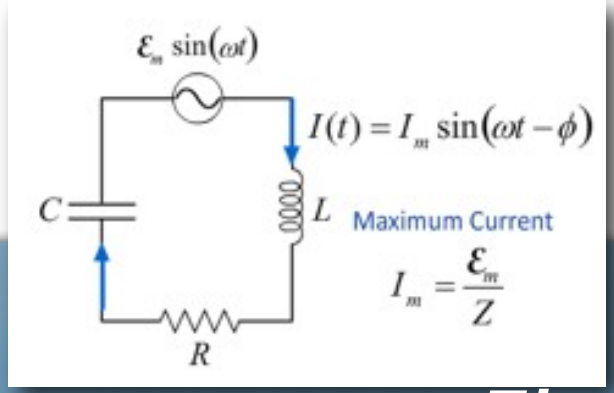


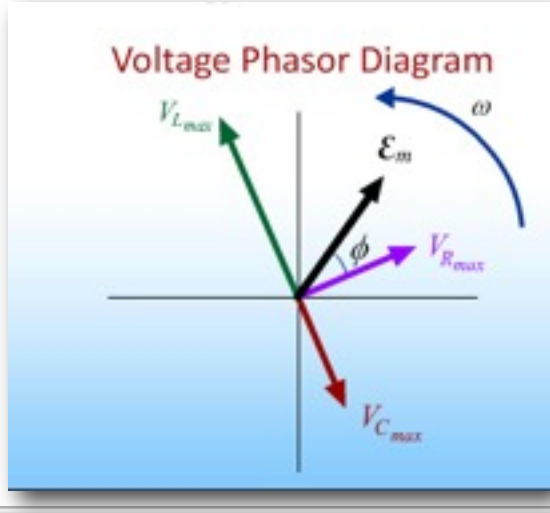
Electricity & Magnetism
Lecture 20

Today's Concept:

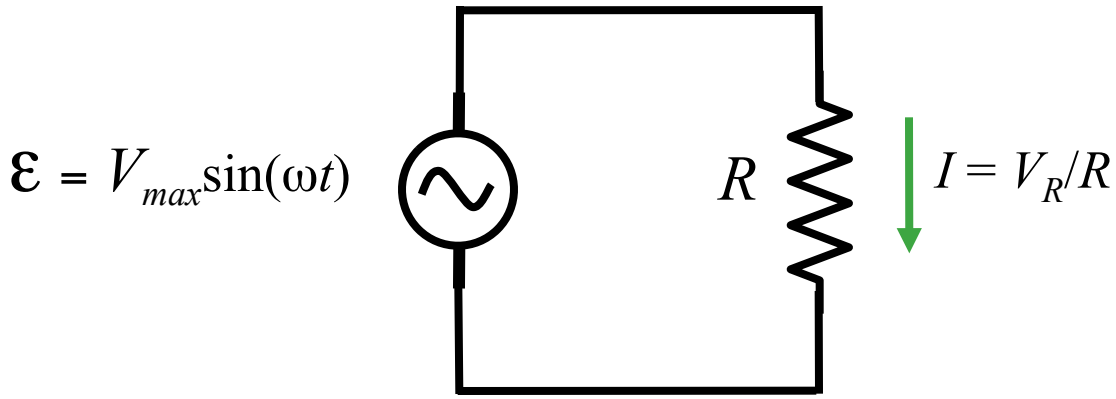
AC Circuits

Maximum currents & voltages

Phasors: A Simple Tool

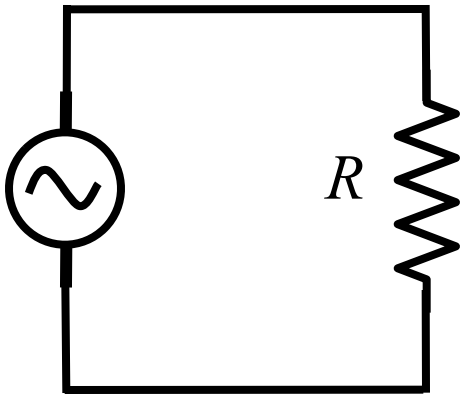


Resistors



Resistors

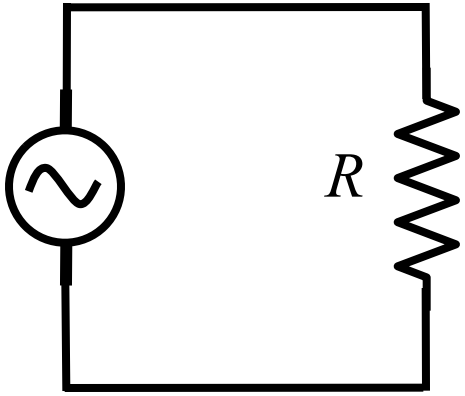
$\varepsilon = V_{max}\sin(\omega t)$



$I = V_R/R = V_{max}/R \sin(\omega t)$

Resistors

$\mathcal{E} = V_{max}\sin(\omega t)$

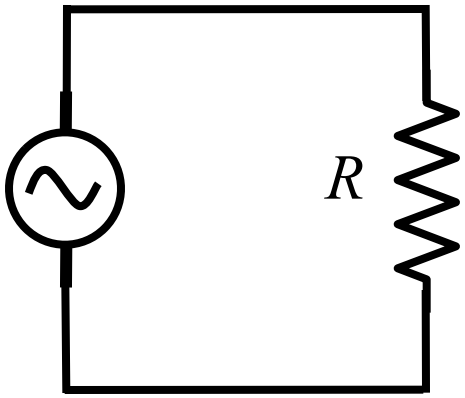


$I = V_R/R = V_{max}/R \sin(\omega t)$

Amplitude = V_{max}/R

Resistors

$\varepsilon = V_{max}\sin(\omega t)$



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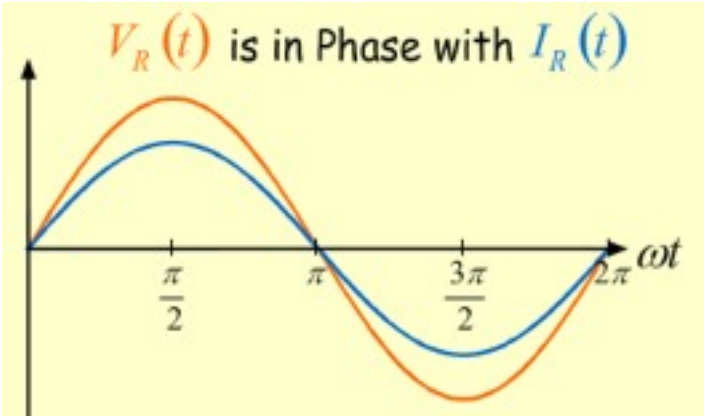
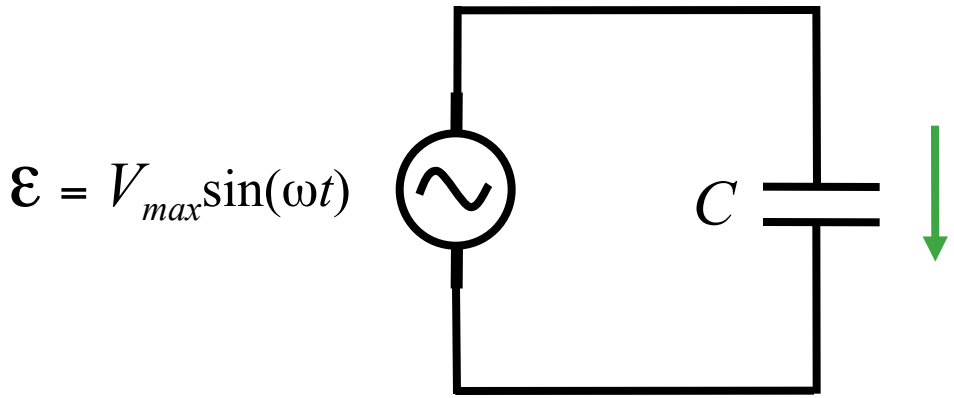
Amplitude = V_{max}/R



Capacitors

$$Q = CV = CV_{max}\sin(\omega t)$$

$$I = dQ/dt$$

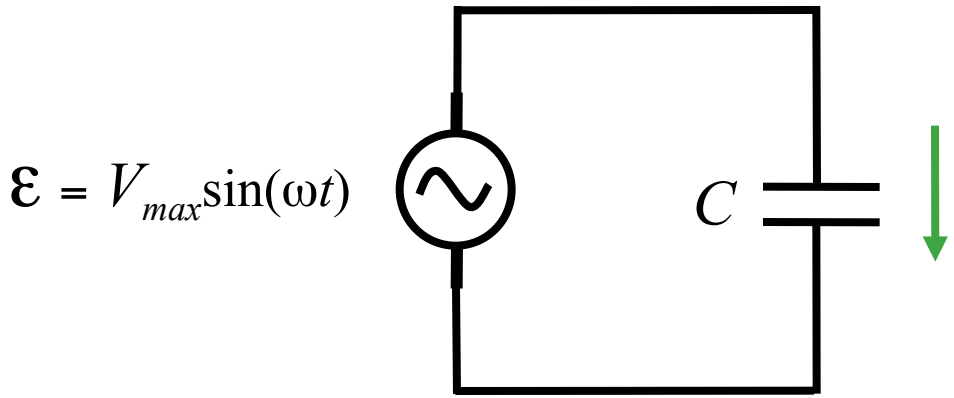


$$I = V_{max}\omega C\cos(\omega t)$$

Capacitors

$$Q = CV = CV_{max}\sin(\omega t)$$

$$I = dQ/dt$$



$$I = V_{max}\omega C\cos(\omega t)$$

Amplitude = V_{max}/X_C

Capacitors

$$Q = CV = CV_{max}\sin(\omega t)$$

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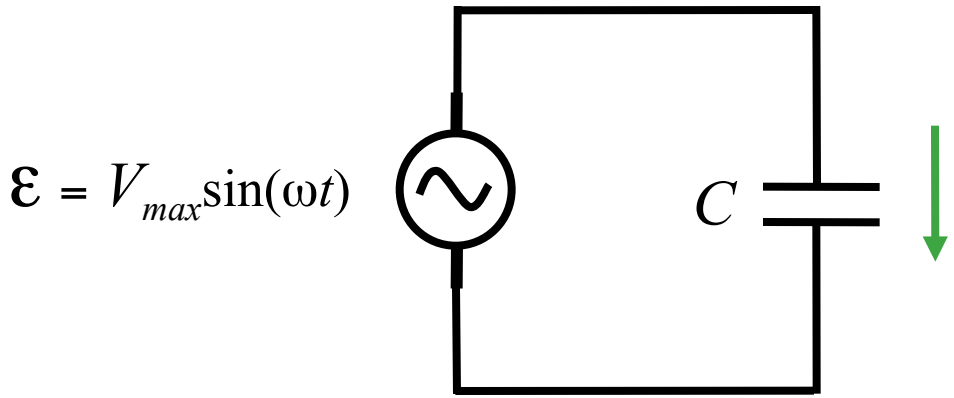


$$I = V_{max}\omega C\cos(\omega t)$$

Amplitude = V_{max}/X_C

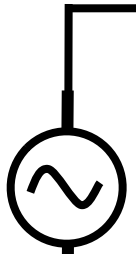
where $X_C = 1/\omega C$
is like the "resistance"
of the capacitor
X_C depends on ω

Capacitors

$$Q = CV = CV_{max}\sin(\omega t)$$

$$I = dQ/dt$$

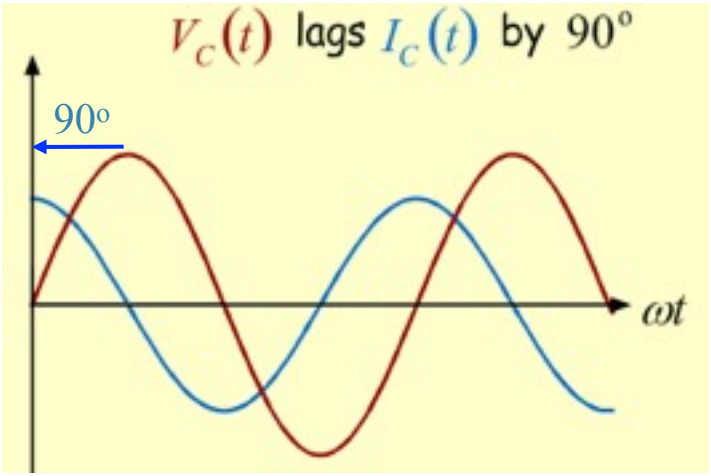
$$\varepsilon = V_{max}\sin(\omega t)$$



C

$$I = V_{max}\omega C\cos(\omega t)$$

Amplitude = V_{max}/X_C



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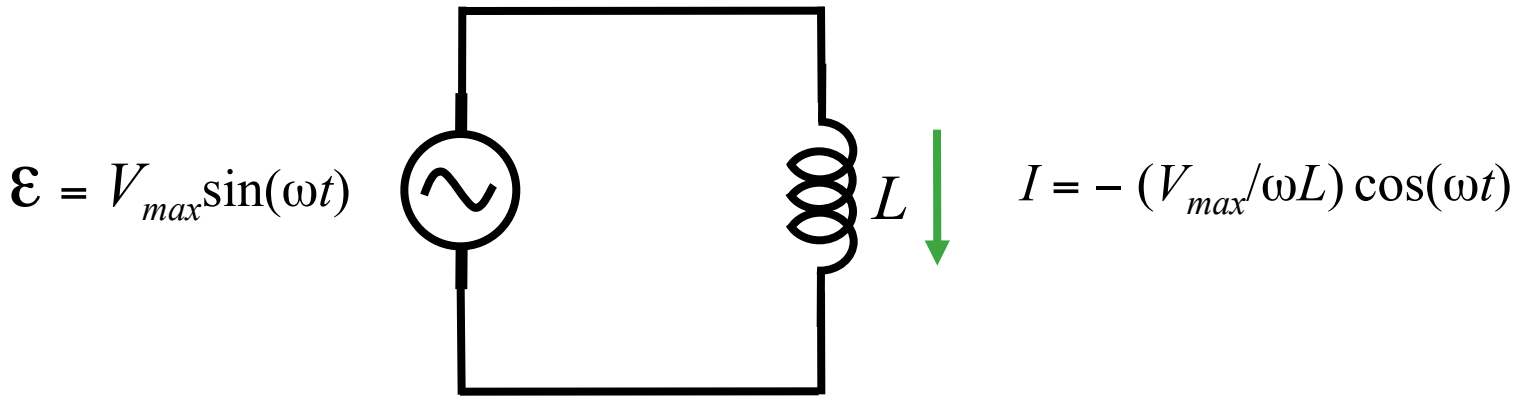
Inductors

$$dI/dt = V_L = V_{max}\sin(\omega t)$$



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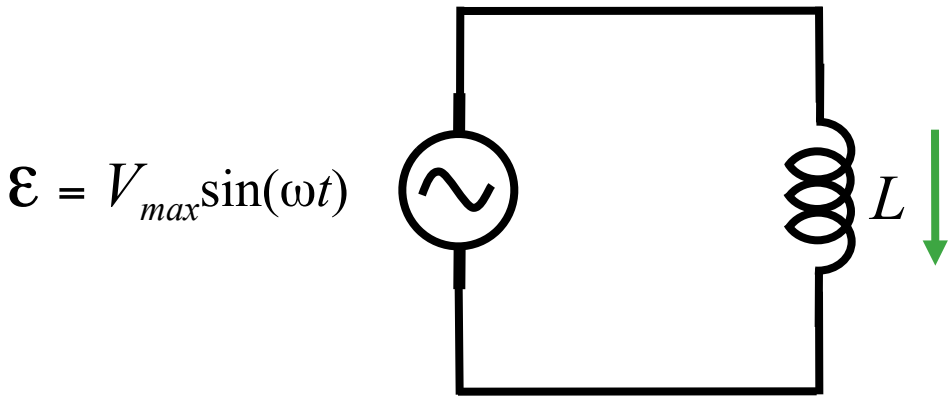
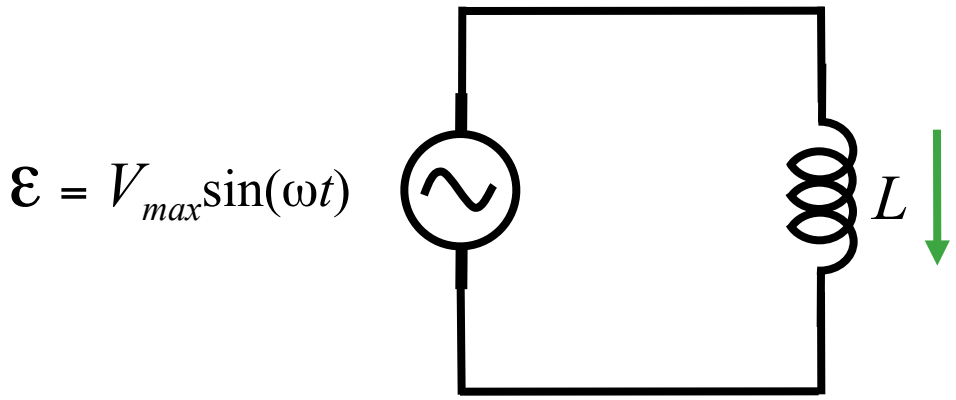


$$I = -(V_{max}/\omega L)\cos(\omega t)$$

Amplitude = V_{max}/X_L

Inductors

$dI/dt = V_L = V_{max}\sin(\omega t)$



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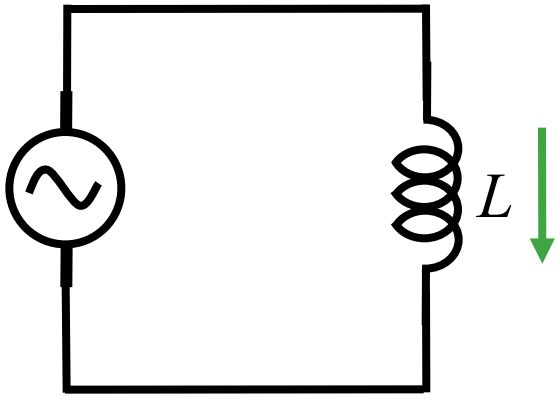

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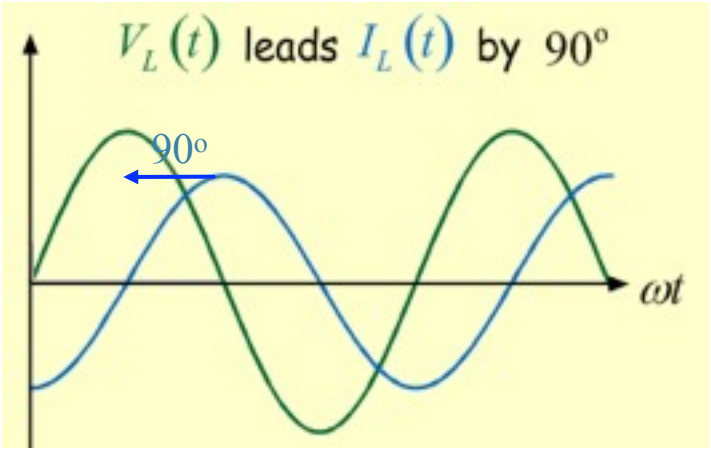

where $X_L = \omega L$

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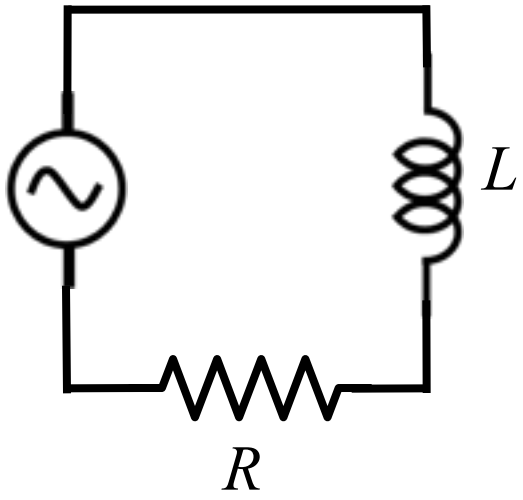
X_L depends on ω

RL Clicker Question

An RL circuit is driven by an AC generator as shown in the figure.



For what driving frequency ω of the generator will the current through the resistor be largest

A) ω large
B) Current through R doesn't depend on ω
C) ω small

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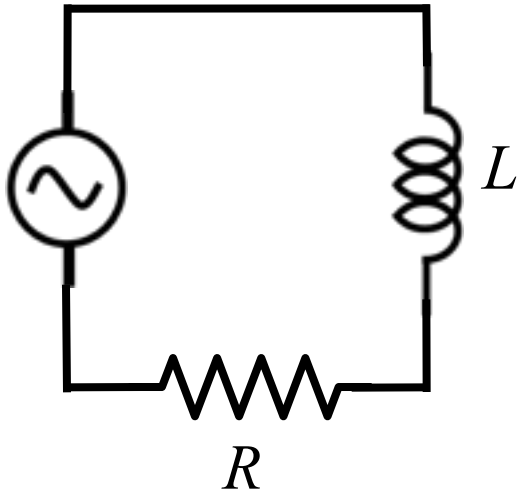

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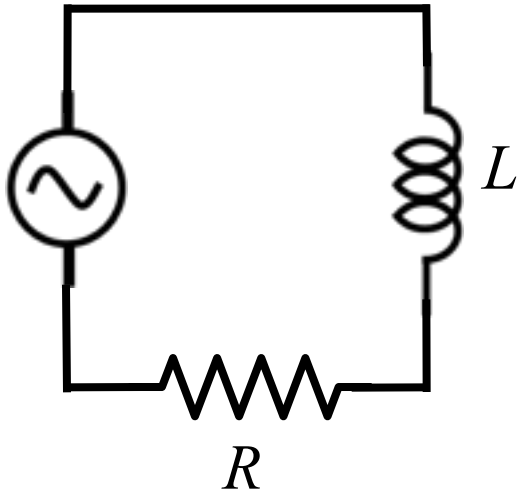

$$X_L = \omega L$$

As $\omega \to 0$, so does X_L

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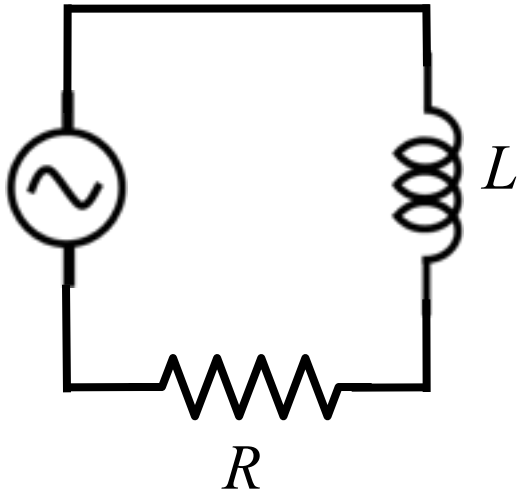

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As $\omega \to 0$,
resistance of circuit $\to R$
current gets bigger

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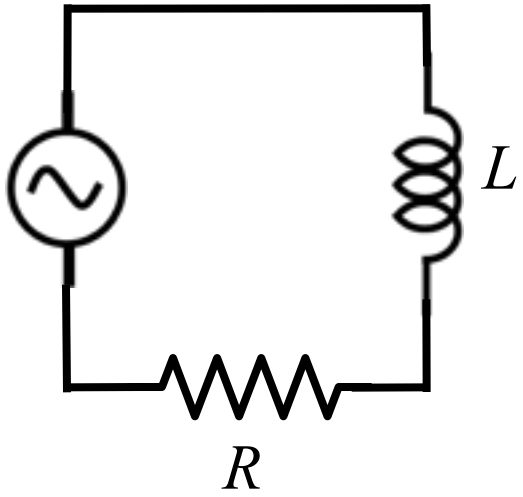

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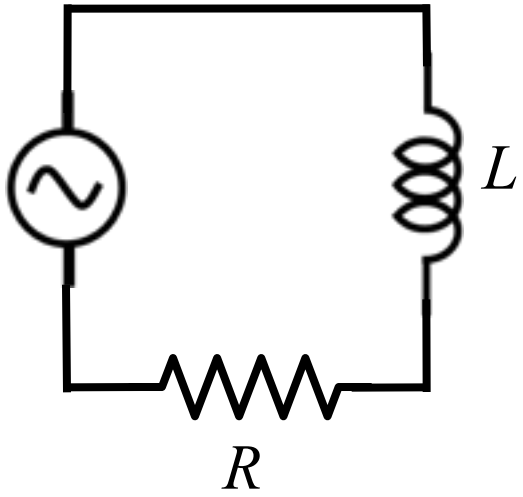

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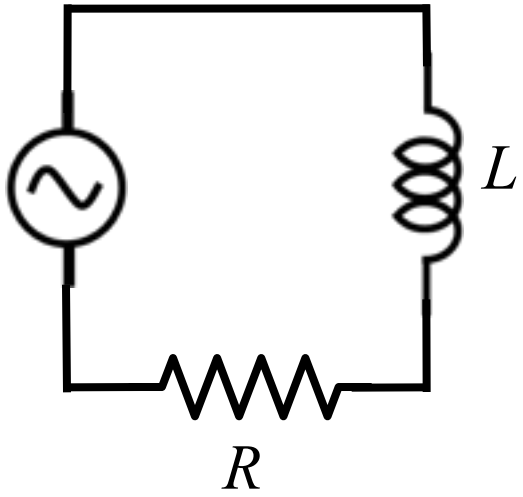

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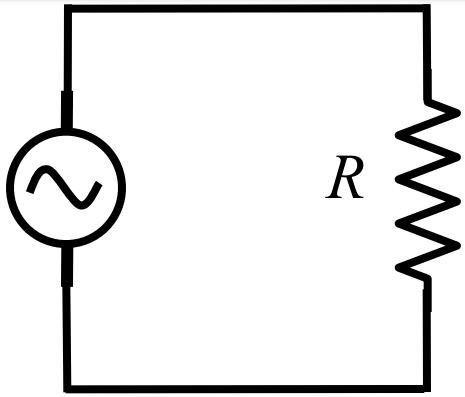
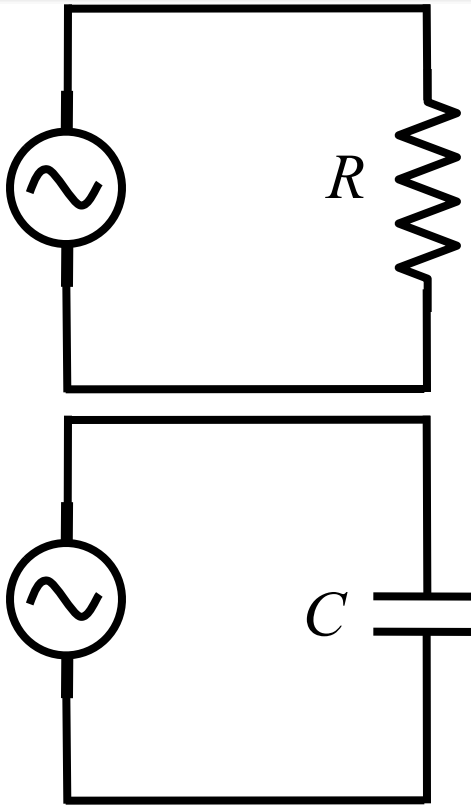


$I_{max} = V_{max}/R$

V_R in phase with I

Summary



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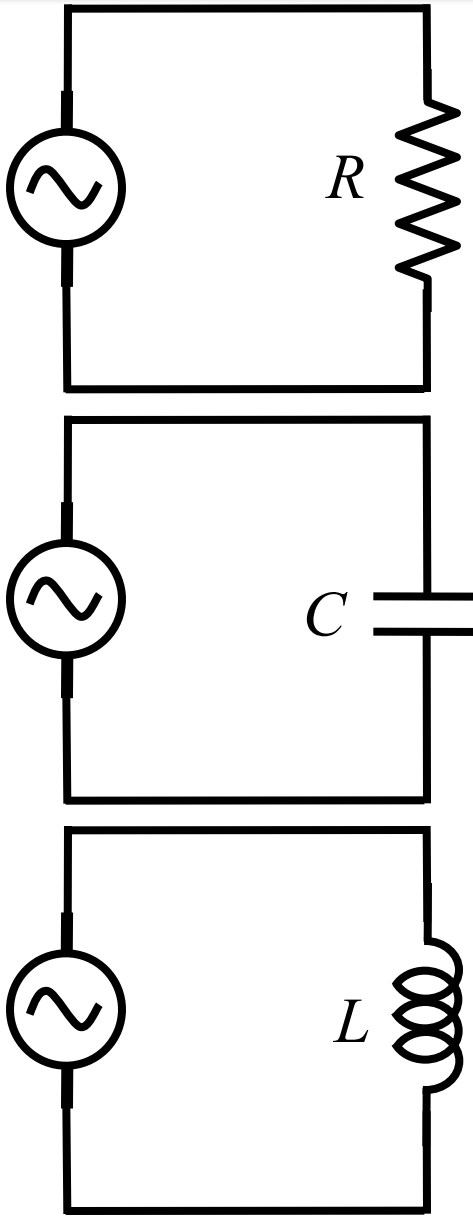
V_R in phase with I

$I_{max} = V_{max}/X_C$

$X_C = 1/\omega C$

V_C 90^o behind I

Summary



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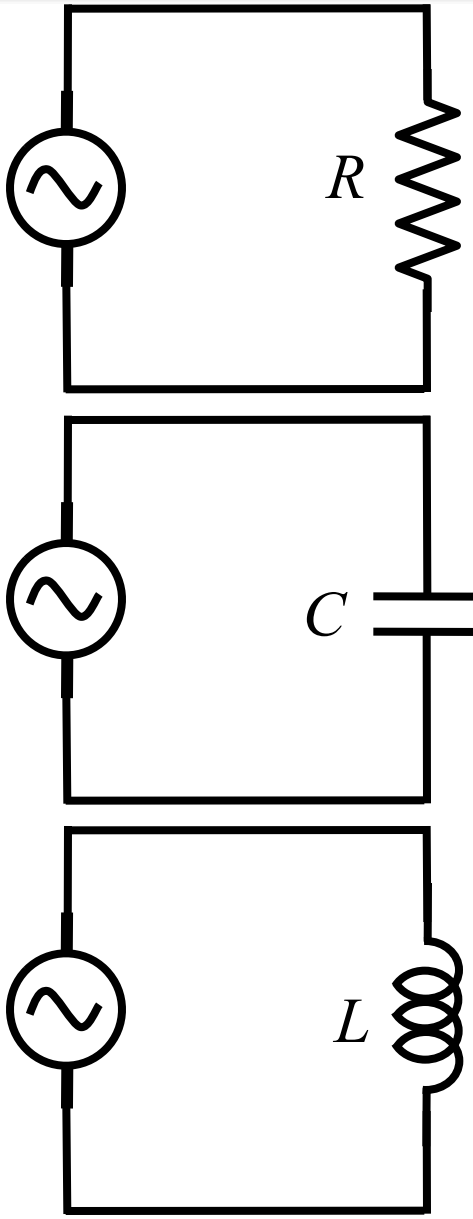
$X_L = \omega L$

V_L 90° ahead of I

Summary



$I_{max} = V_{max}/R$

V_R in phase with I

Because resistors are simple

$I_{max} = V_{max}/X_C$

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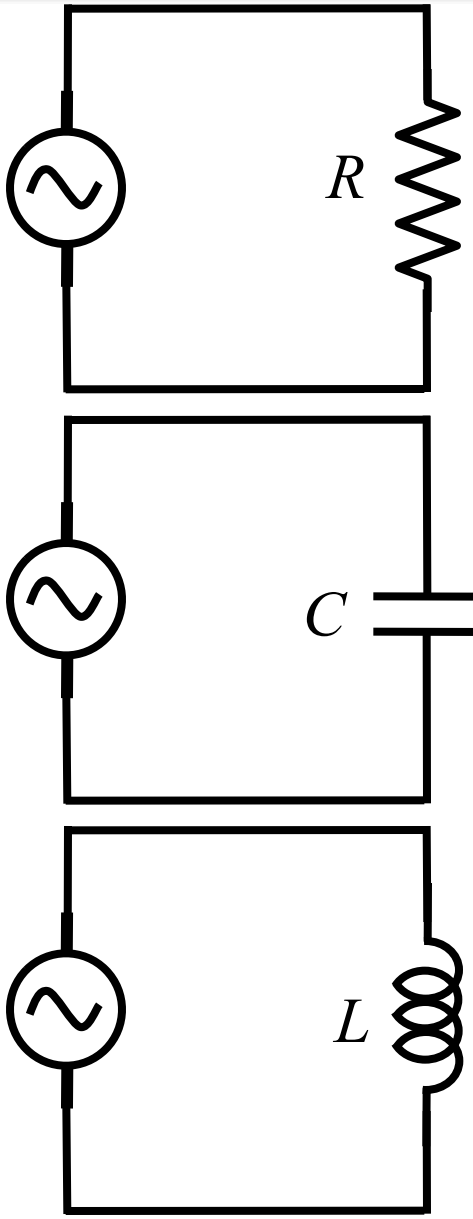
Summary



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$X_C = 1/\omega C$

V_C 90° behind I

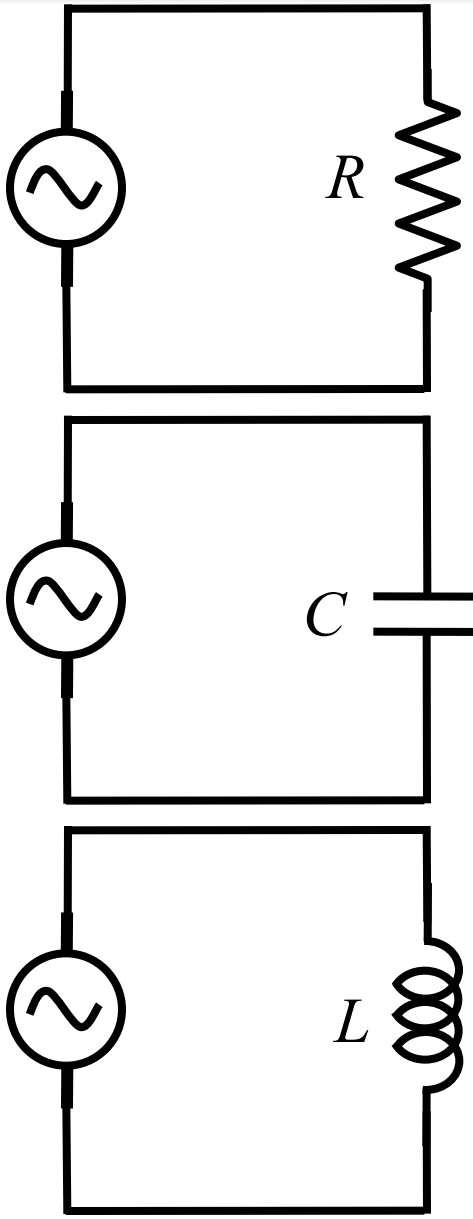
Current comes first since it charges capacitor

$I_{max} = V_{max}/X_L$

$X_L = \omega L$

V_L 90° ahead of I

Summary



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V_R in phase with I

Because resistors are simple

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$X_C = 1/\omega C$

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Current comes first since it charges capacitor

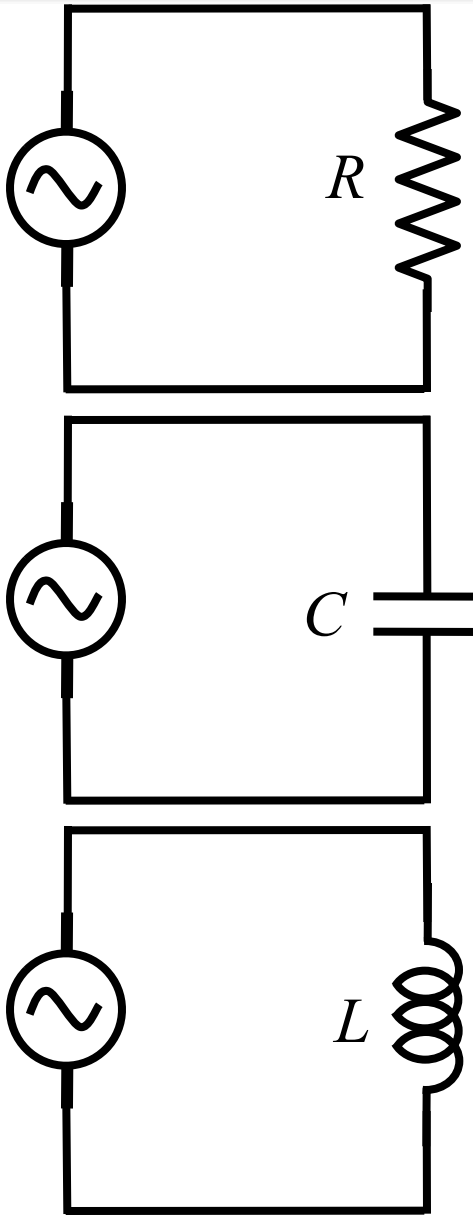
$I_{max} = V_{max}/X_L$

$X_L = \omega L$

V_L 90° ahead of I

Opposite of capacitor

Summary



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V_R in phase with I

Because resistors are simple

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V_C 90° behind I

Current comes first since it charges capacitor

Like a wire at high ω

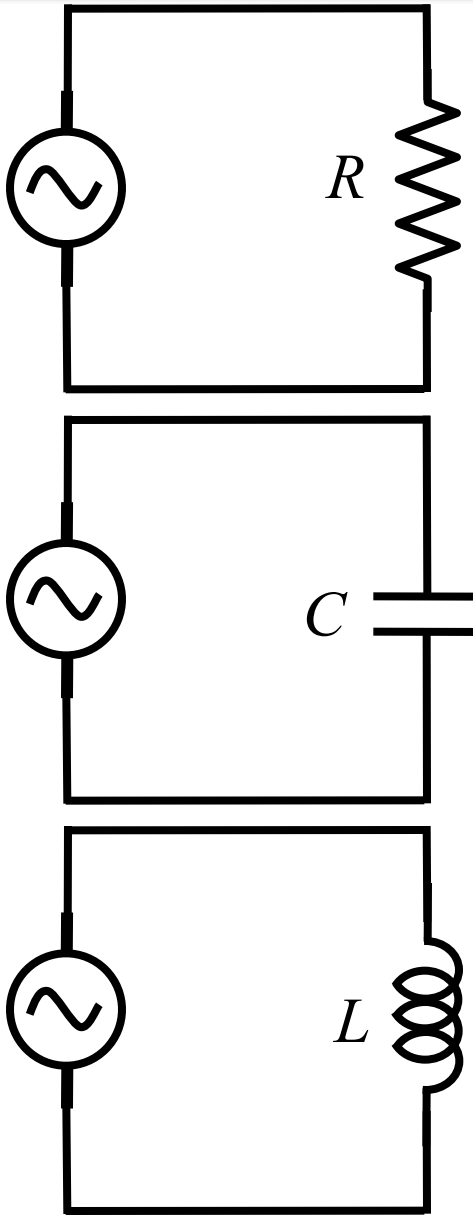
$I_{max} = V_{max}/X_L$

$X_L = \omega L$

V_L 90° ahead of I

Opposite of capacitor

Summary



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Current comes first since it charges capacitor

Like a wire at high ω

$I_{max} = V_{max}/X_L$

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V_L 90° ahead of I

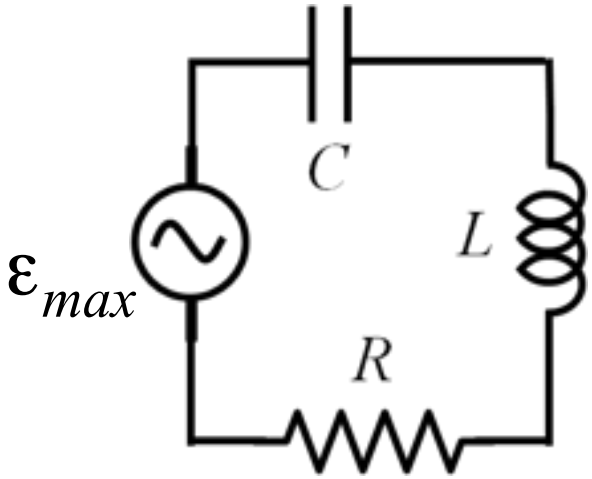
Opposite of capacitor

Like a wire at low ω

Makes sense to write everything in terms of I since this is the same everywhere in a one-loop circuit:

$V_{max} = I_{max} X_C$

V 90^o behind I



$V_{max} = I_{max} X_L$

V 90^o ahead of I

$V_{max} = I_{max} R$

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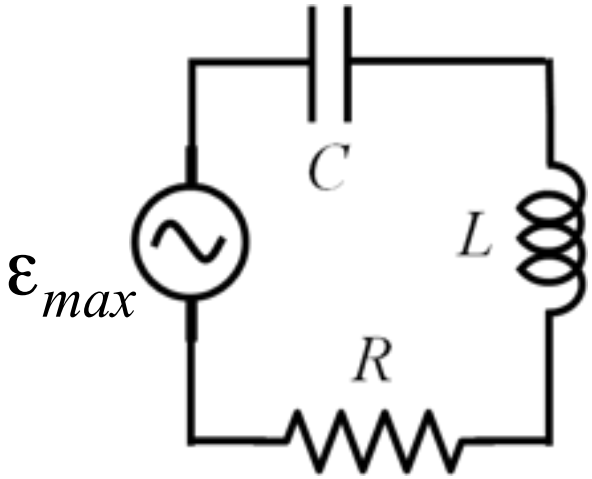

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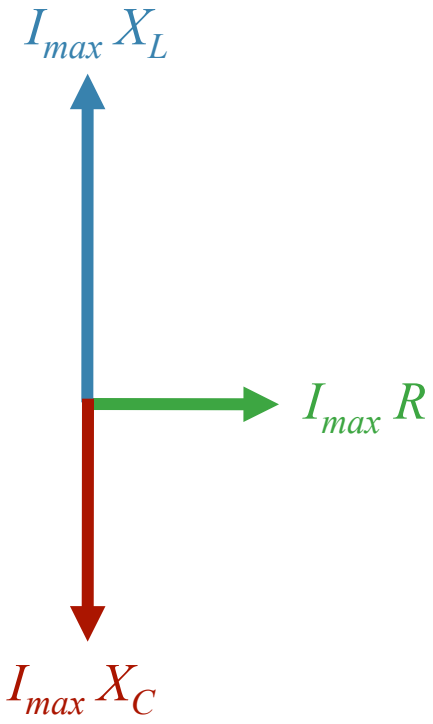
V in phase with I

Phasors make this simple to see



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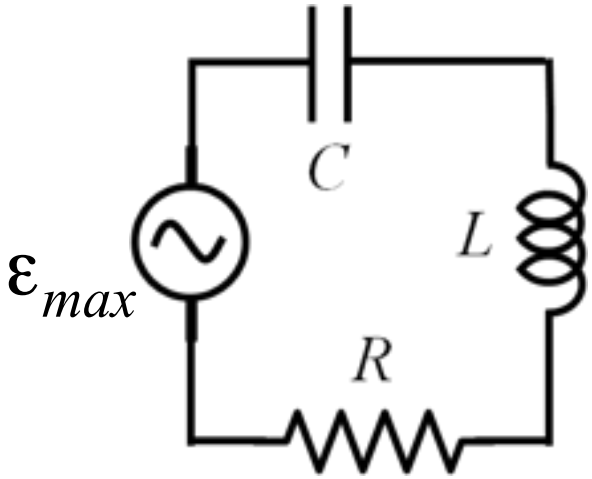

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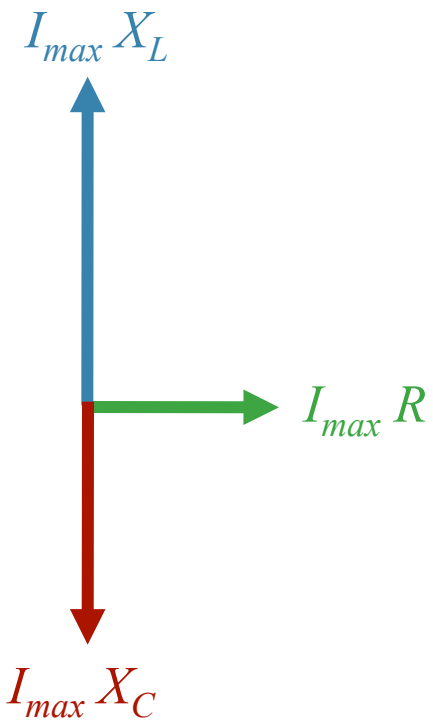

Always looks the same.
Only the lengths will change

Makes sense to write everything in terms of I since this is the same everywhere in a one-loop circuit:

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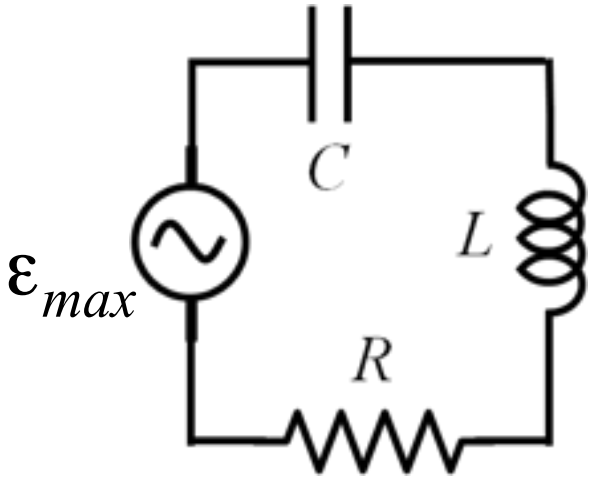

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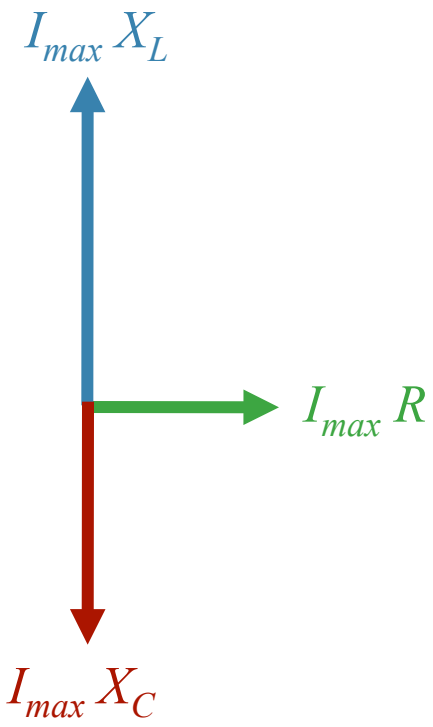
V 90^o ahead of I

$V_{max} = I_{max} R$

V in phase with I

"Do you have any fancy-schmancy simulations for to show me?"

Phasors make this simple to see



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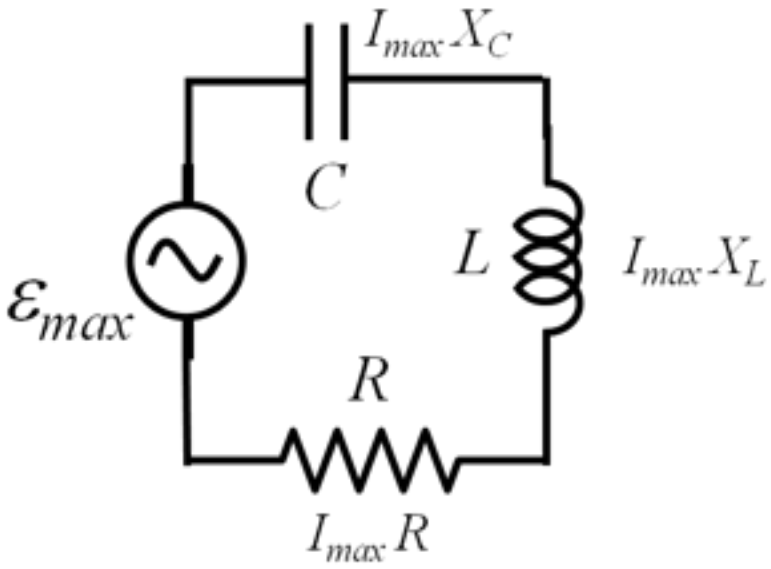
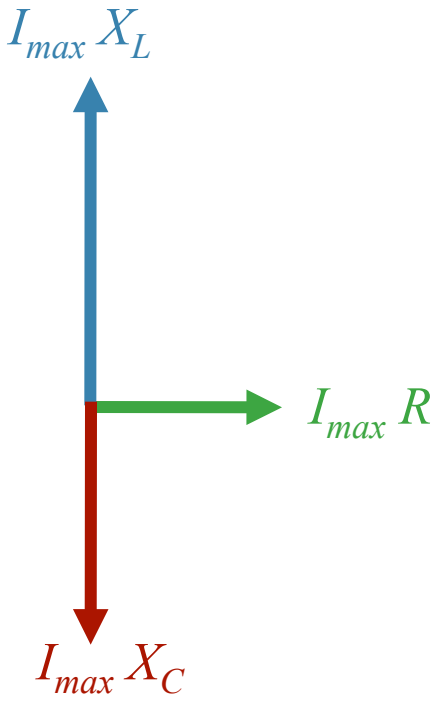
The Voltages still Add Up

But now we are adding vectors:





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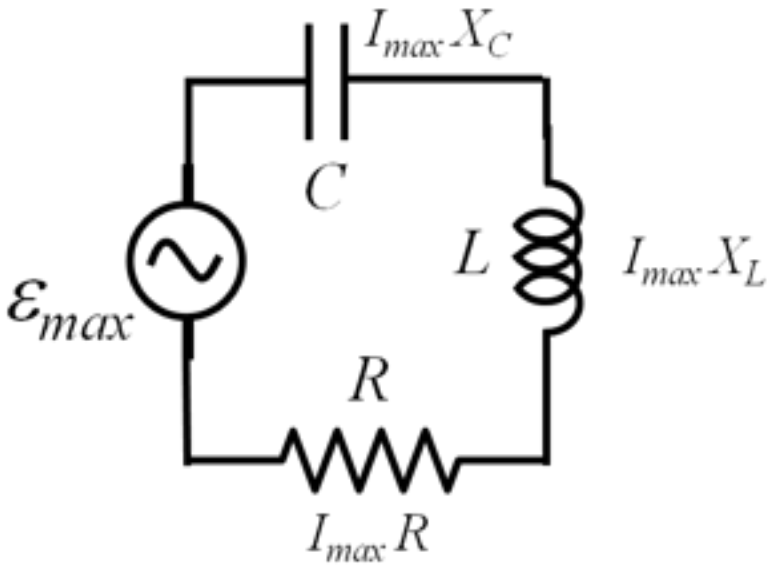

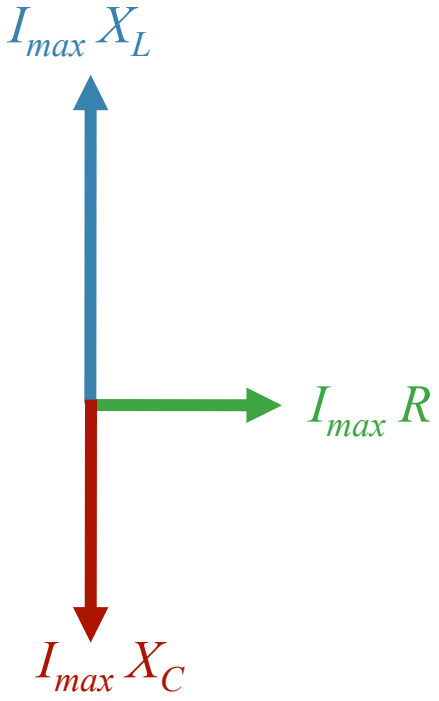

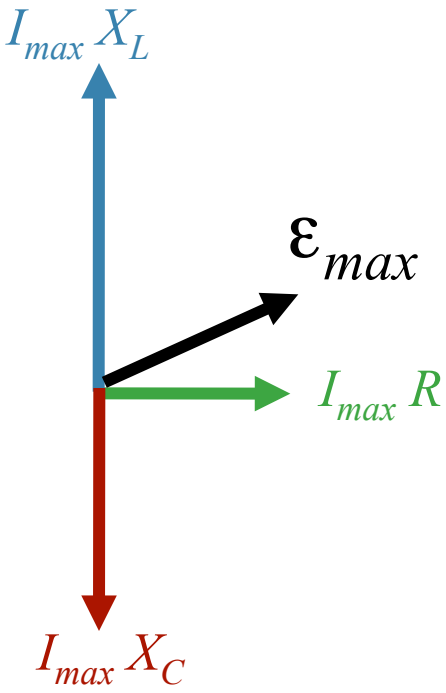

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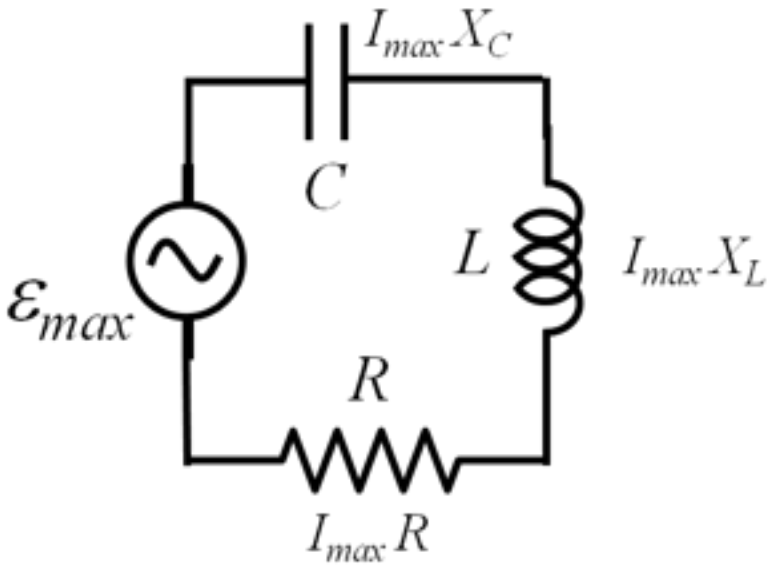
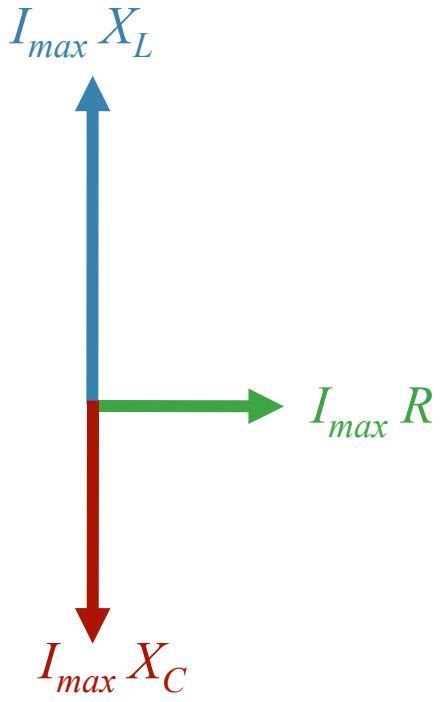
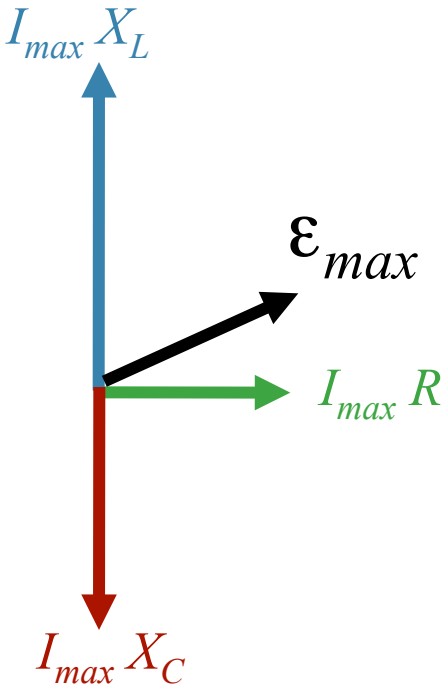
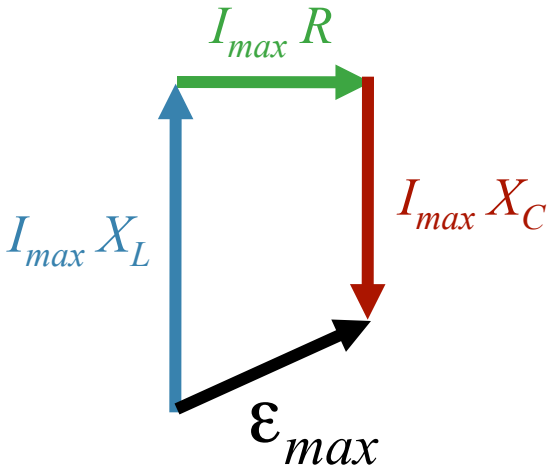
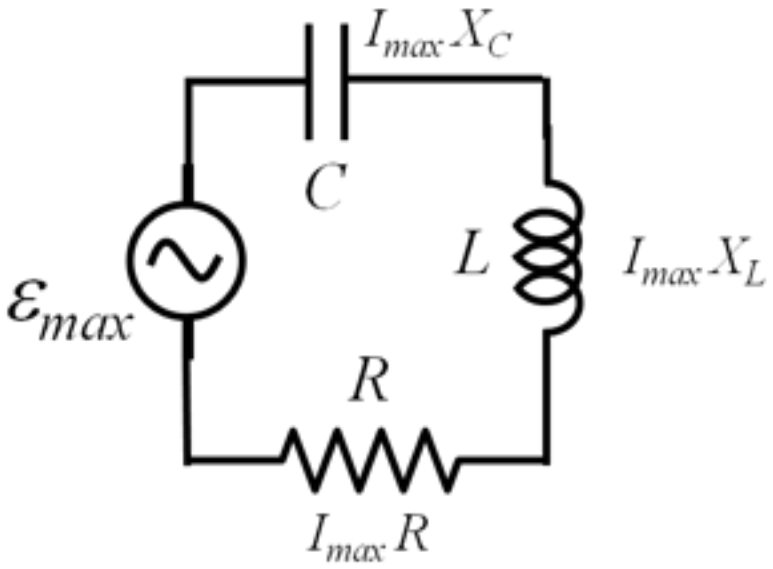


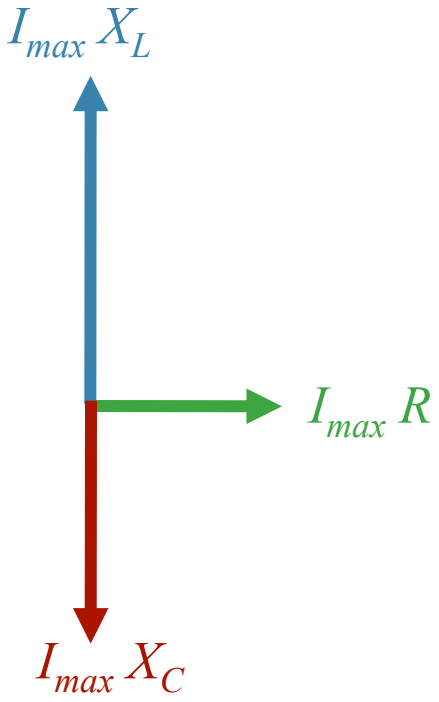


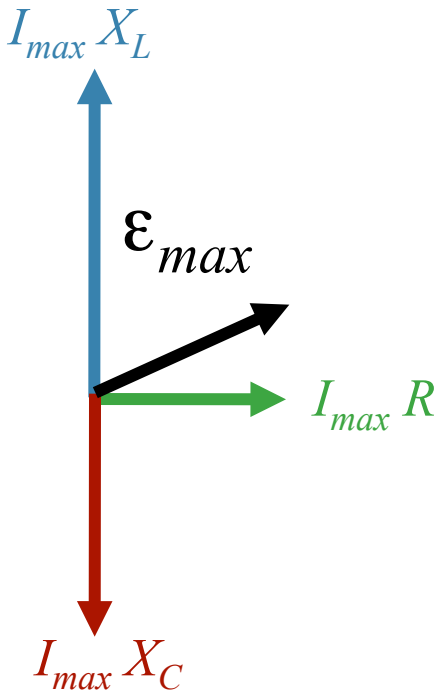




Make this Simpler







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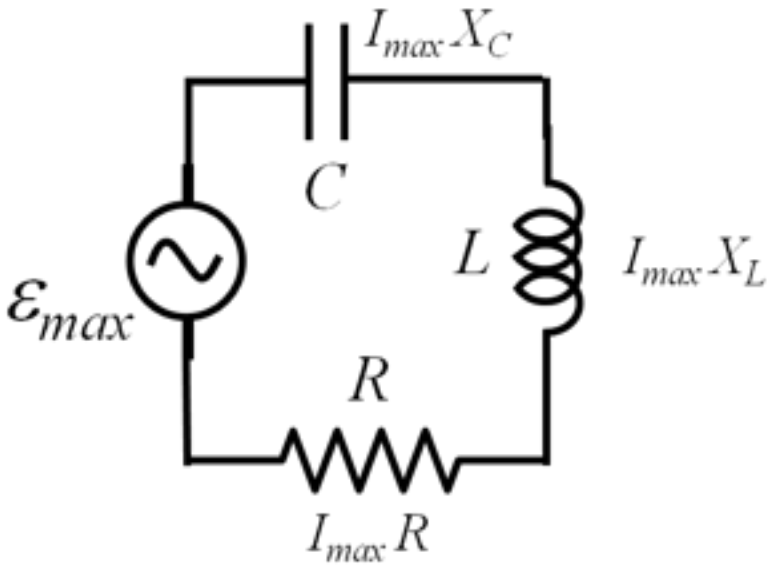

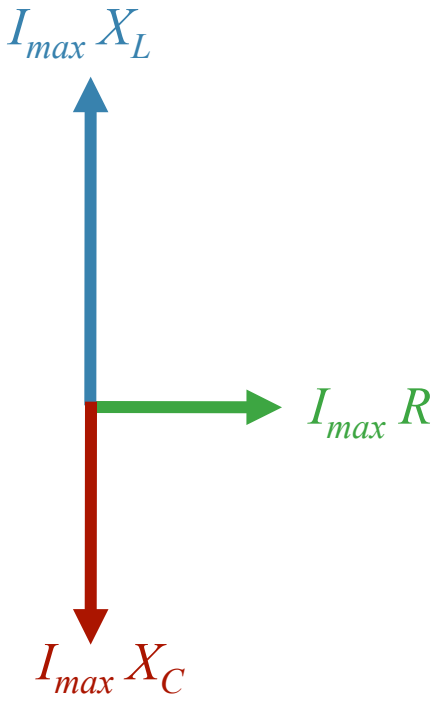

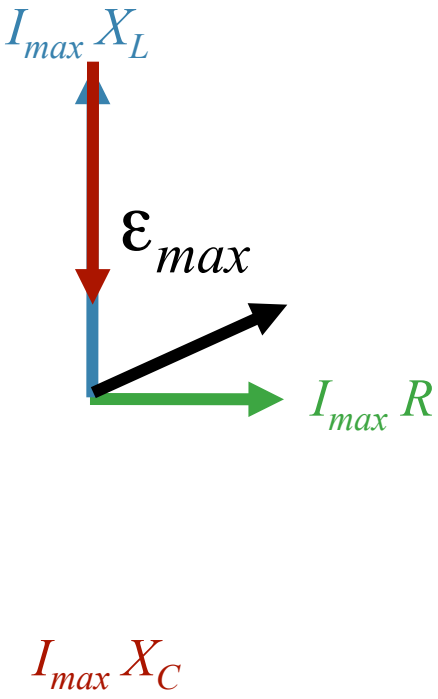

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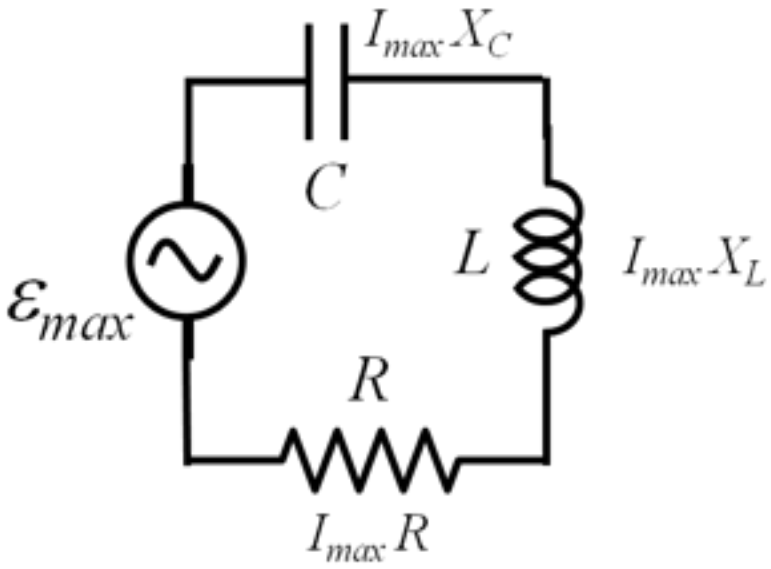

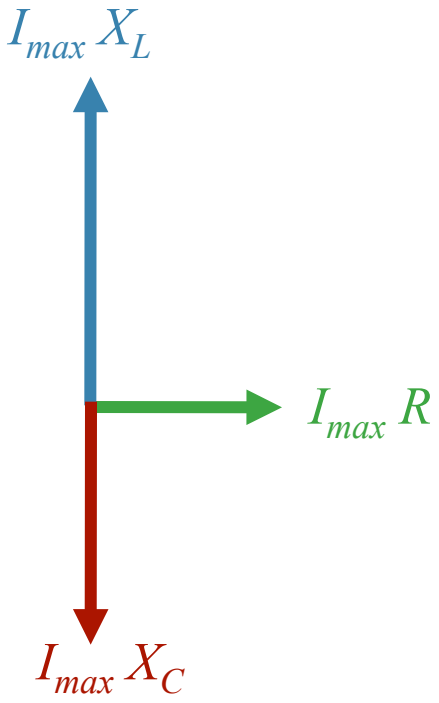

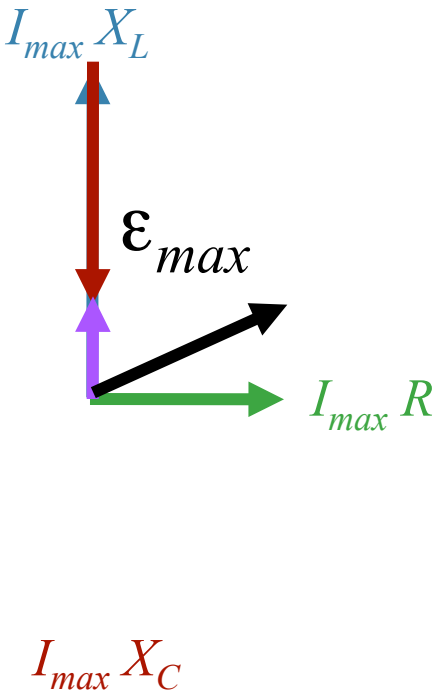

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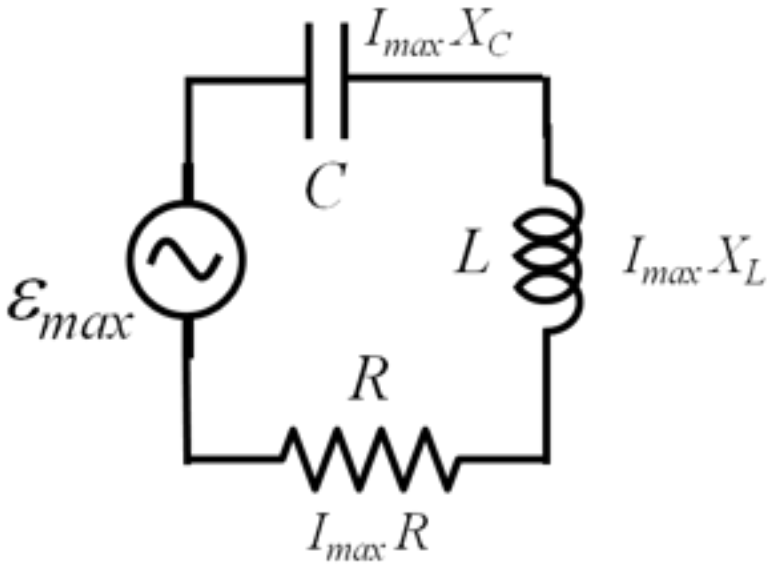
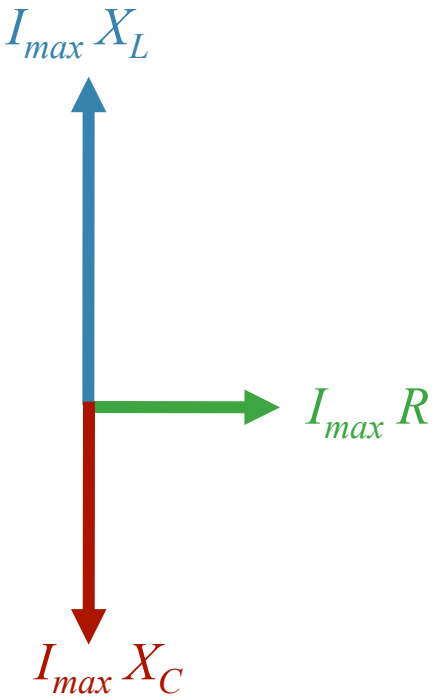
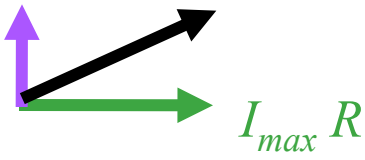




$$\mathcal{E}_{max} = I_{max} Z$$



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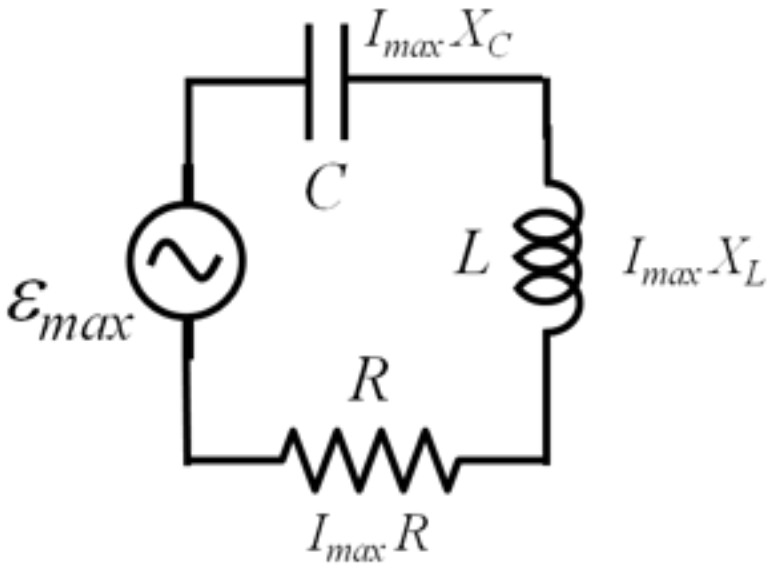

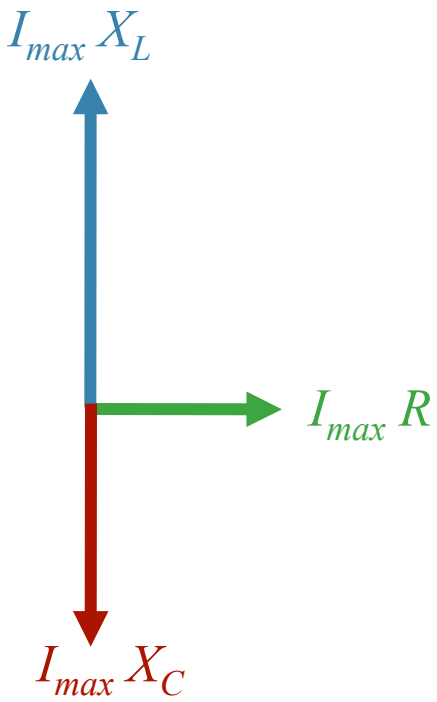

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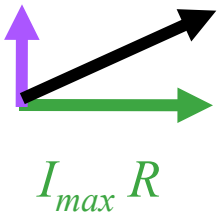

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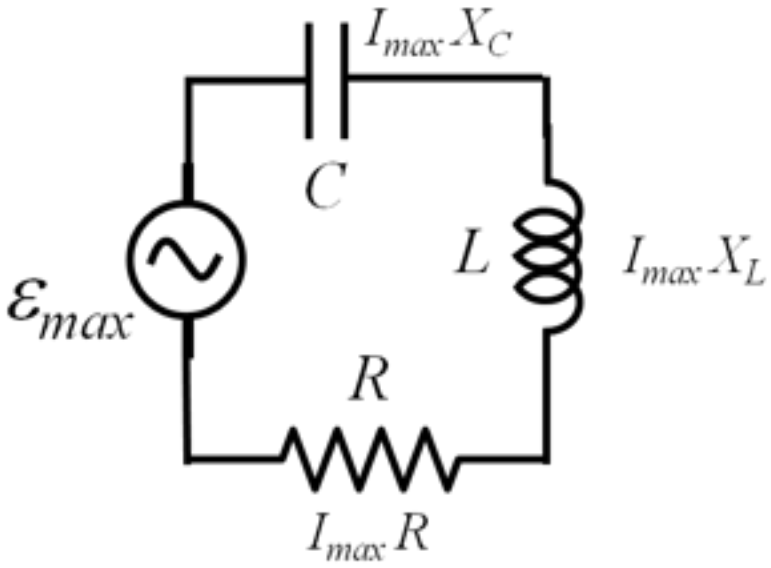

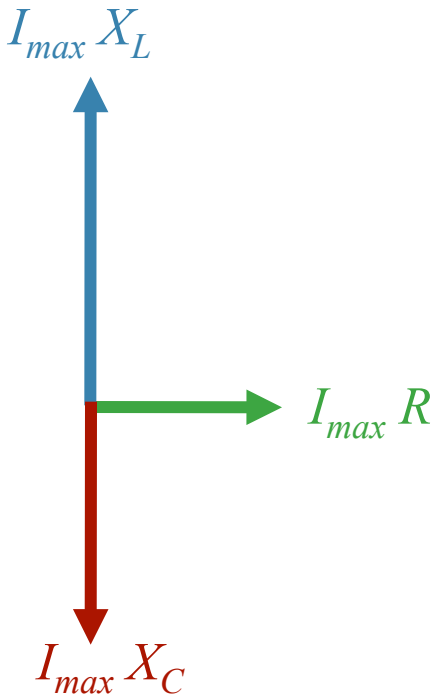

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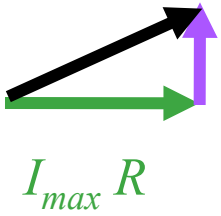
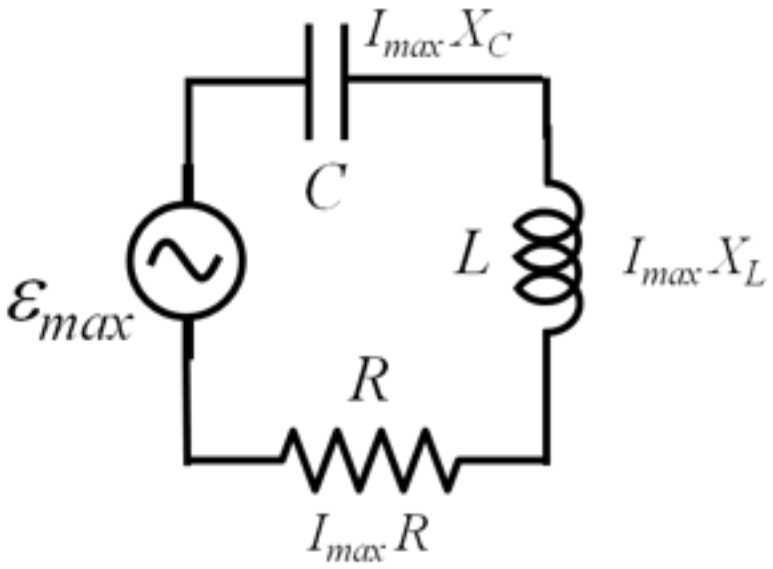
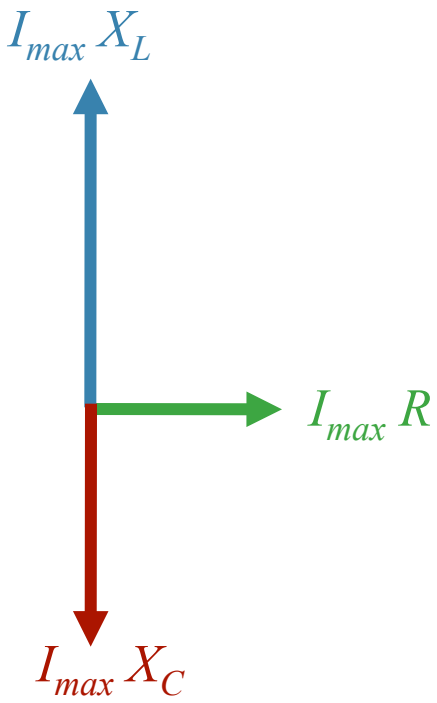


Make this Simpler





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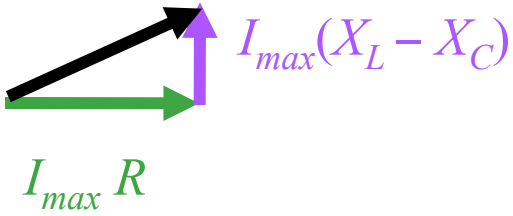

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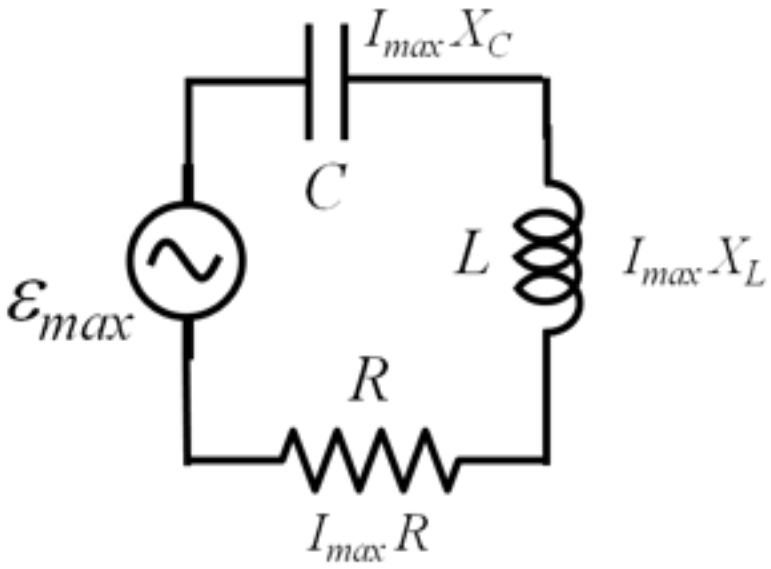

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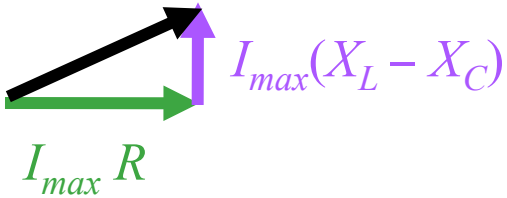

Make this Simpler

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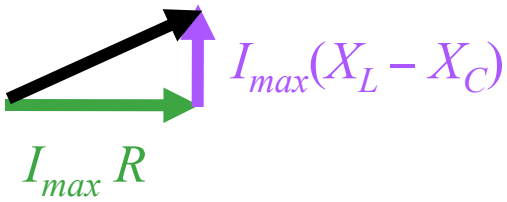

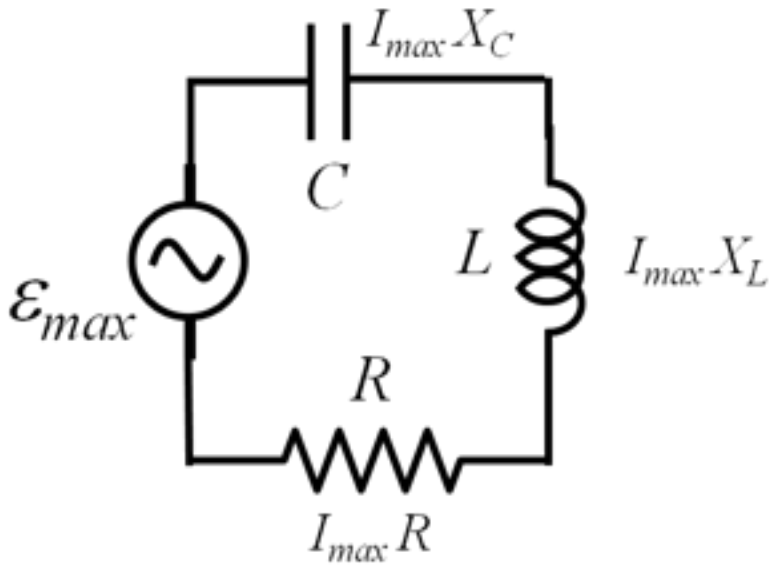

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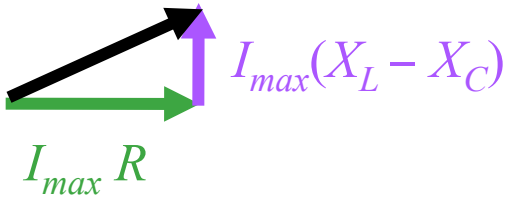
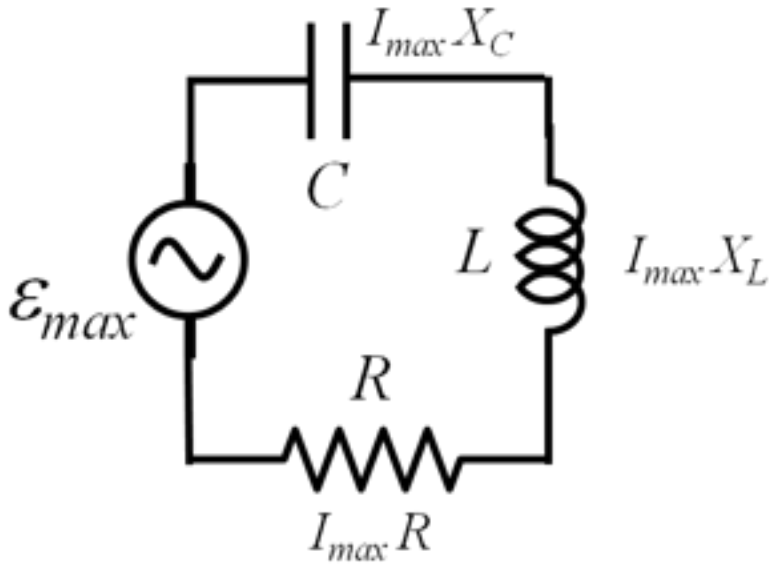
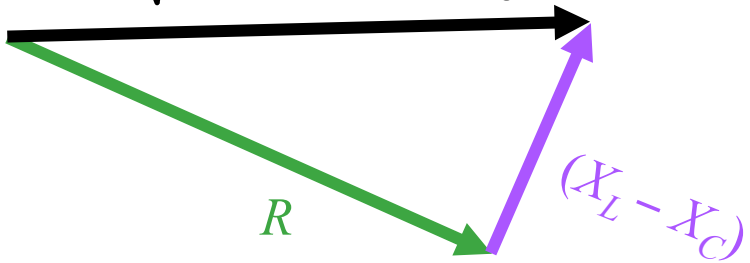




$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$



$$\tan(\phi) = \frac{X_L - X_C}{R}$$

Make this Simpler

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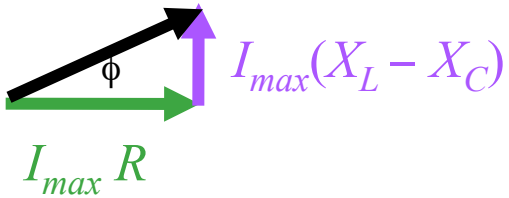
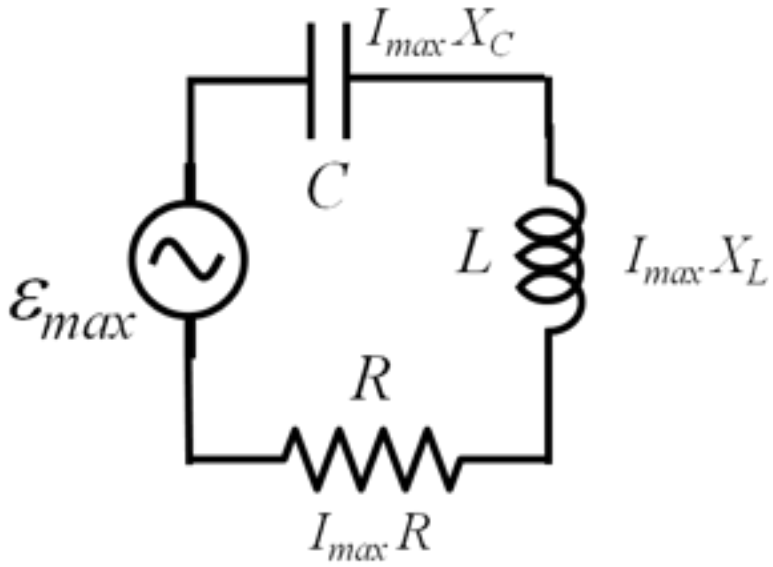
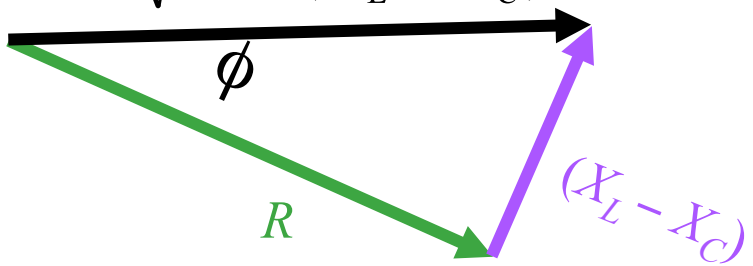




$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$



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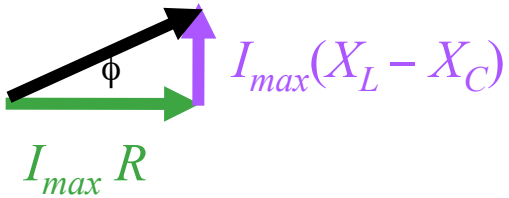

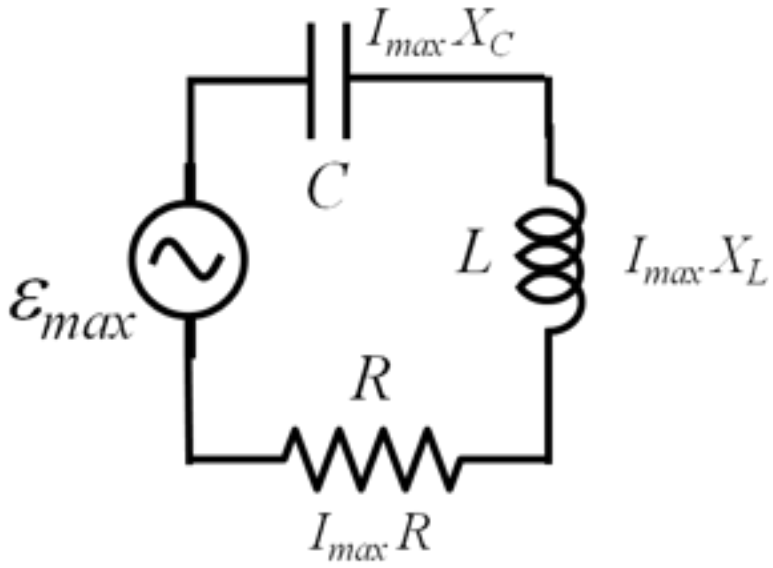

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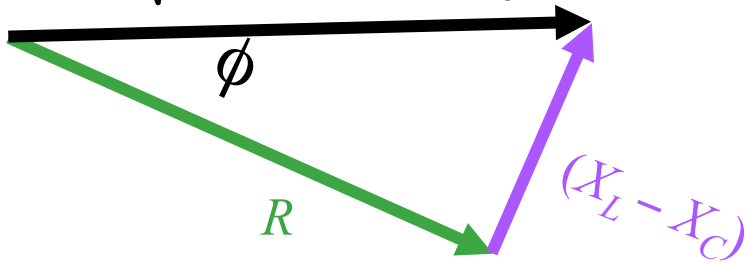
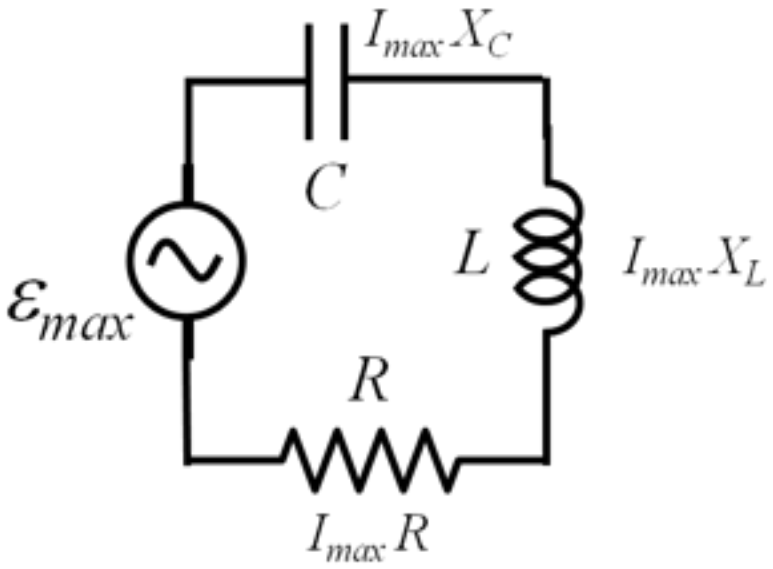


Impedance Triangle

$$\tan(\phi) = \frac{X_L - X_C}{R}$$

Summary

$$V_{Cmax} = I_{max} X_C$$
$$V_{Lmax} = I_{max} X_L$$
$$V_{Rmax} = I_{max} R$$
$$\varepsilon_{max} = I_{max} Z$$



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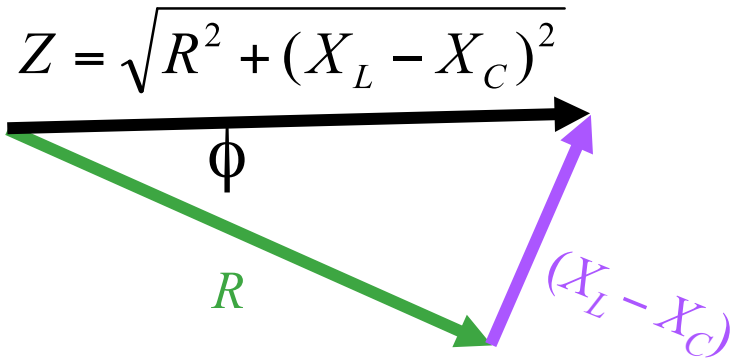
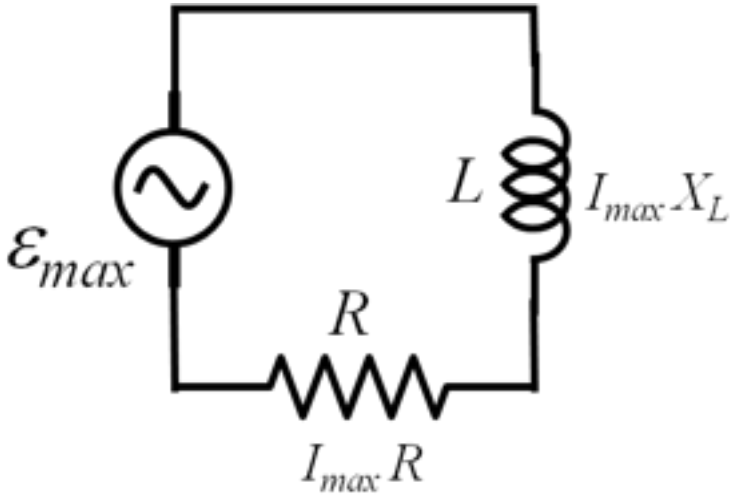
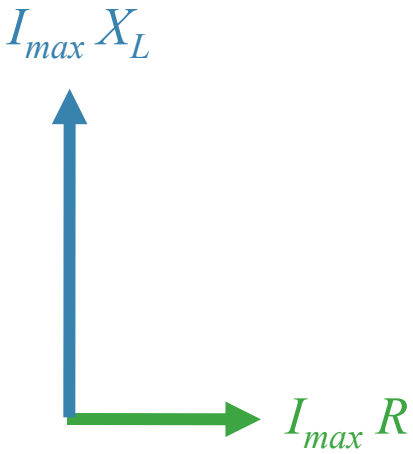


Example: RL Circuit $X_c = 0$





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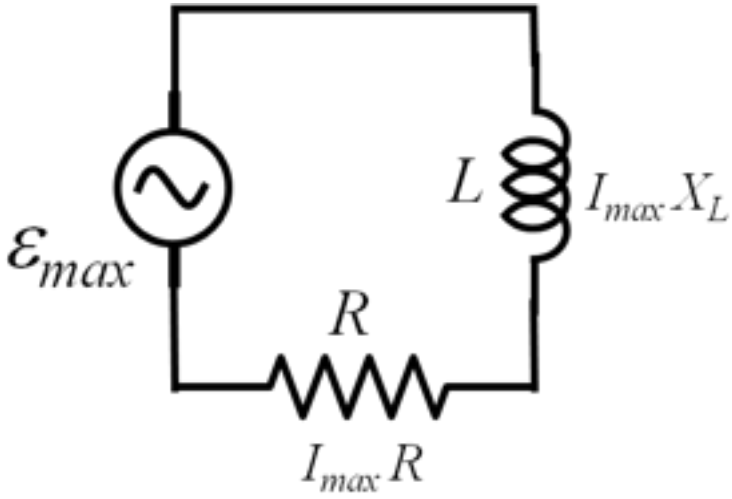
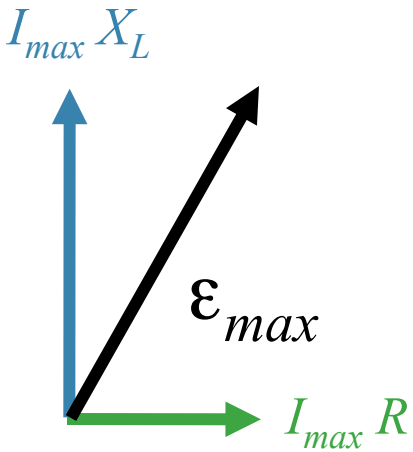
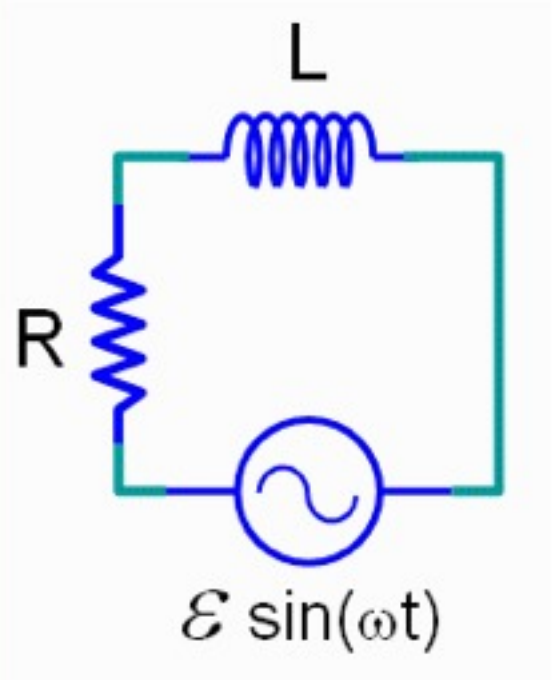




CheckPoint 2

2) A RL circuit is driven by an AC generator as shown in the figure.



The voltages across the resistor and generator are _____.

A ○ always out of phase

B ○ always in phase

C ○ sometimes in phase and sometimes out of phase

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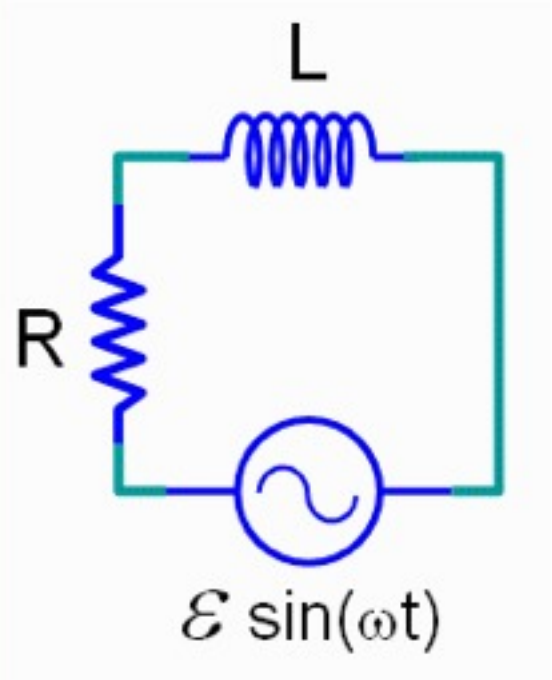

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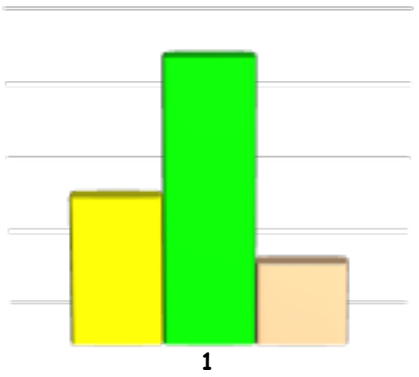

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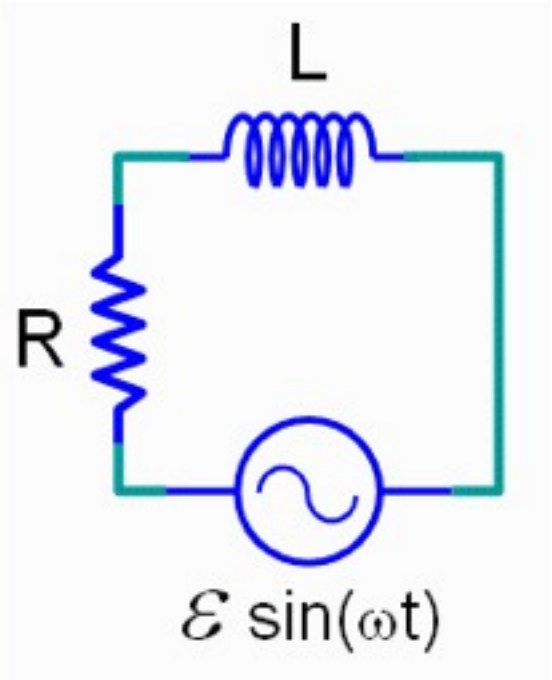
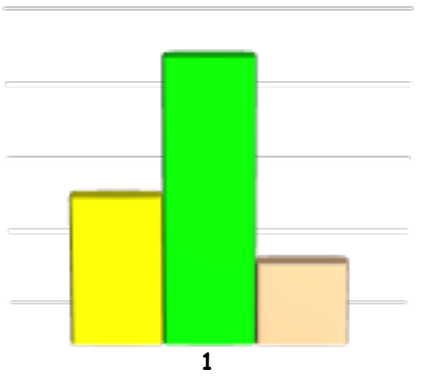


Draw Voltage Phasors



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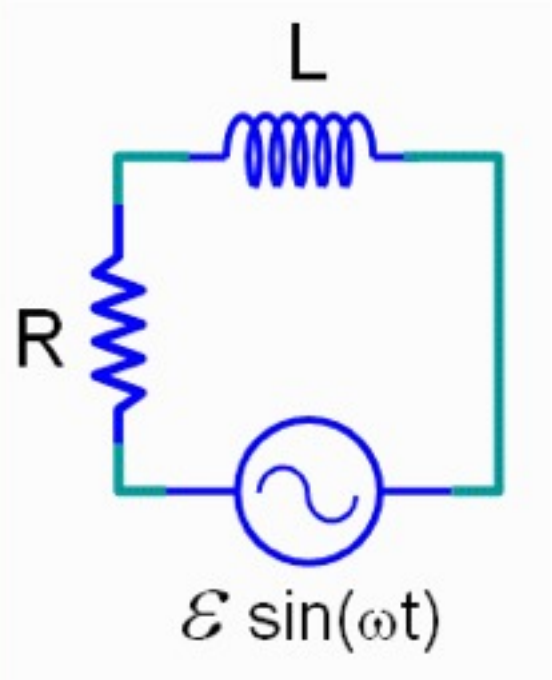

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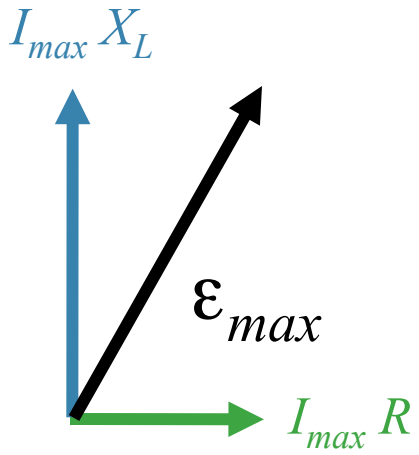

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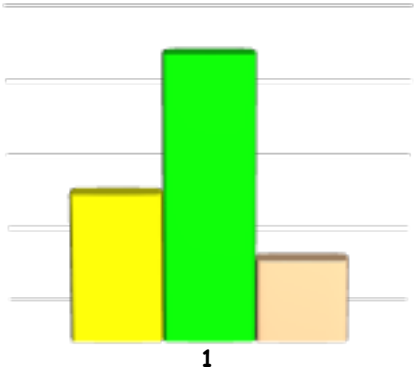

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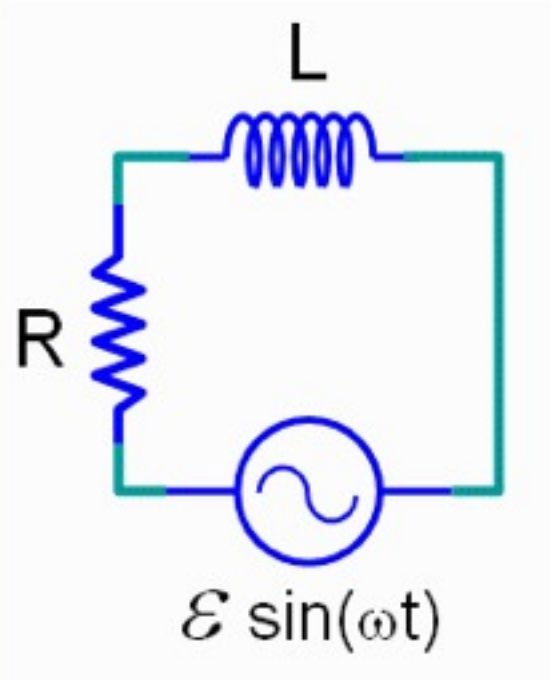
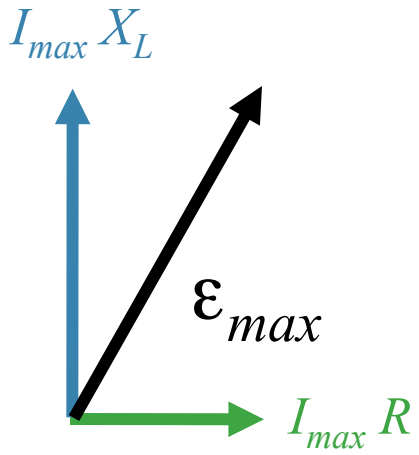


Draw Voltage Phasors

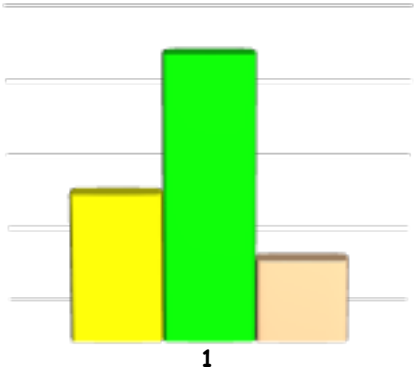


The voltages across the resistor and generator are _____.

A ◯ always out of phase

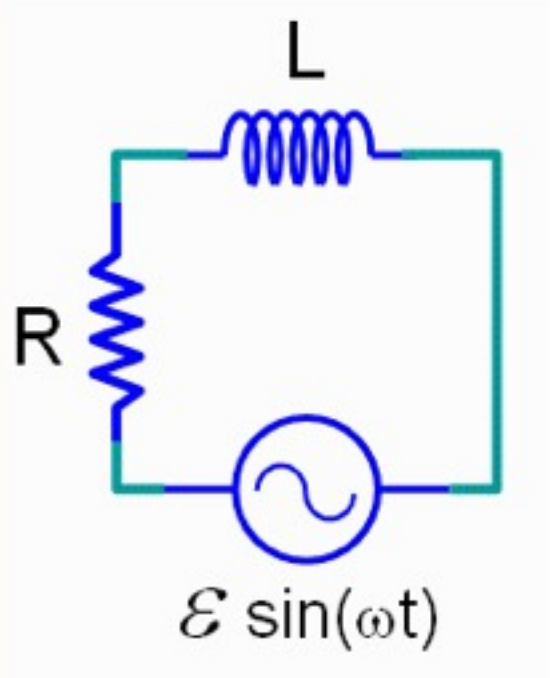
B ◯ always in phase

C ◯ sometimes in phase and sometimes out of phase



CheckPoint 4

A RL circuit is driven by an AC generator as shown in the figure.



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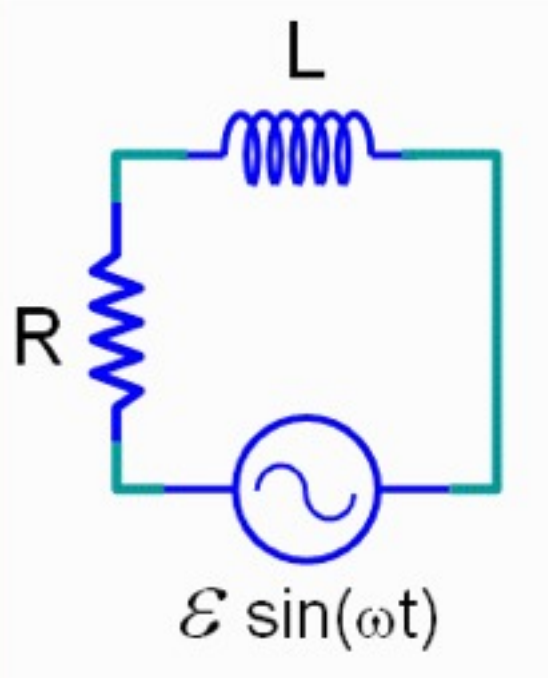

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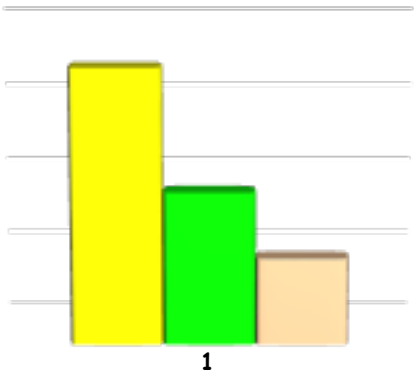

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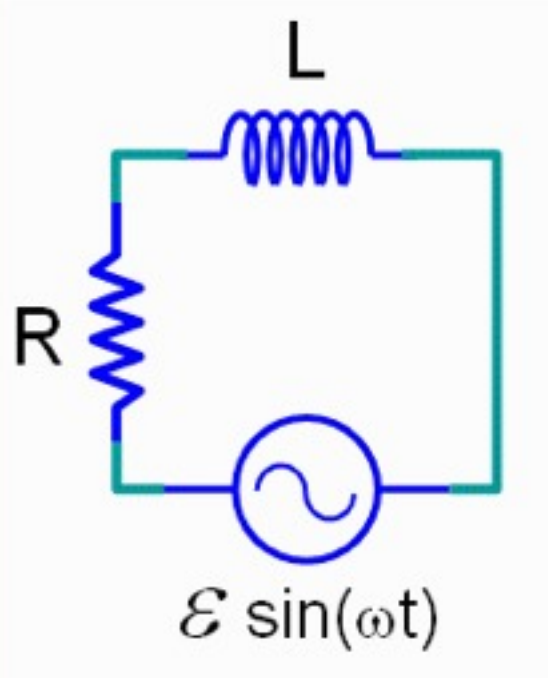

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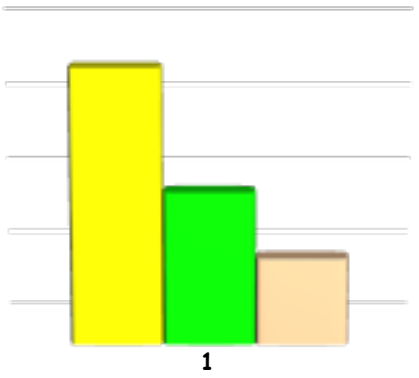

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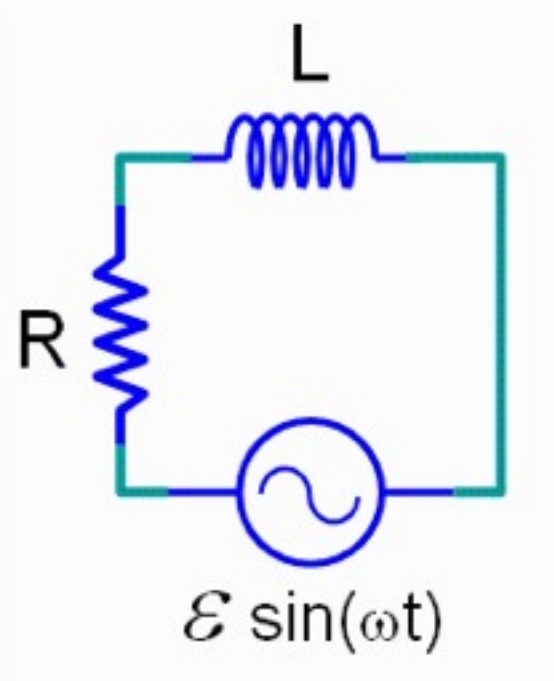

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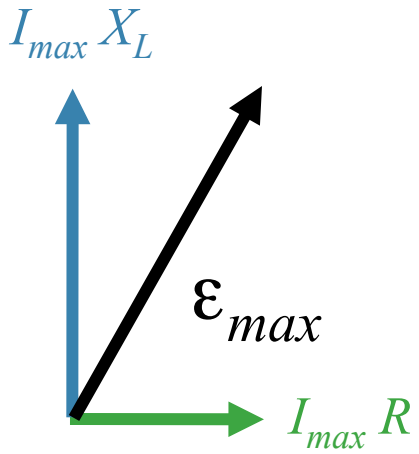

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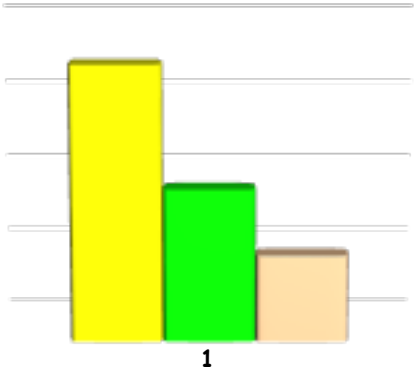

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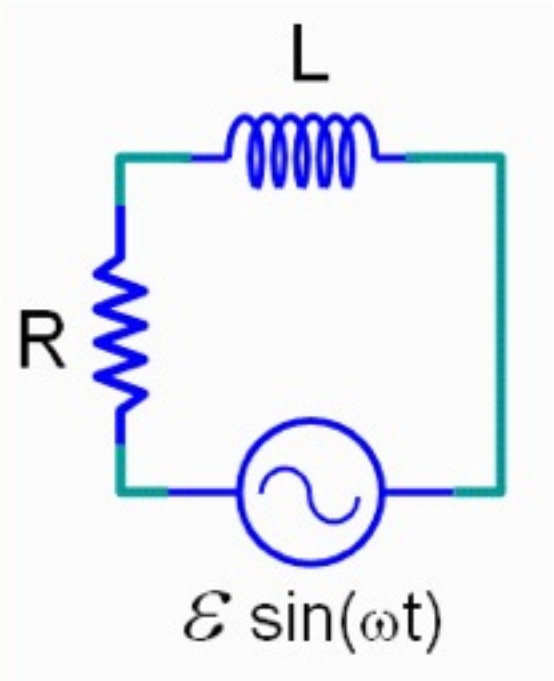

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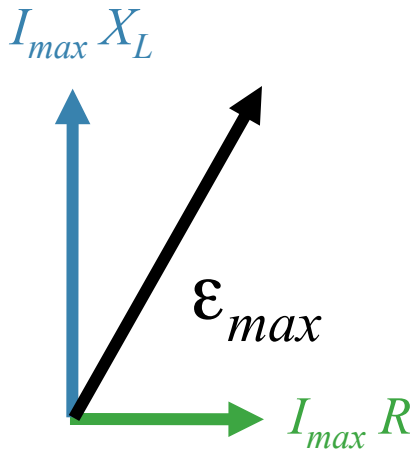

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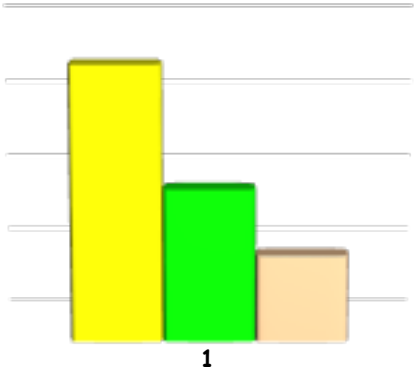
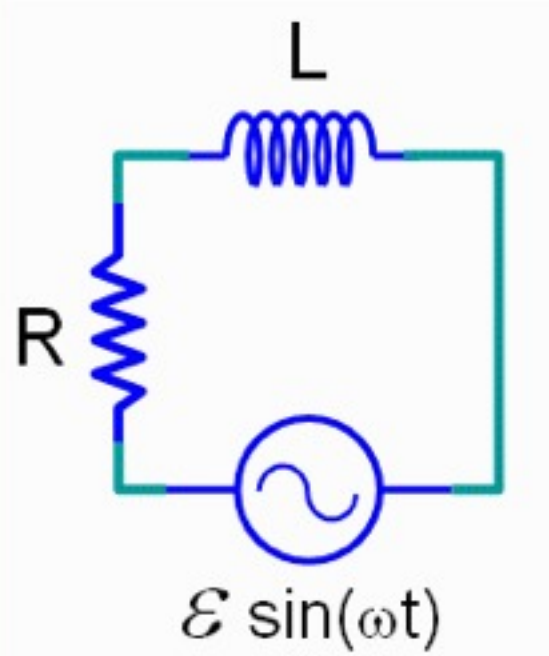


CheckPoint 6

A RL circuit is driven by an AC generator as shown in the figure.



6) The phase difference between the CURRENT through the resistor and inductor ____

A ○ is always zero
B ○ is always 90°
C ○ depends on the value of L and R
D ○ depends on L, R and the generator voltage

CheckPoint 6

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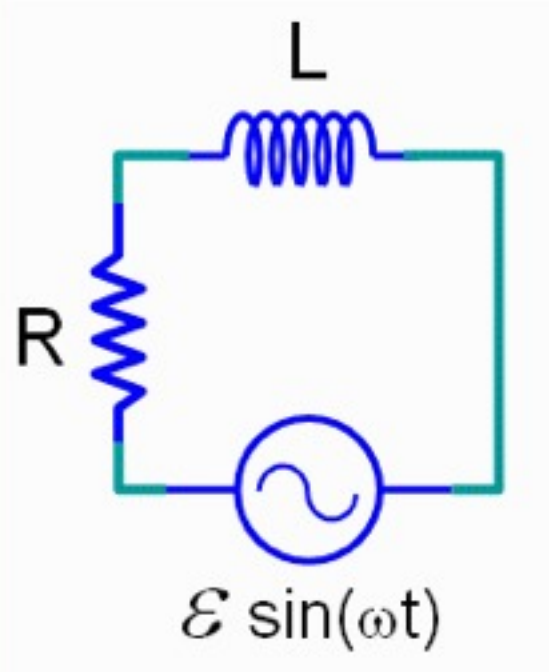

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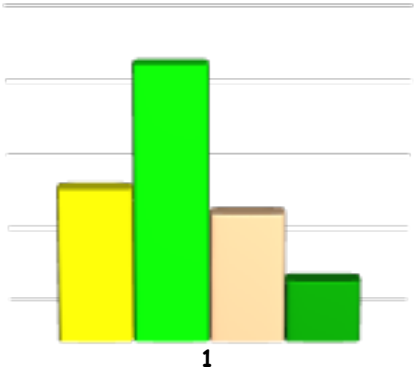

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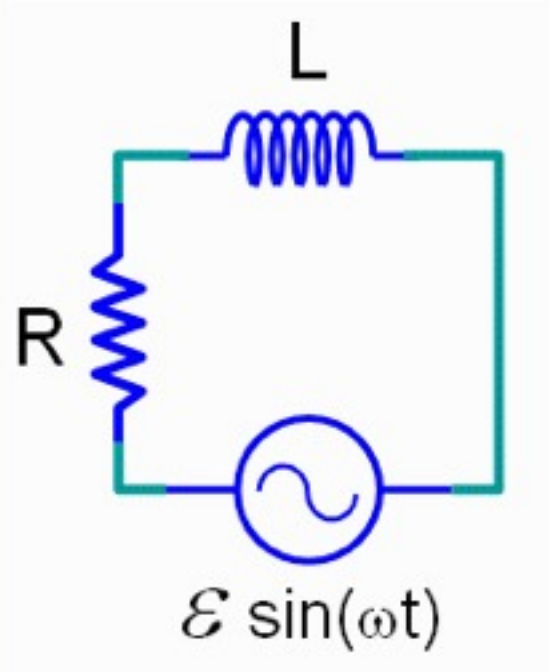

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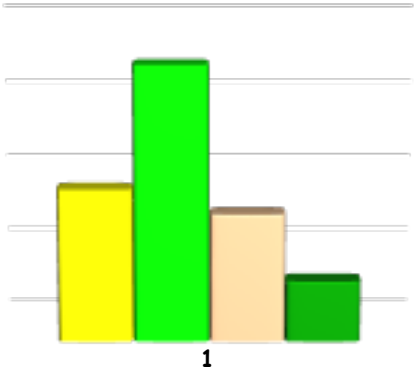

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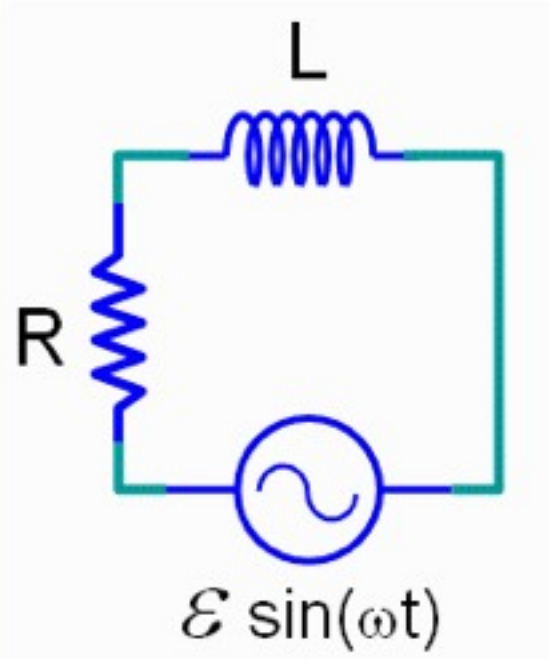

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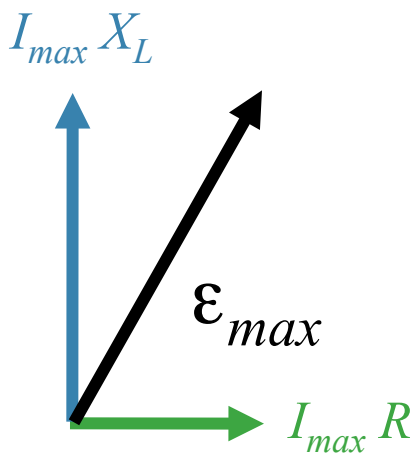

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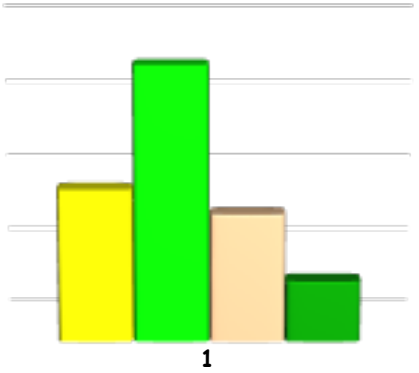

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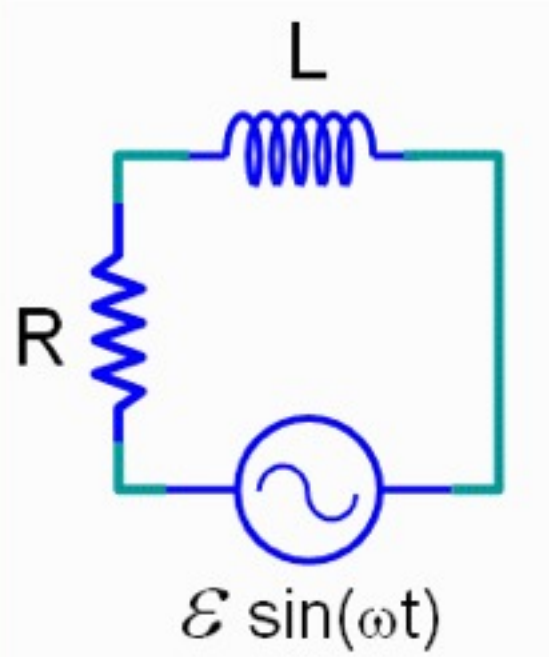

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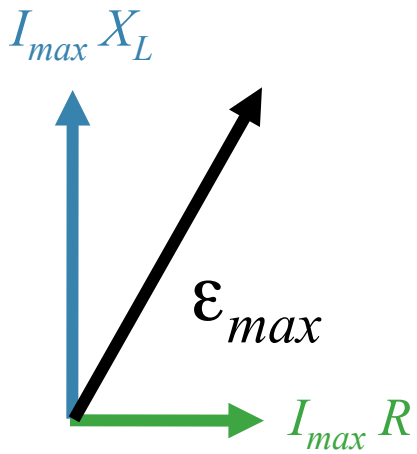

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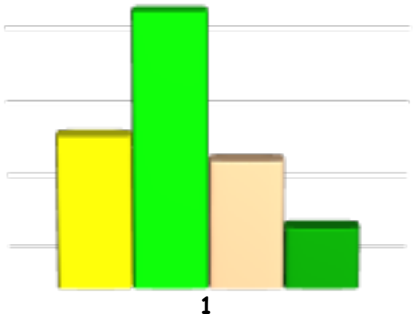

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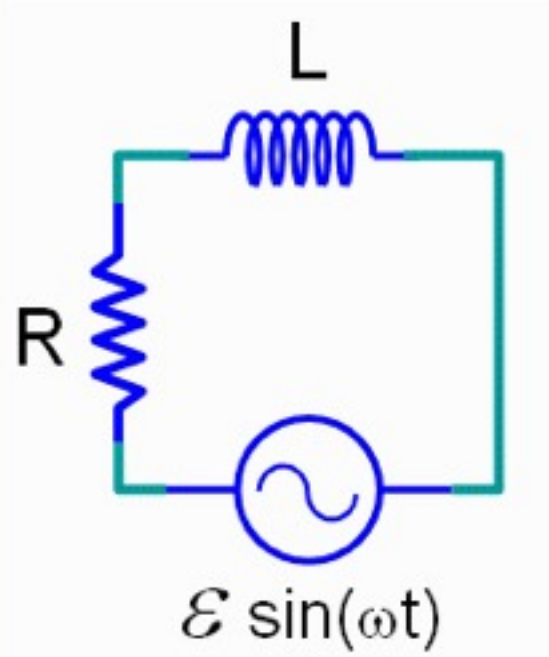

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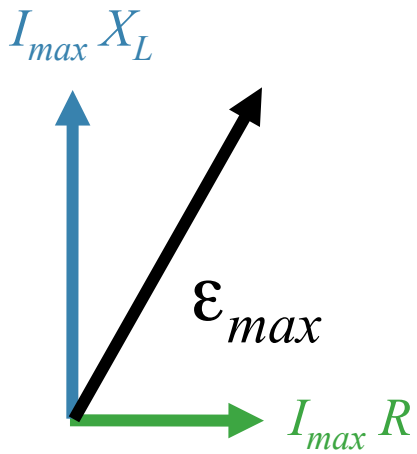

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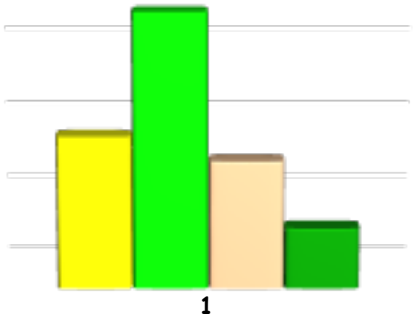
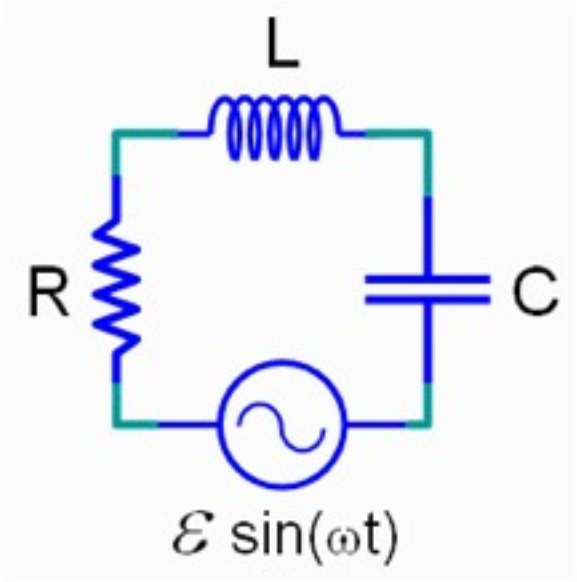
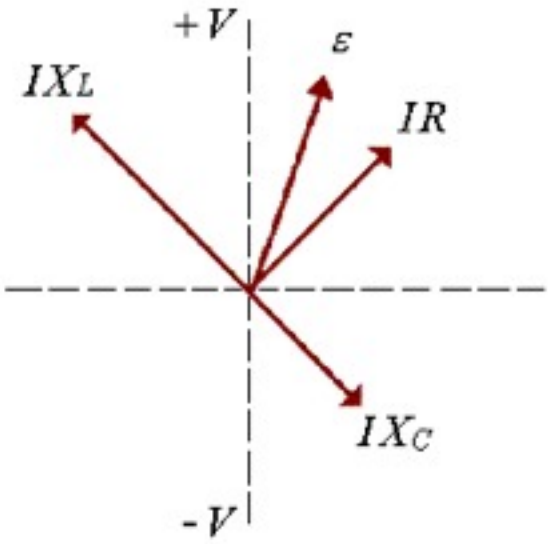


CheckPoint 8

A driven RLC circuit is represented by the phasor diagram below.





The vertical axis of the phasor diagram represents voltage. When the current through the circuit is maximum, what is the potential difference across the inductor?

A ○ $V_L = 0$

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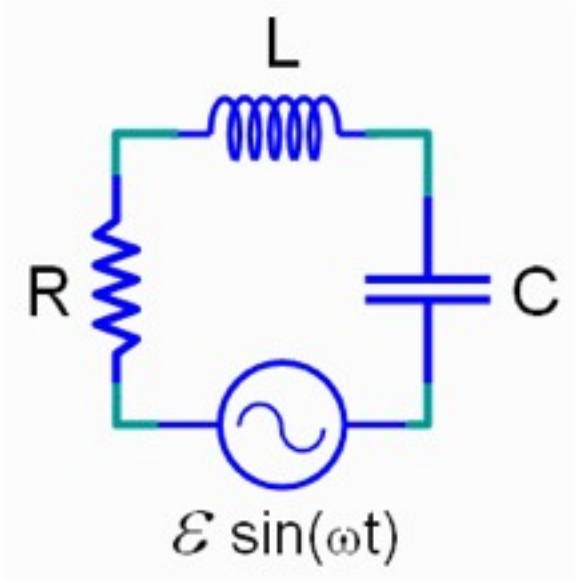

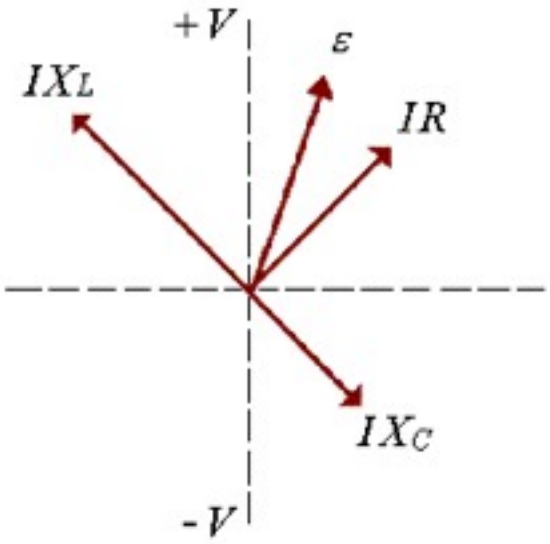

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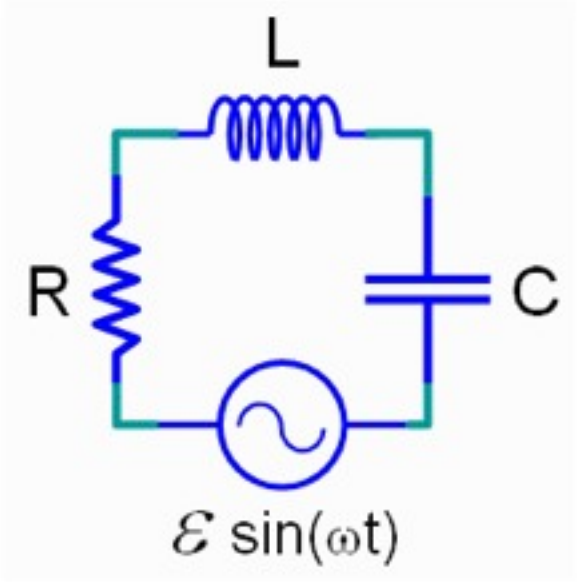

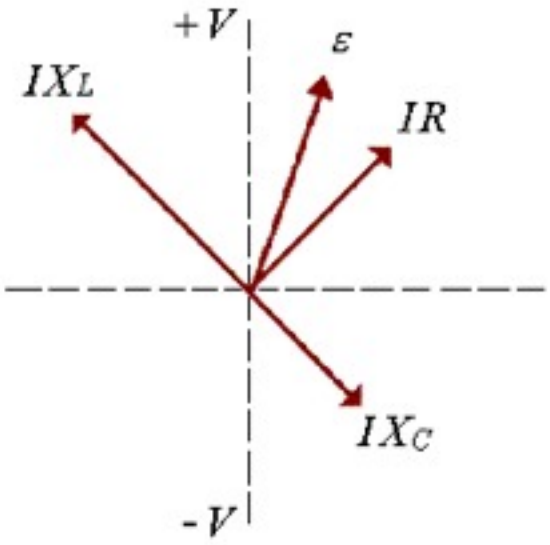

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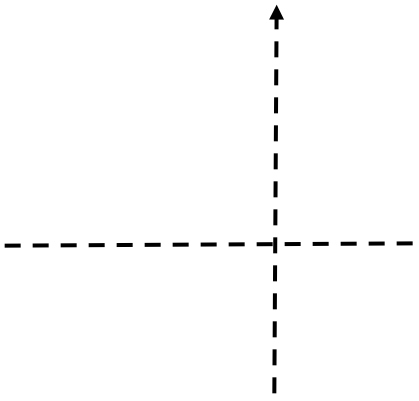

What does the voltage phasor diagram look like when the current is a maximum?

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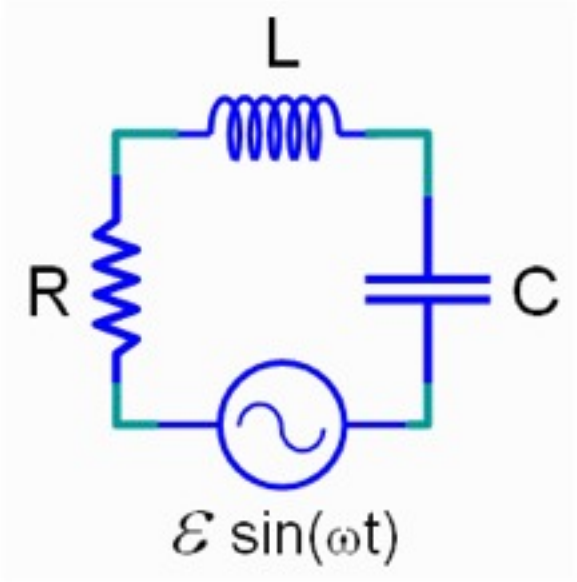

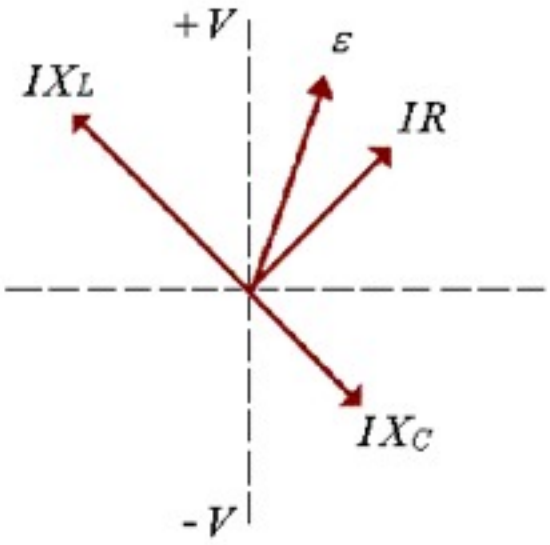

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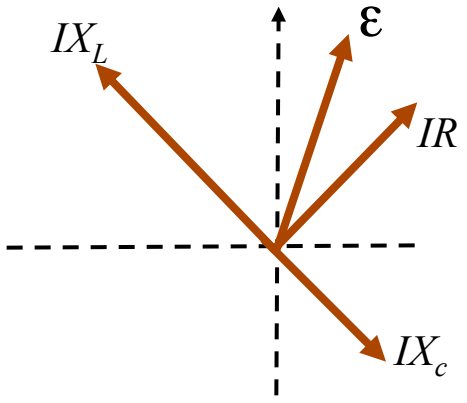

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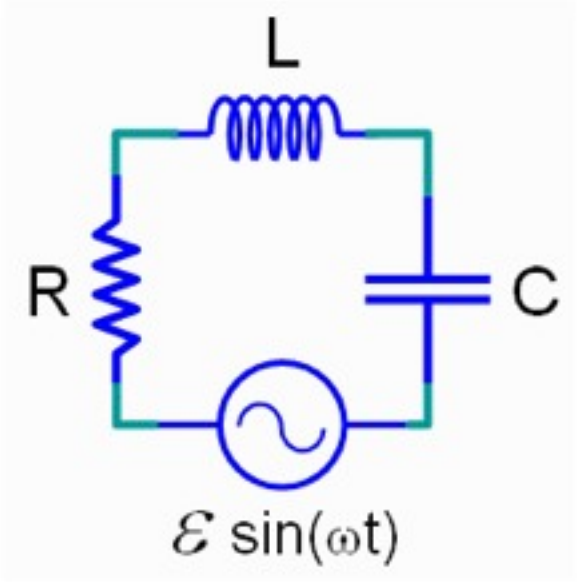

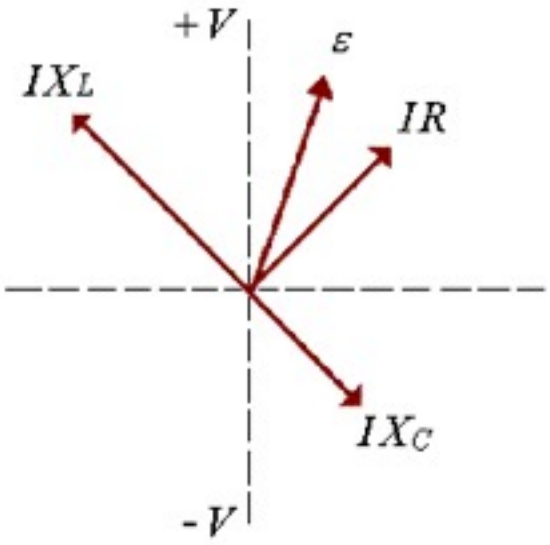

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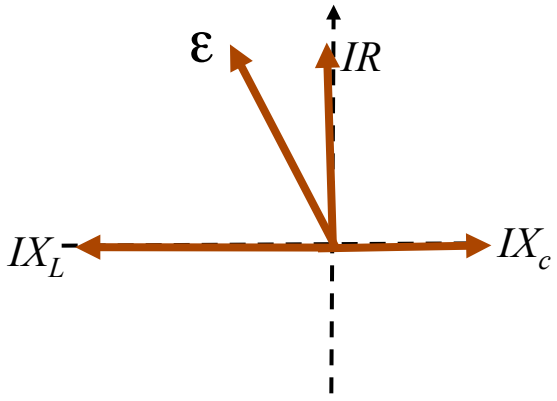

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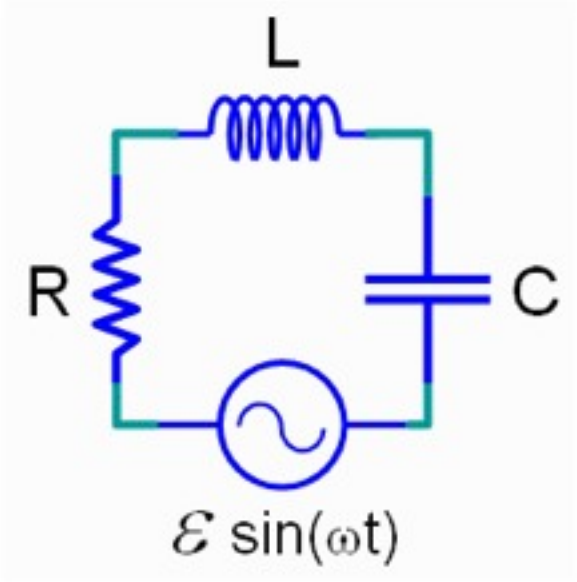

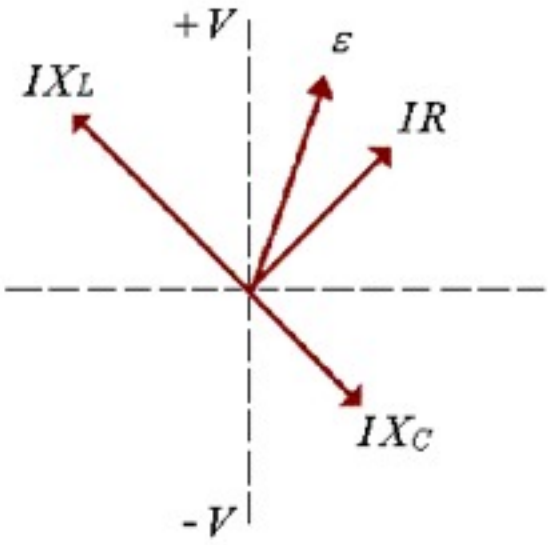

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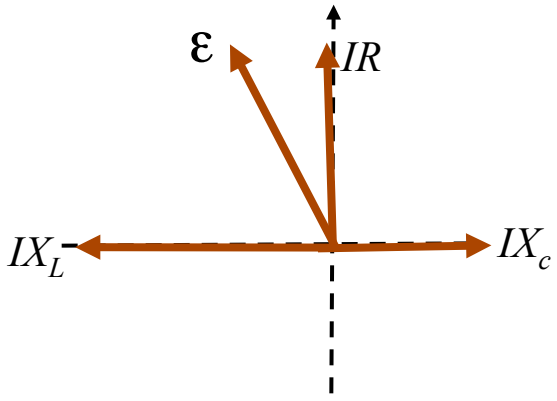

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CheckPoint 10

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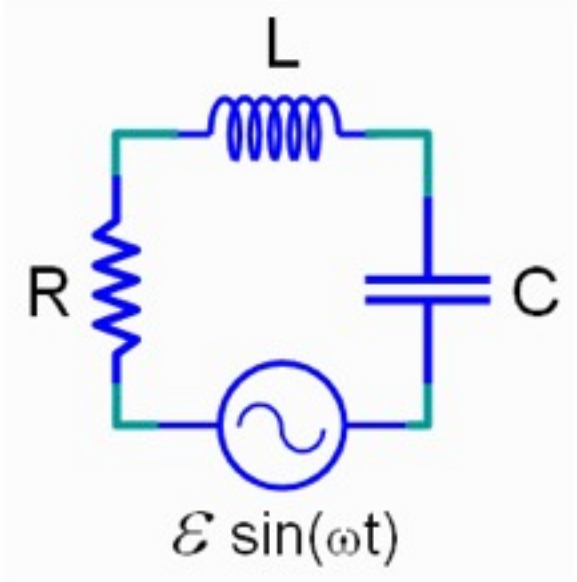

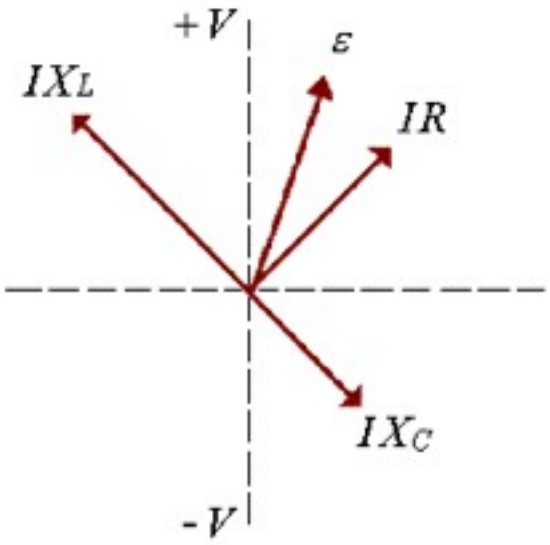

When the capacitor is fully charged, what is the magnitude of the voltage across the inductor?

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CheckPoint 10

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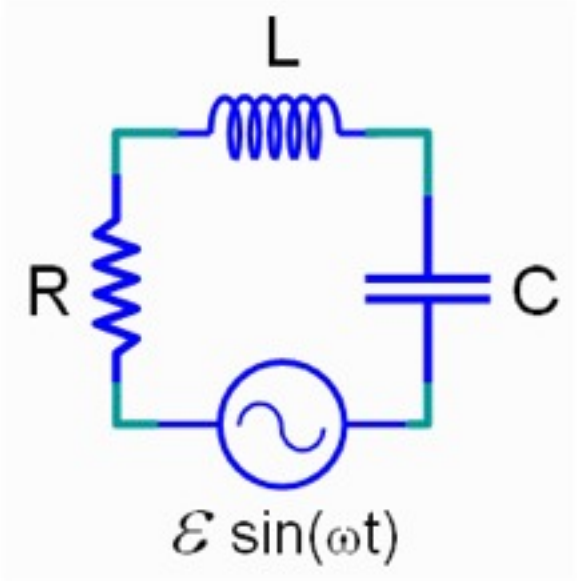

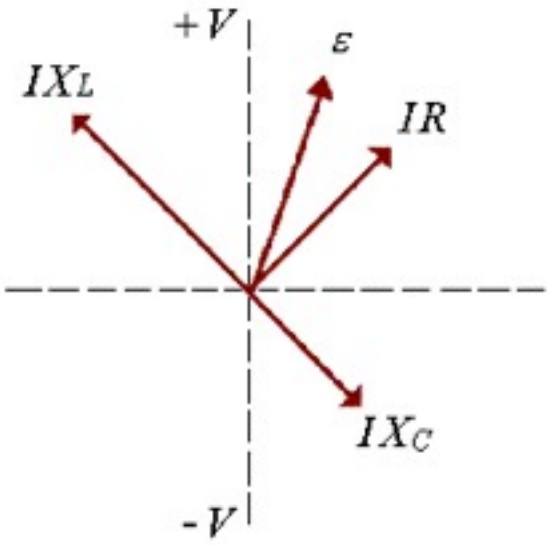

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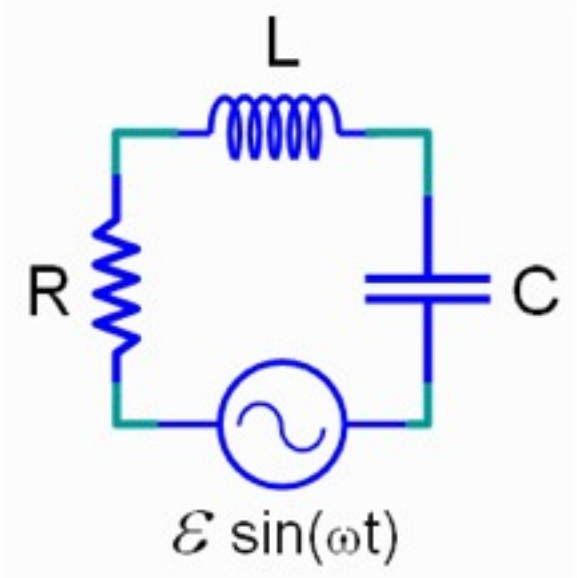

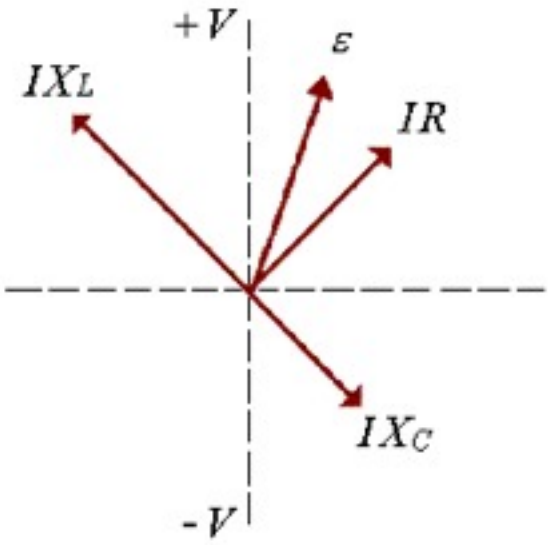

When the capacitor is fully charged, what is the magnitude of the voltage across the inductor?

A ○ $V_L = 0$

B ○ $V_L = V_{Lmax}/2$

C ○ $V_L = V_{Lmax}$

What does the voltage phasor diagram look like when the capacitor is fully charged?

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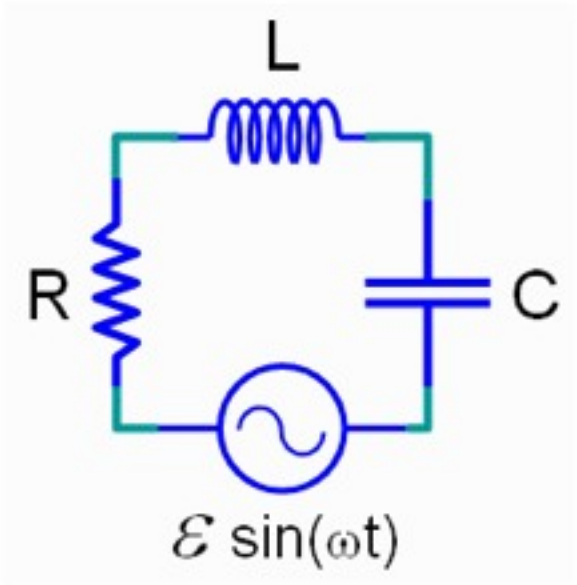

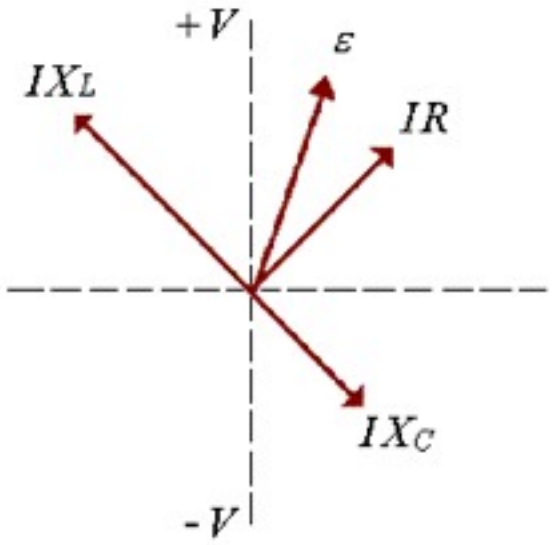

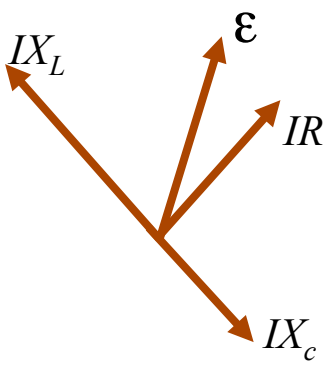

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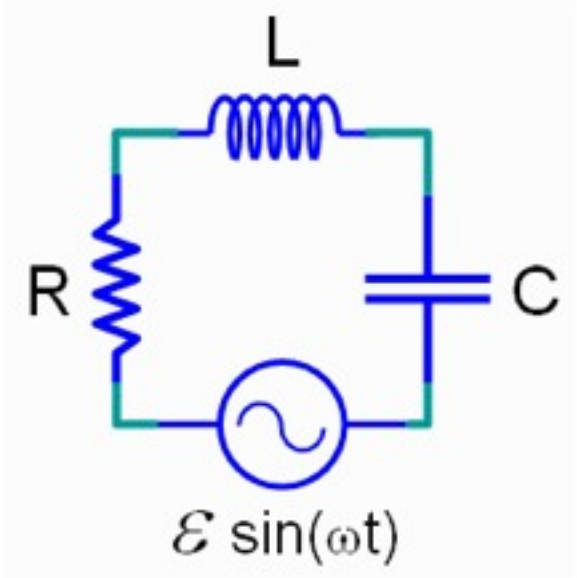

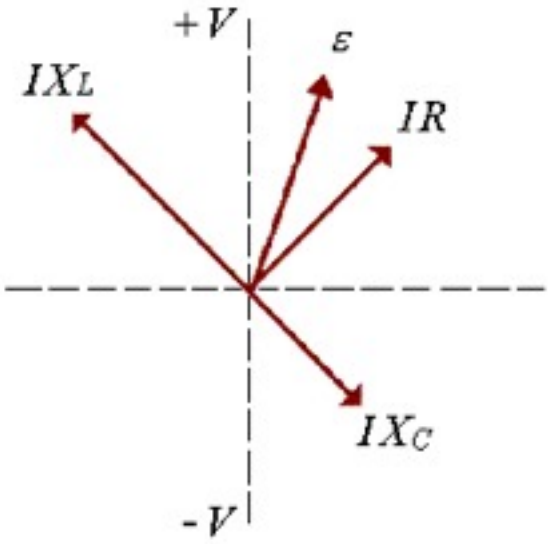

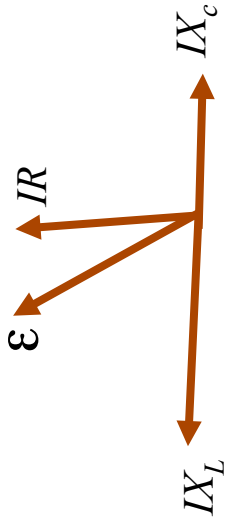

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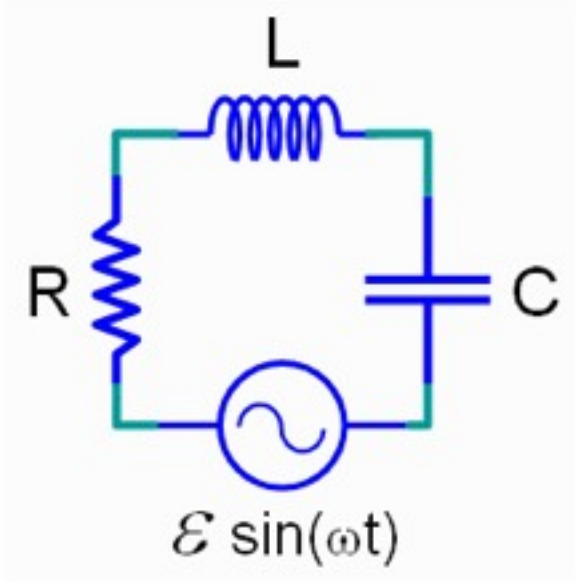

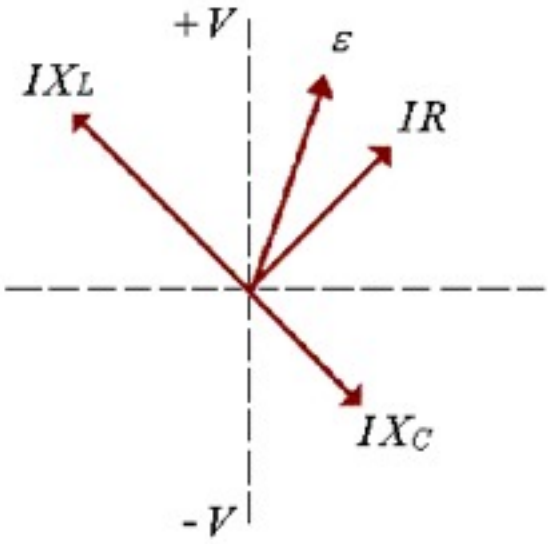

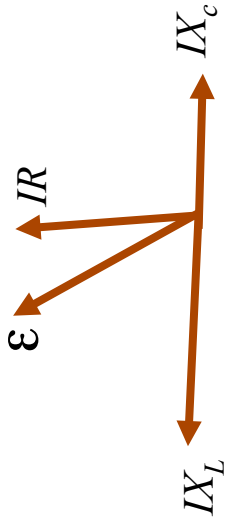

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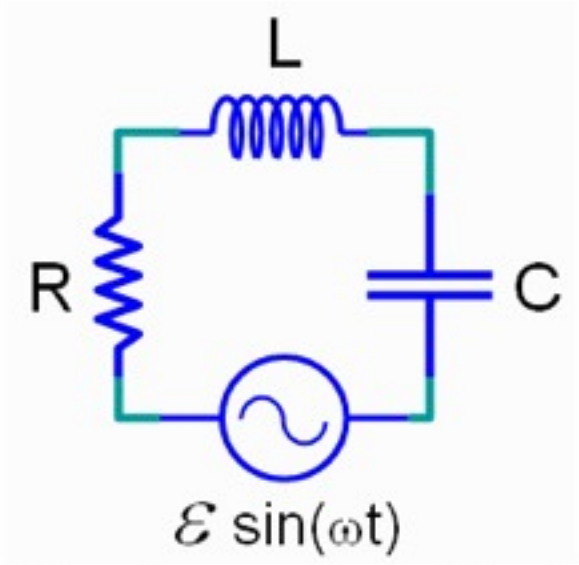
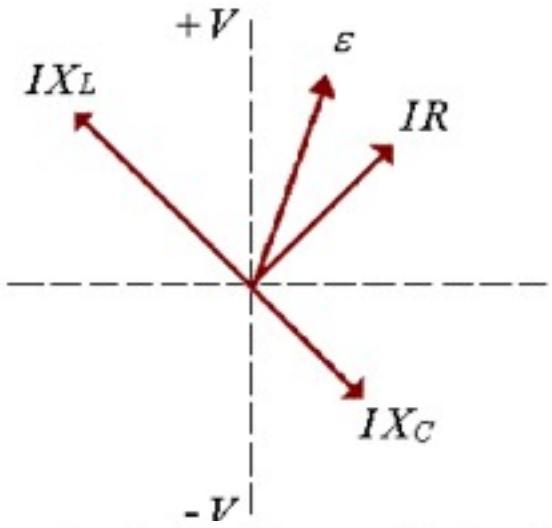
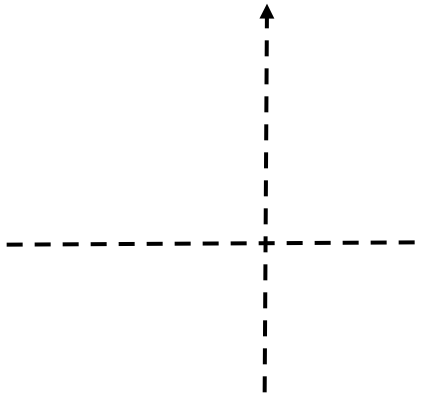
CheckPoint 12

A driven RLC circuit is represented by the phasor diagram below.







12) When the voltage across the capacitor is at its positive maximum, $V_C=+V_{Cmax}$, what is the voltage across the inductor?

A ○ $V_L = 0$

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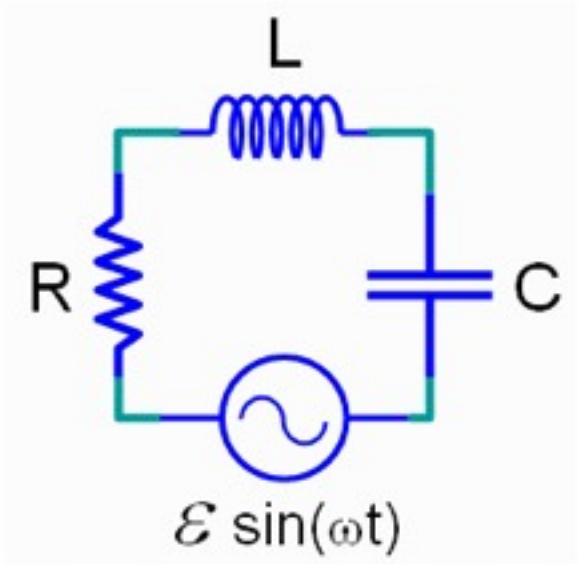

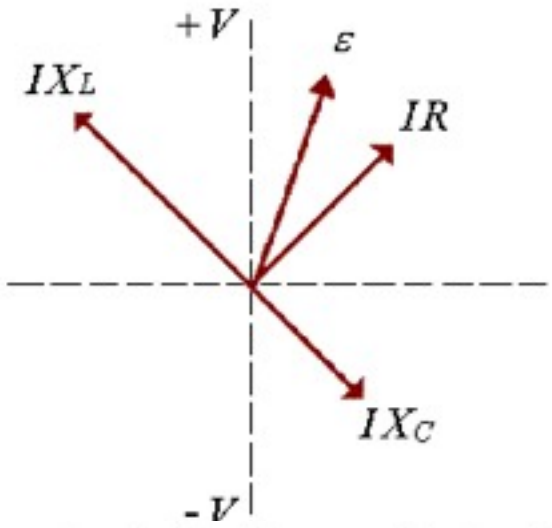

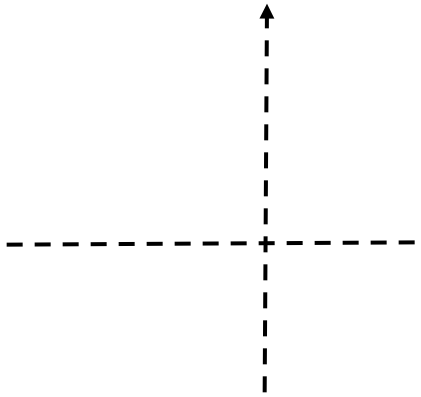

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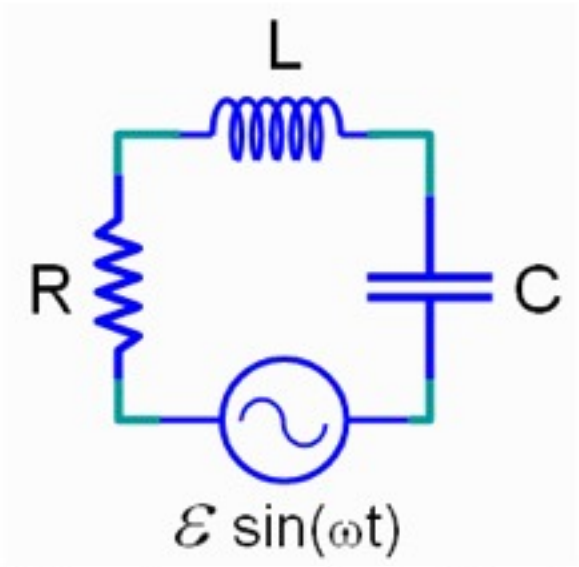

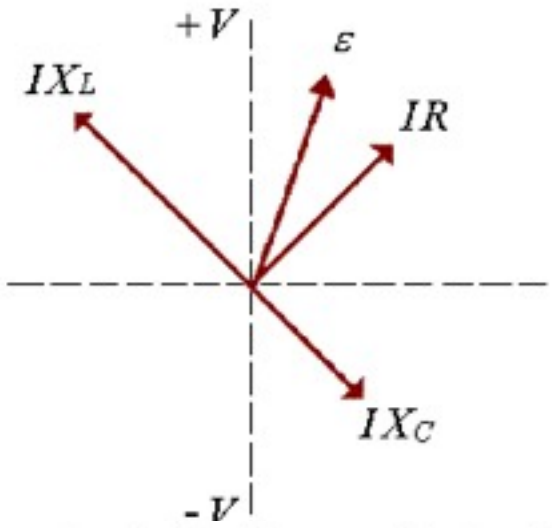

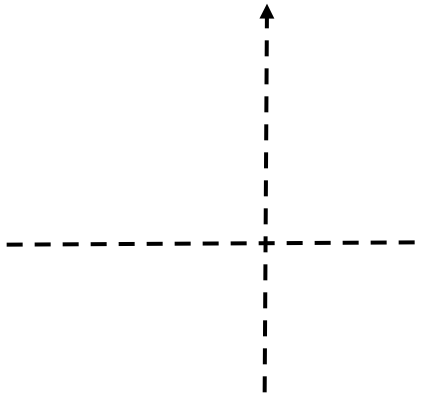

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What does the voltage phasor diagram look like when the voltage across capacitor is at its positive maximum?

CheckPoint 12

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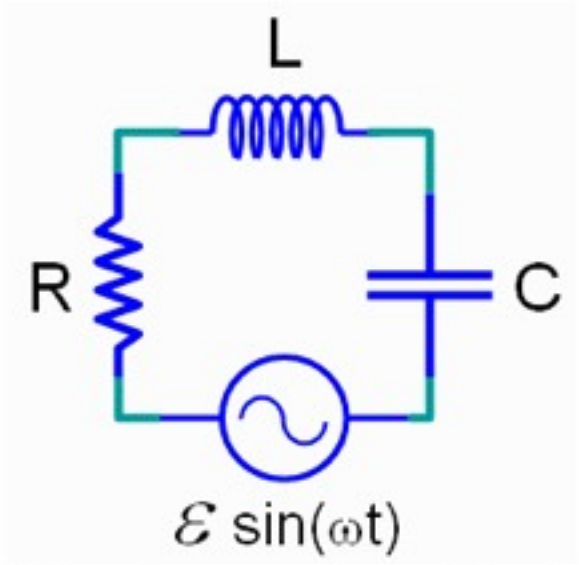

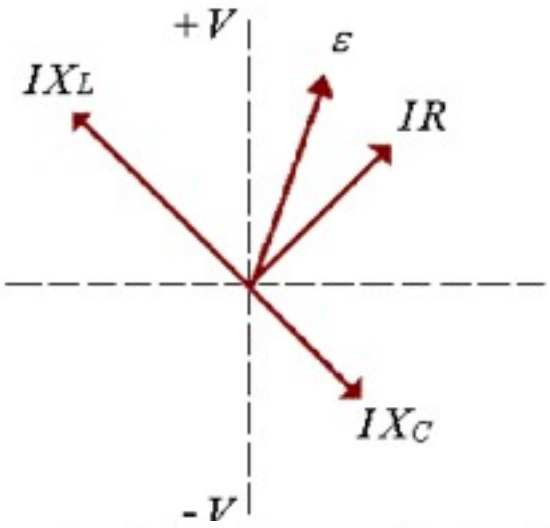

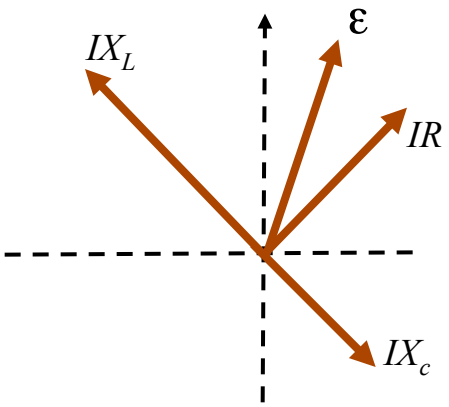

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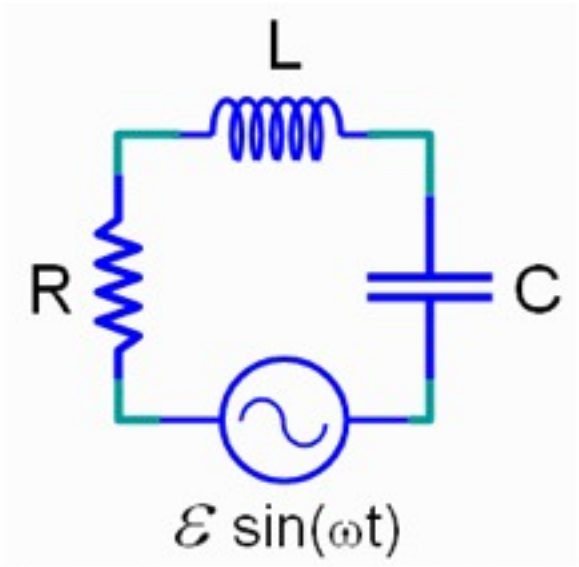

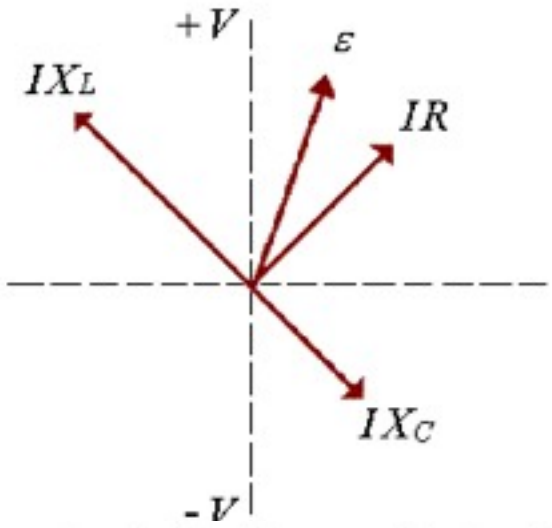

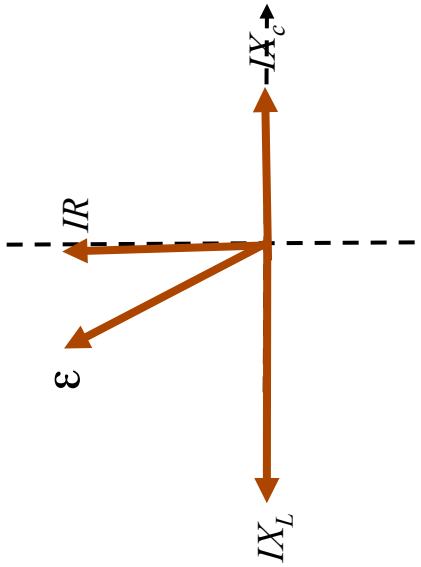

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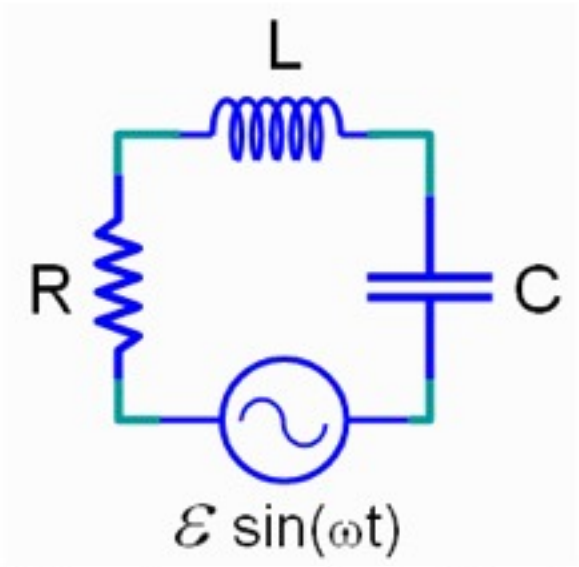

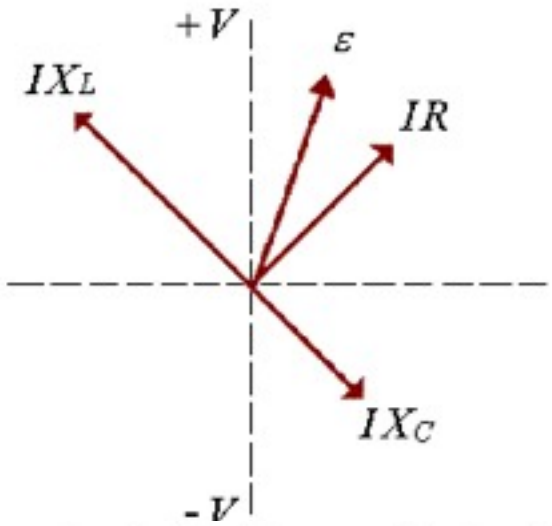

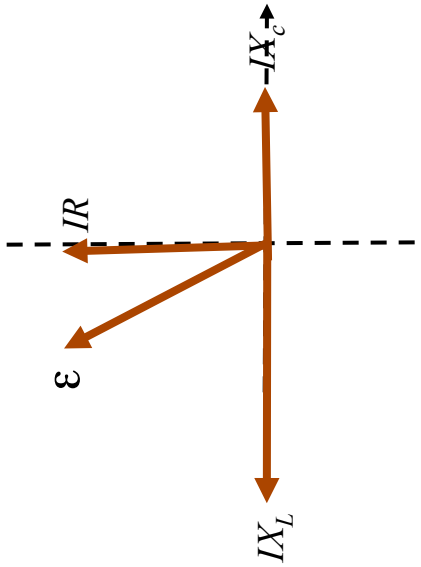

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What does the voltage phasor diagram look like when the voltage across capacitor is at its positive maximum?

Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

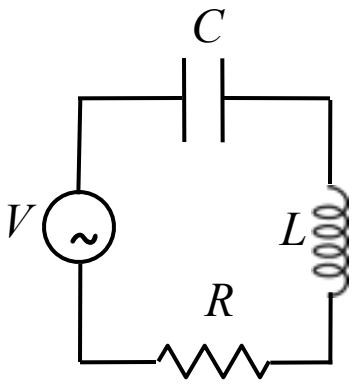
$I_{max} = 2$ mA

$V_{Cmax} = 113$ V

The current leads generator voltage by 45^o

L and R are unknown.

What is X_L, the reactance of the inductor, at this frequency?



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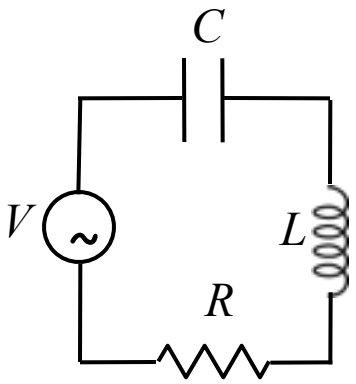

Conceptual Analysis

Calculation

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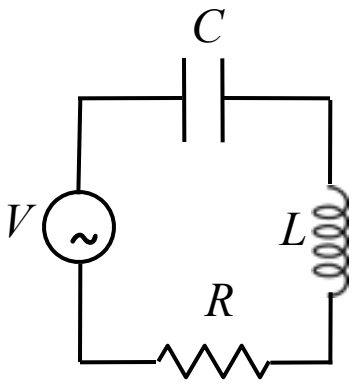

Conceptual Analysis

The maximum voltage for each component is related to its reactance and to the maximum current.

Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

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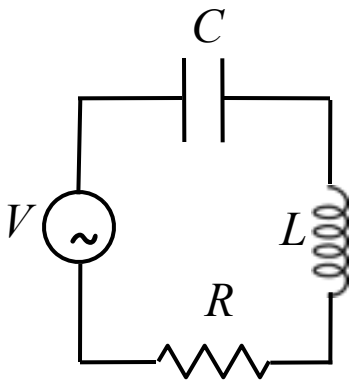

Conceptual Analysis

The maximum voltage for each component is related to its reactance and to the maximum current.

The impedance triangle determines the relationship between the maximum voltages for the components

Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

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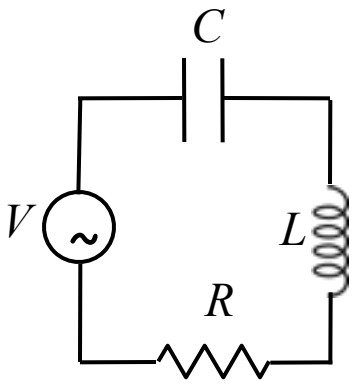

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Strategic Analysis

Calculation

Consider the harmonically driven series LCR circuit shown.

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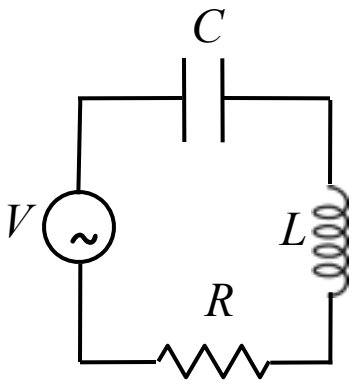

Conceptual Analysis

The maximum voltage for each component is related to its reactance and to the maximum current.

The impedance triangle determines the relationship between the maximum voltages for the components

Strategic Analysis

Use V_{max} and I_{max} to determine Z

Calculation

Consider the harmonically driven series LCR circuit shown.

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$V_{Cmax} = 113$ V

The current leads generator voltage by 45^o

L and R are unknown.

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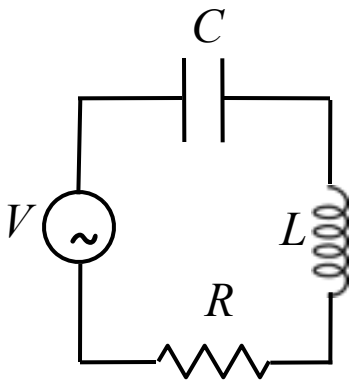

Conceptual Analysis

The maximum voltage for each component is related to its reactance and to the maximum current.

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Strategic Analysis

Use V_{max} and I_{max} to determine Z

Use impedance triangle to determine R

Calculation

Consider the harmonically driven series LCR circuit shown.

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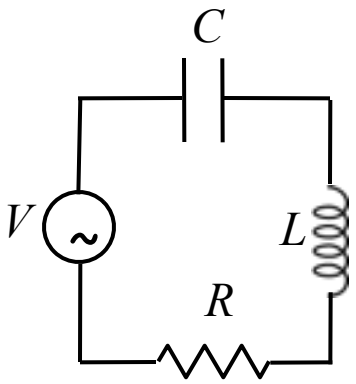

Conceptual Analysis

The maximum voltage for each component is related to its reactance and to the maximum current.

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Strategic Analysis

Use V_{max} and I_{max} to determine Z

Use impedance triangle to determine R

Use V_{Cmax} and impedance triangle to determine X_L

Calculation

Consider the harmonically driven series LCR circuit shown.

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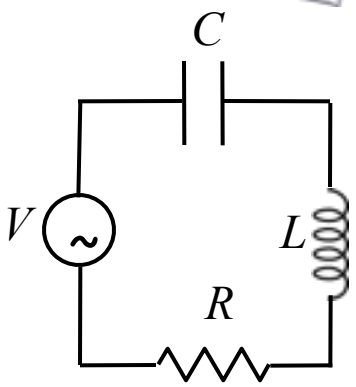

Compare X_L and X_C at this frequency:

A) $X_L < X_C$ B) $X_L = X_C$ C) $X_L > X_C$ D) Not enough information

Calculation

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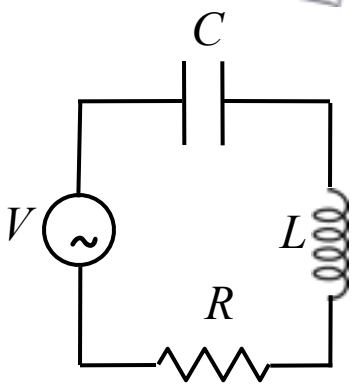

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This information is determined from the phase

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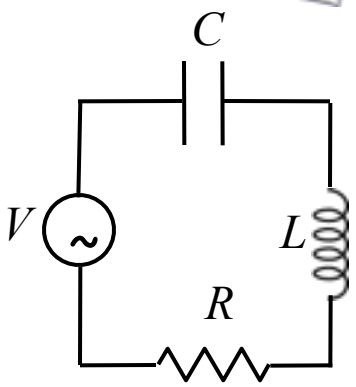

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Current leads voltage

Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

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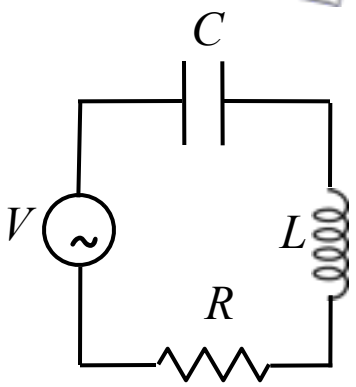
The current leads generator voltage by 45^o

L and R are unknown.

What is X_L, the reactance of the inductor, at this frequency?



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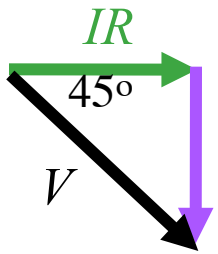
This information is determined from the phase

Current leads voltage



Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

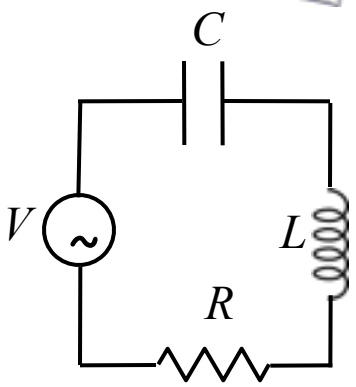
$I_{max} = 2$ mA

$V_{Cmax} = 113$ V

The current leads generator voltage by 45^o

L and R are unknown.

What is X_L, the reactance of the inductor, at this frequency?

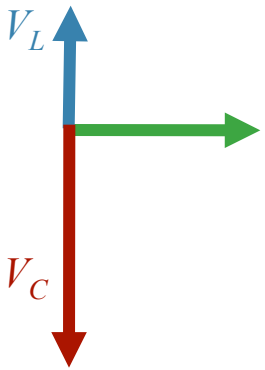


Compare X_L and X_C at this frequency:

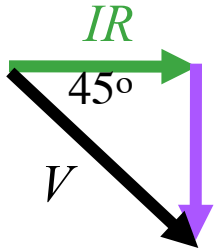
A) $X_L < X_C$ B) $X_L = X_C$ C) $X_L > X_C$ D) Not enough information

This information is determined from the phase

Current leads voltage



V_R (phase of current)



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Consider the harmonically driven series LCR circuit shown.

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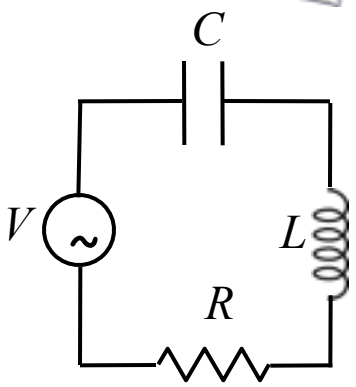

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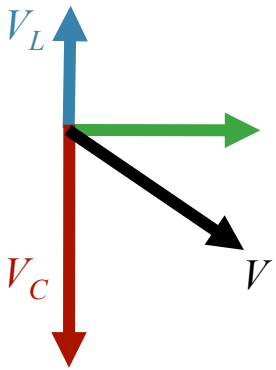

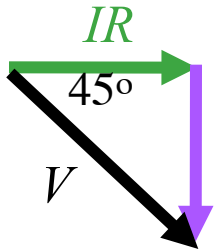

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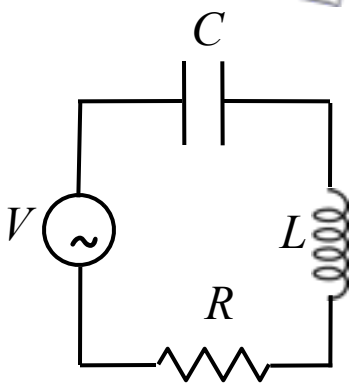

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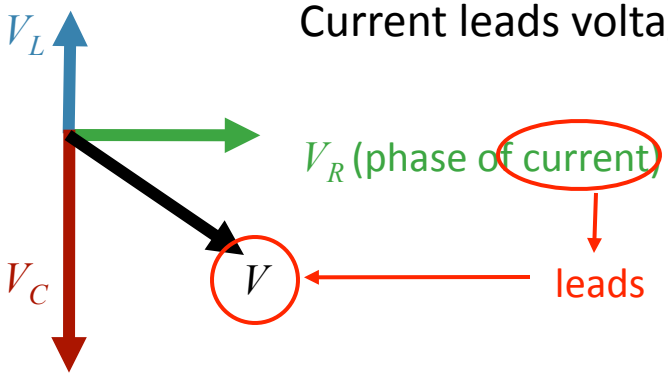
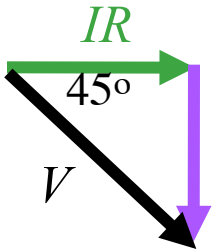
Current leads voltage





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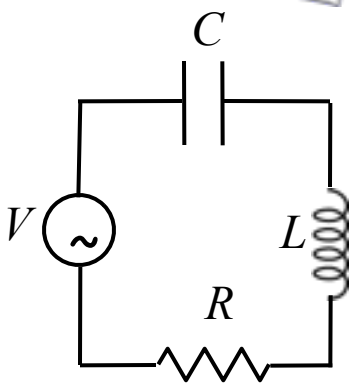

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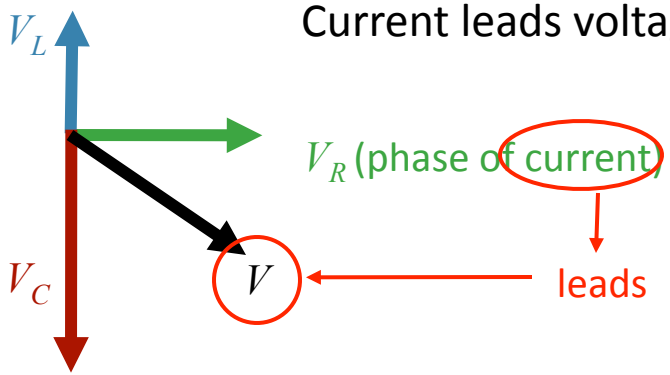
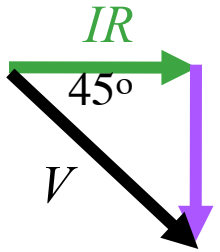
A) $X_L < X_C$ B) $X_L = X_C$ C) $X_L > X_C$ D) Not enough information

This information is determined from the phase

Current leads voltage

$$V_L = I_{max} X_L$$
$$V_C = I_{max} X_C$$





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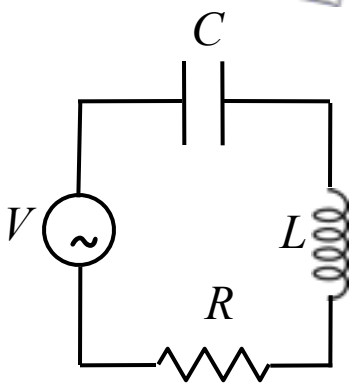

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Current leads voltage

$$V_L = I_{max} X_L$$
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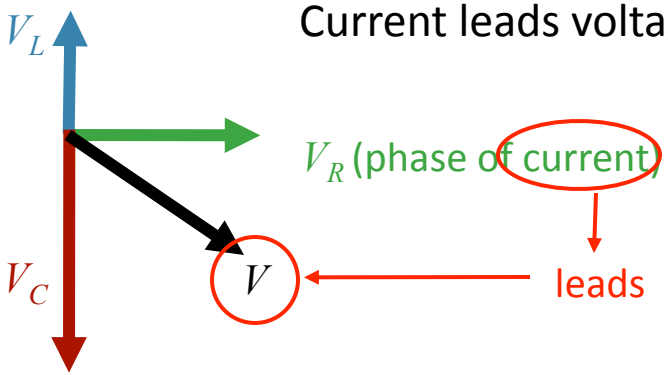

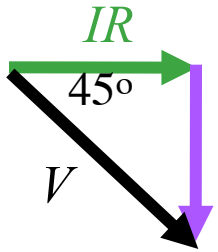

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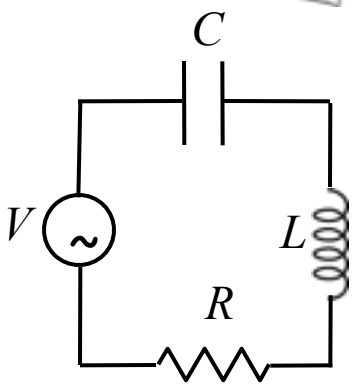

What is Z, the total impedance of the circuit?

A) 70.7 kΩ B) 50 kΩ C) 35.4 kΩ D) 21.1 kΩ

Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

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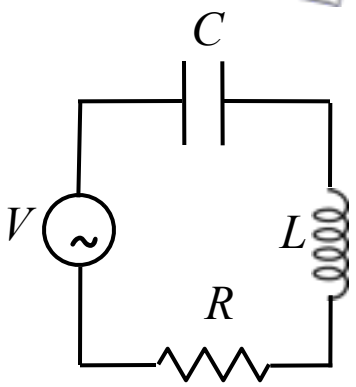

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A) 70.7 kΩ B) 50 kΩ C) 35.4 kΩ D) 21.1 kΩ

$$Z = \frac{V_{\max}}{I_{\max}} = \frac{100V}{2mA} = 50k\Omega$$

Calculation

Consider the harmonically driven series LCR circuit shown.

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L and R are unknown.

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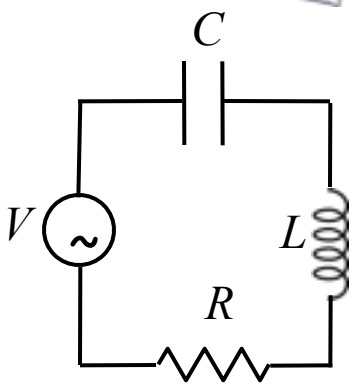

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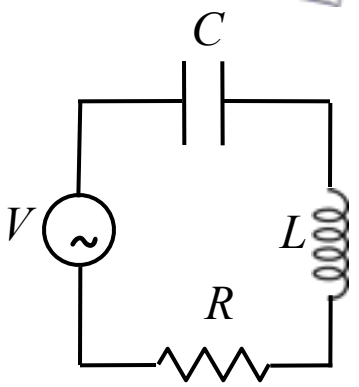

$Z = 50$ kΩ

$\sin(45°) = 0.707$

$\cos(45°) = 0.707$

What is R?

A) 70.7 kΩ B) 50 kΩ C) 35.4 kΩ D) 21.1 kΩ

Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

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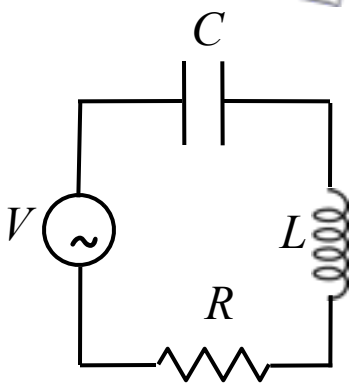

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What is R?

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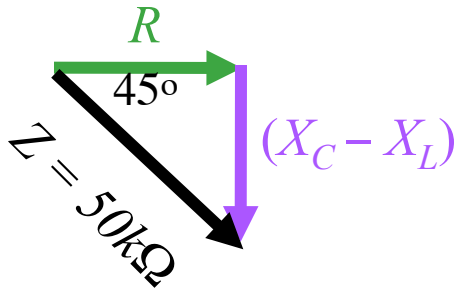
Determined from impedance triangle



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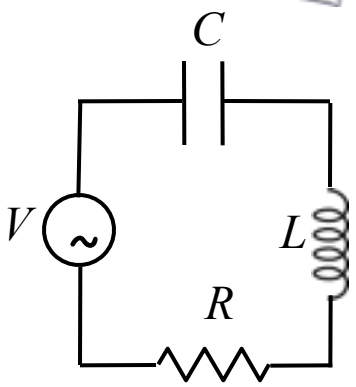

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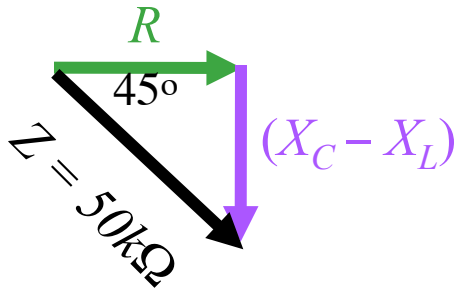

$$\cos(45) = \frac{R}{Z}$$

Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

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The current leads generator voltage by 45^o

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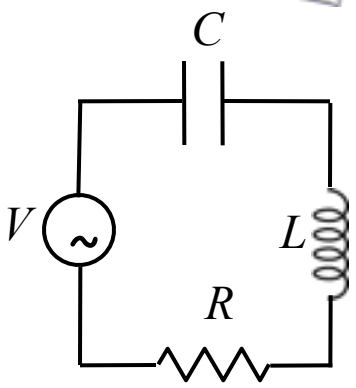

$Z = 50\ \text{k}\Omega$

$\sin(45°) = 0.707$

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What is R?

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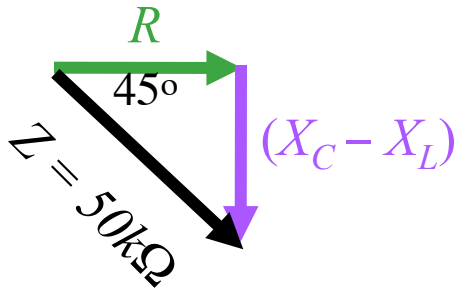

$$\cos(45) = \frac{R}{Z} \rightarrow R = Z\cos(45^o)$$

Calculation

Consider the harmonically driven series LCR circuit shown.

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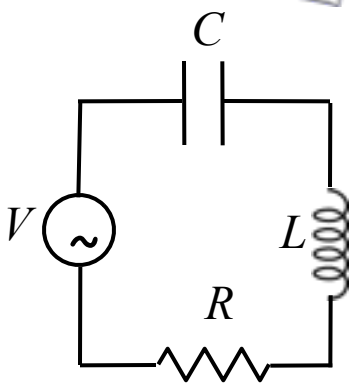

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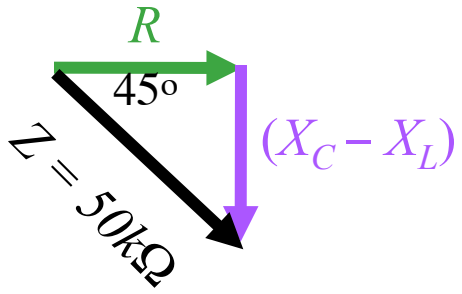

$$\cos(45) = \frac{R}{Z} \rightarrow R = Z\cos(45^o)$$

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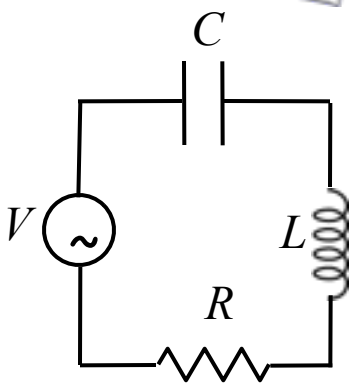

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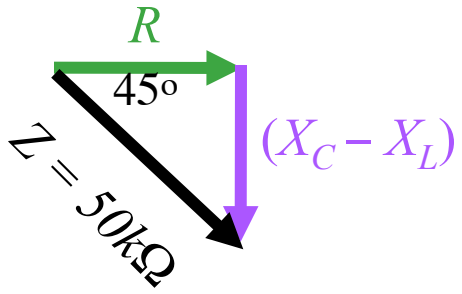
$\sin(45°) = 0.707$

$\cos(45°) = 0.707$

What is R?

A) 70.7 kΩ B) 50 kΩ **C) 35.4 kΩ** D) 21.1 kΩ

Determined from impedance triangle



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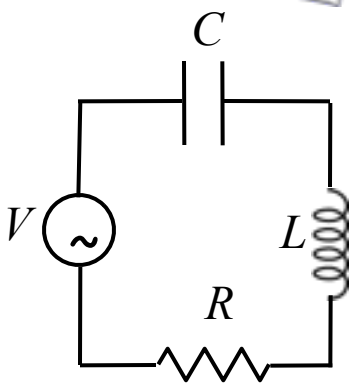

$Z = 50$ kΩ

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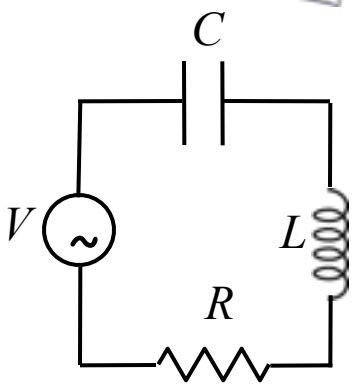

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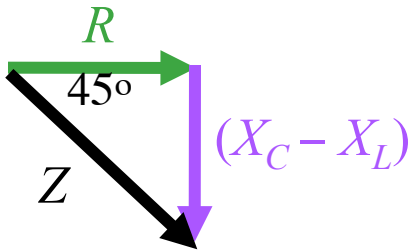
We start with the impedance triangle:



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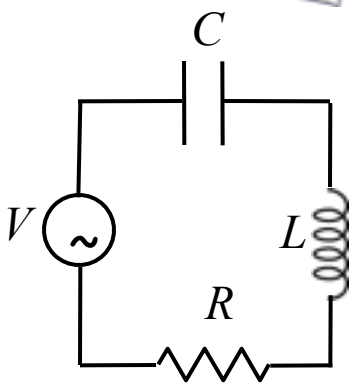

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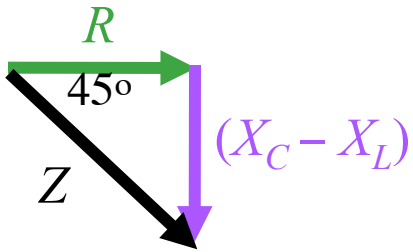

$$\frac{X_C - X_L}{R} = \tan 45° = 1$$

Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

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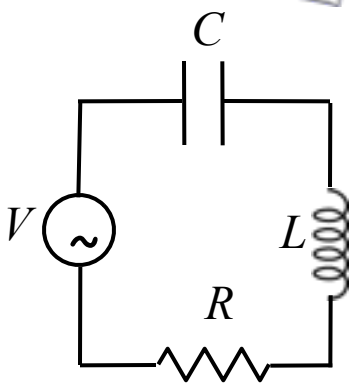
$V_{Cmax} = 113$ V

The current leads generator voltage by 45^o

L and R are unknown.

What is X_L, the reactance of the inductor, at this frequency?



$Z = 50$ kΩ

$R = 35.4$kΩ

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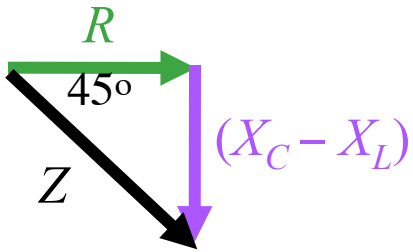
We start with the impedance triangle:



$$\frac{X_C - X_L}{R} = \tan 45° = 1 \quad \rightarrow \quad X_L = X_C - R$$

Calculation

Consider the harmonically driven series LCR circuit shown.

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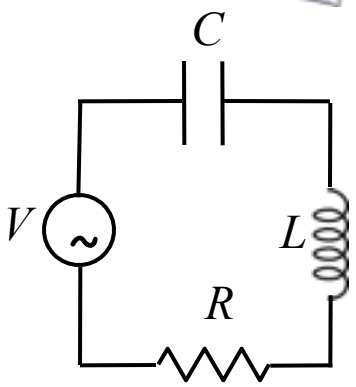
The current leads generator voltage by 45^o

L and R are unknown.

What is X_L, the reactance of the inductor, at this frequency?

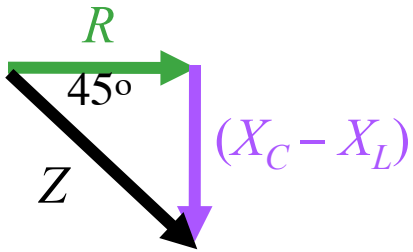


$Z = 50$ kΩ

$R = 35.4$kΩ

A) 70.7 kΩ B) 50 kΩ C) 35.4 kΩ D) 21.1 kΩ

We start with the impedance triangle:



$$\frac{X_C - X_L}{R} = \tan 45^\circ = 1 \quad \rightarrow \quad X_L = X_C - R$$

What is X_C?

Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

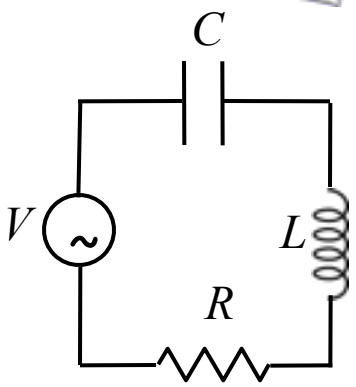
$I_{max} = 2$ mA

$V_{Cmax} = 113$ V

The current leads generator voltage by 45^o

L and R are unknown.

What is X_L, the reactance of the inductor, at this frequency?



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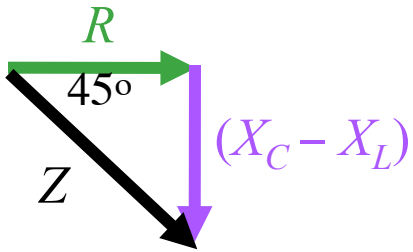

$$\frac{X_C - X_L}{R} = \tan 45^\circ = 1 \quad \rightarrow \quad X_L = X_C - R$$

What is X_C?

$V_{Cmax} = I_{max} X_C$

Calculation

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L and R are unknown.

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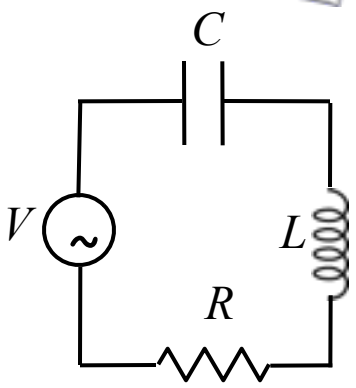
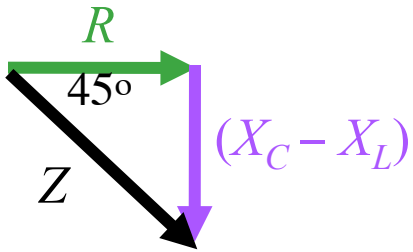


$Z = 50\ \text{k}\Omega$

$R = 35.4\text{k}\Omega$

A) $70.7\ \text{k}\Omega$ B) $50\ \text{k}\Omega$ C) $35.4\ \text{k}\Omega$ D) $21.1\ \text{k}\Omega$

We start with the impedance triangle:



$$\frac{X_C - X_L}{R} = \tan 45^\circ = 1 \rightarrow X_L = X_C - R$$

What is X_C?

$$V_{Cmax} = I_{max} X_C$$

$$X_C = \frac{113}{2} = 56.5k\Omega$$

Calculation

Consider the harmonically driven series LCR circuit shown.

$V_{max} = 100$ V

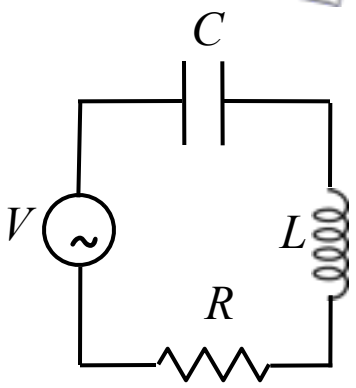
$I_{max} = 2$ mA

$V_{Cmax} = 113$ V

The current leads generator voltage by 45^o

L and R are unknown.

What is X_L, the reactance of the inductor, at this frequency?

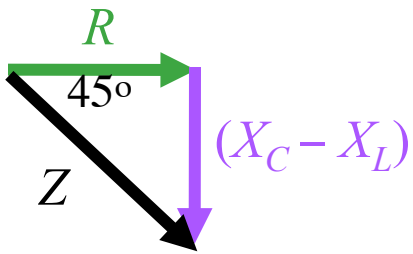


$Z = 50$ kΩ

$R = 35.4$kΩ

A) 70.7 kΩ B) 50 kΩ C) 35.4 kΩ D) 21.1 kΩ

We start with the impedance triangle:



$$\frac{X_C - X_L}{R} = \tan 45° = 1 \rightarrow X_L = X_C - R$$

What is X_C?

$$V_{Cmax} = I_{max} X_C$$

$$X_C = \frac{113}{2} = 56.5k\Omega$$

$$X_L = 56.5\ \text{k}\Omega - 35.4\ \text{k}\Omega$$

Calculation

Consider the harmonically driven series LCR circuit shown.

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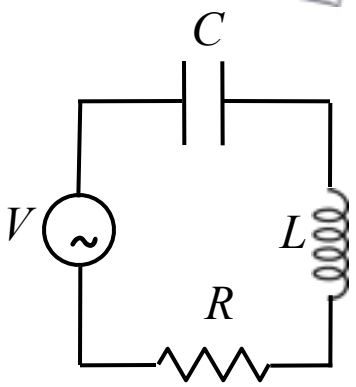
$I_{max} = 2$ mA

$V_{Cmax} = 113$ V

The current leads generator voltage by 45^o

L and R are unknown.

What is X_L, the reactance of the inductor, at this frequency?



$Z = 50\ \text{k}\Omega$

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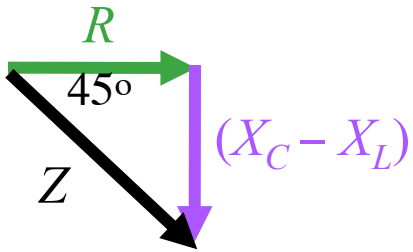
We start with the impedance triangle:



$$\frac{X_C - X_L}{R} = \tan 45^\circ = 1 \rightarrow X_L = X_C - R$$

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$$V_{Cmax} = I_{max} X_C$$

$$X_C = \frac{113}{2} = 56.5k\Omega$$

$$X_L = 56.5\ \text{k}\Omega - 35.4\ \text{k}\Omega$$