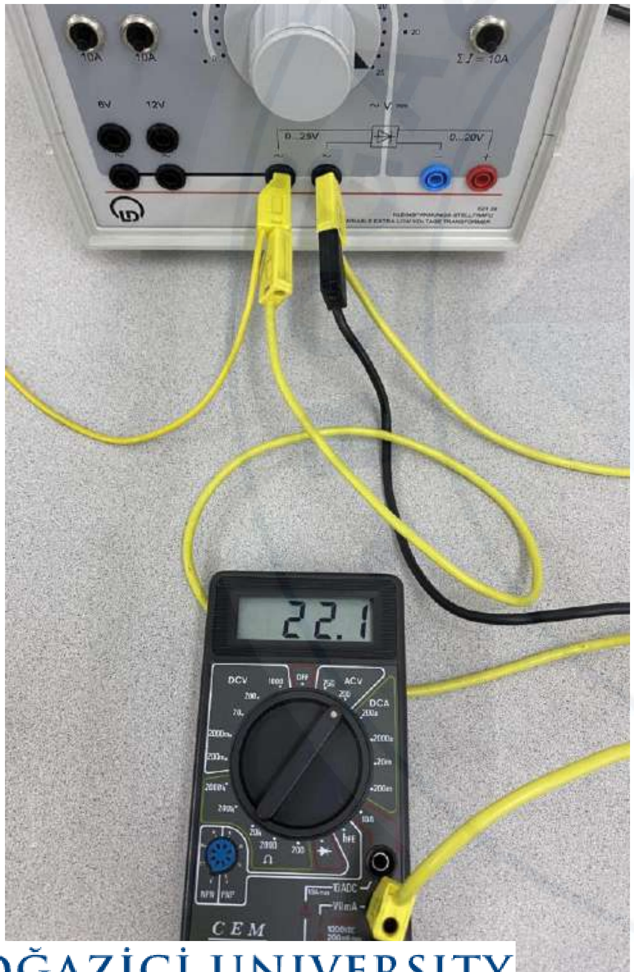
RLC CIRCUIT

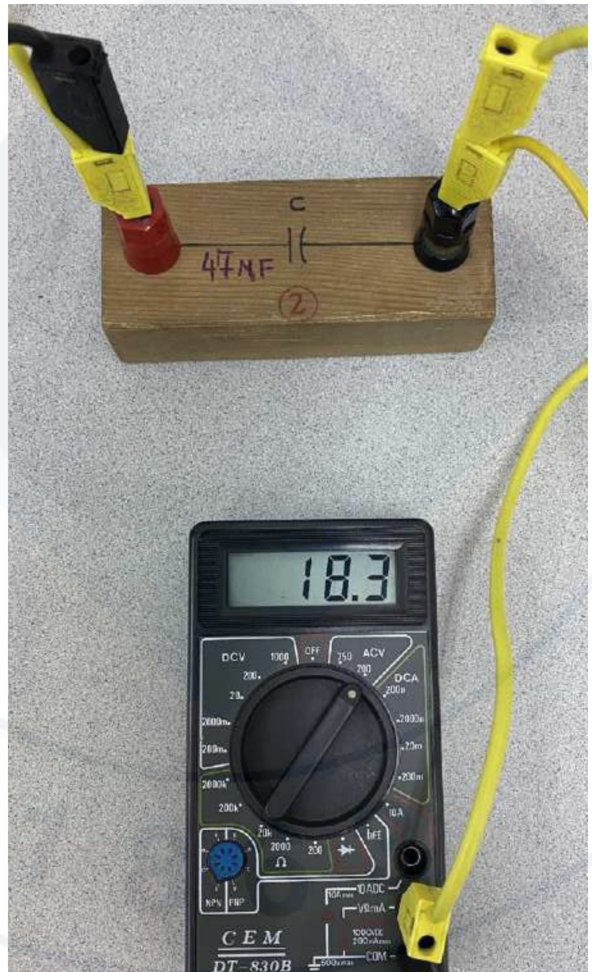
- Construct an RLC circuit.



RLC CIRCUIT

- **Measure the voltage across each element.**





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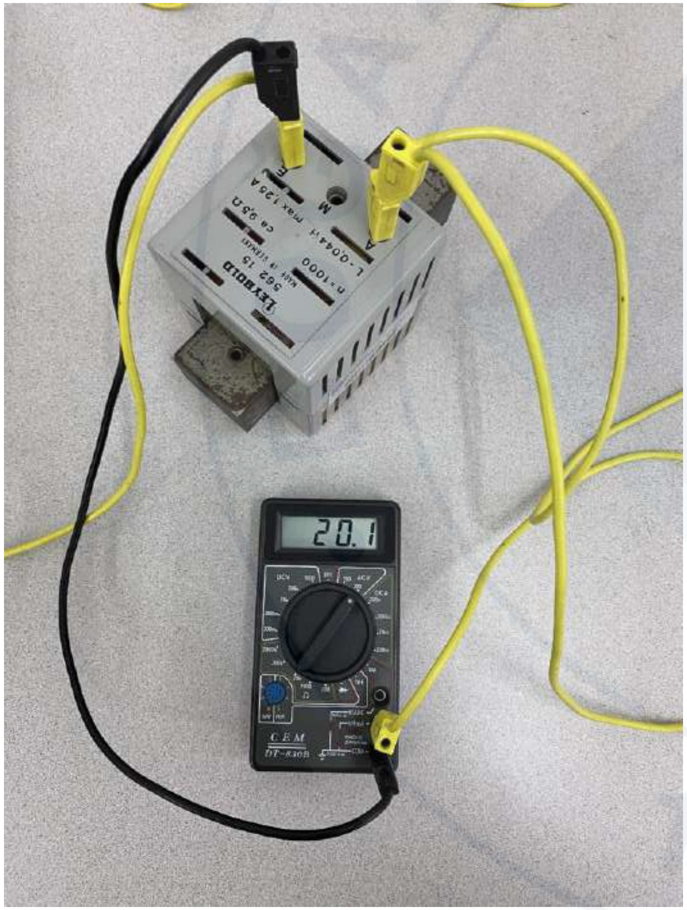
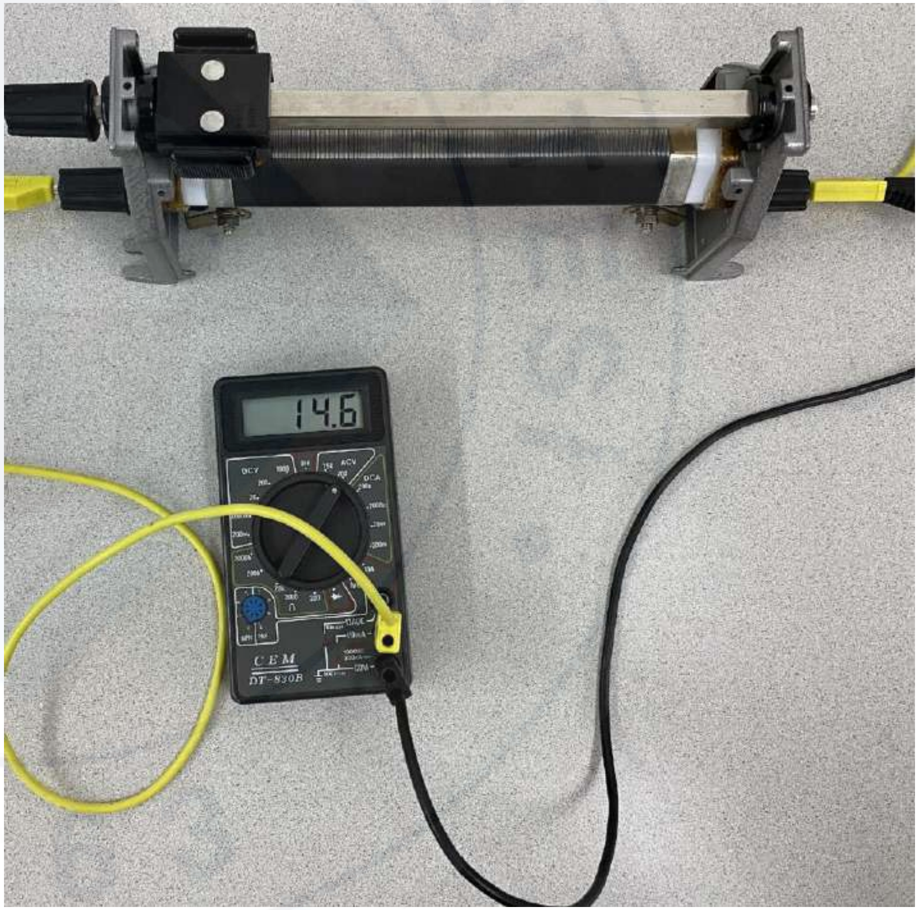
RLC CIRCUIT

- **Measure the voltage across each element.**





RLC CIRCUIT

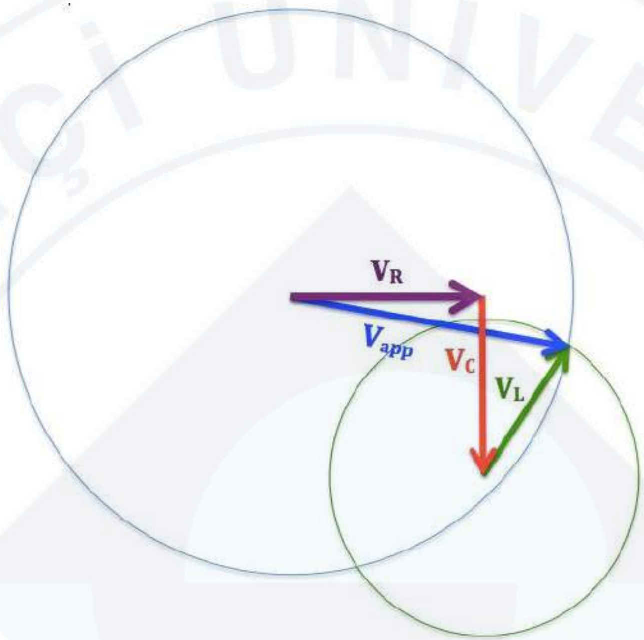
Description / Notation		Value & Unit
Current in the circuit I	=	....
Potential difference across the resistance V_R	=	....
Potential difference across the inductor V_L	=	....
Potential difference across the capacitor V_C	=	....
Applied potential V_{app}	=	....

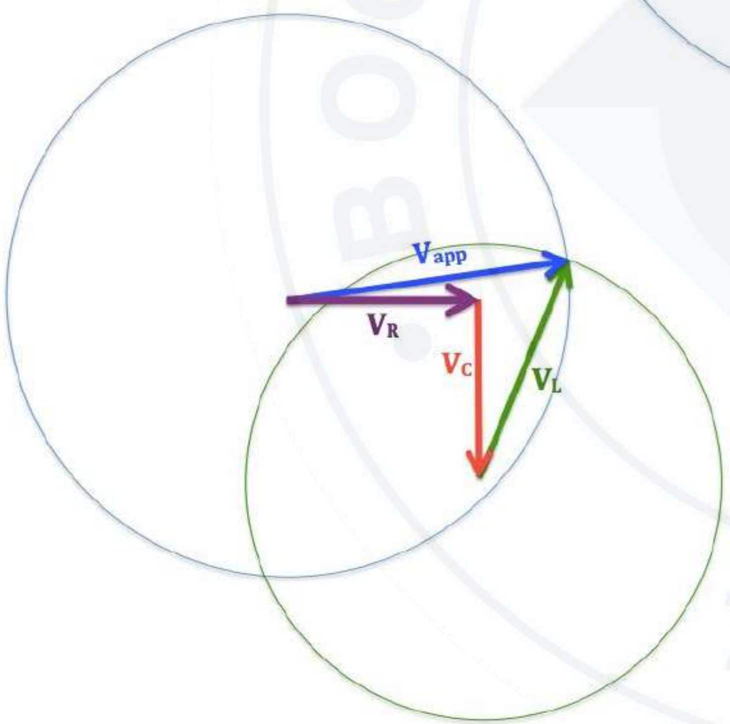
Phasor Diagram of the RLC Circuit: **Scaling factor:**

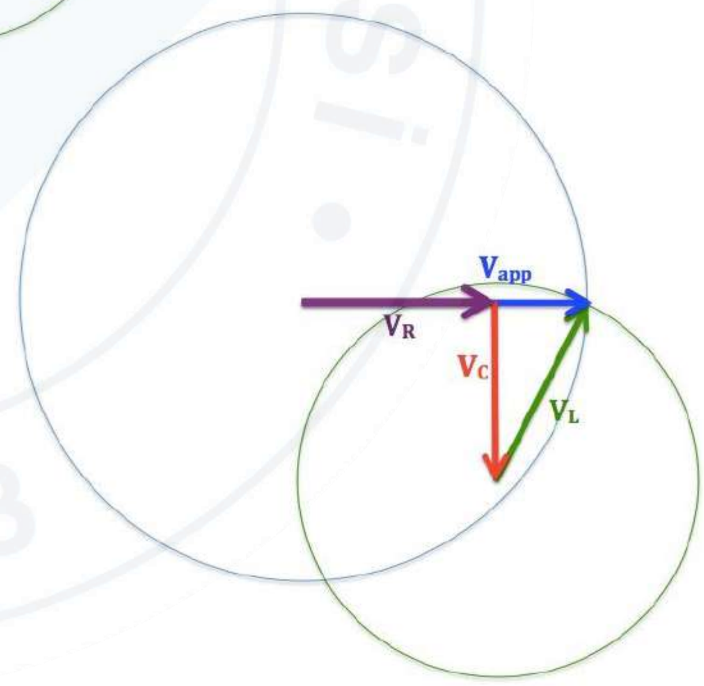
RLC CIRCUIT

- **Then draw the phasor diagram by taking the current (i.e. the voltage across the resistor) as the reference.**
- **Then draw V_C 90º behind V_R (or perpendicular in the negative direction) by assuming it is pure capacitance.**
- **Then draw two circles by using compasses with radii equal to V_L from the tip of the phasor corresponding to the voltage across the capacitor, V_C and V_{app} from the beginning of the phasor corresponding to the voltage across the resistor, V_R.**
- **Phasors for V_L and V_{app} will meet each other at the point where the circles intersect.**

RLC CIRCUIT







RLC CIRCUIT

Using the current value and the internal resistance of the inductor determined in the previous step,

- **Determine the capacitive and inductive reactances first and**
- **Then calculate the value of the capacitor and the inductor.**

RLC CIRCUIT

Capacitive reactance $X_C =$ . . . .

. . . .

Value of the capacitor $C =$ . . . .

. . . .

Inductive reactance $X_L =$ . . . .

. . . .

Value of the inductor $L =$ . . . .

RLC CIRCUIT

- **Finally determine the phase angle Φ and the average power dissipated in the RLC circuit.**

Description / Symbol			Value / Calculation (show step by step)	Result
Phase angle	φ	=	....	....
			....	
Average dissipated power	P	=	....	....