

# Chapter 31

# Alternating Current

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*University Physics, Thirteenth Edition*  
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**Lectures by Wayne Anderson**

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## Goals for Chapter 31

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- To use phasors to describe sinusoidally varying quantities
- To use reactance to describe voltage in a circuit
- To analyze an  $L$ - $R$ - $C$  series circuit
- To determine power in ac circuits
- To see how an  $L$ - $R$ - $C$  circuit responds to frequency
- To learn how transformers work

# Introduction

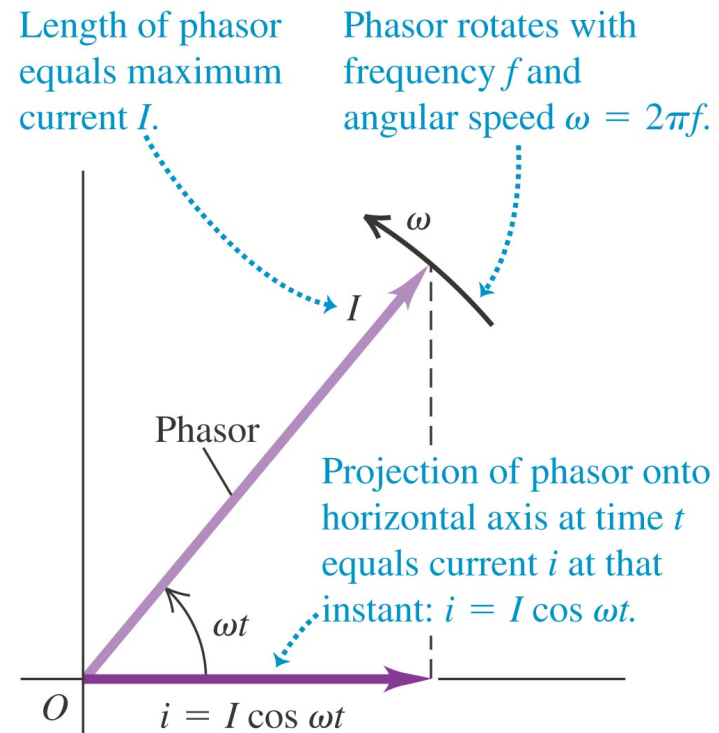
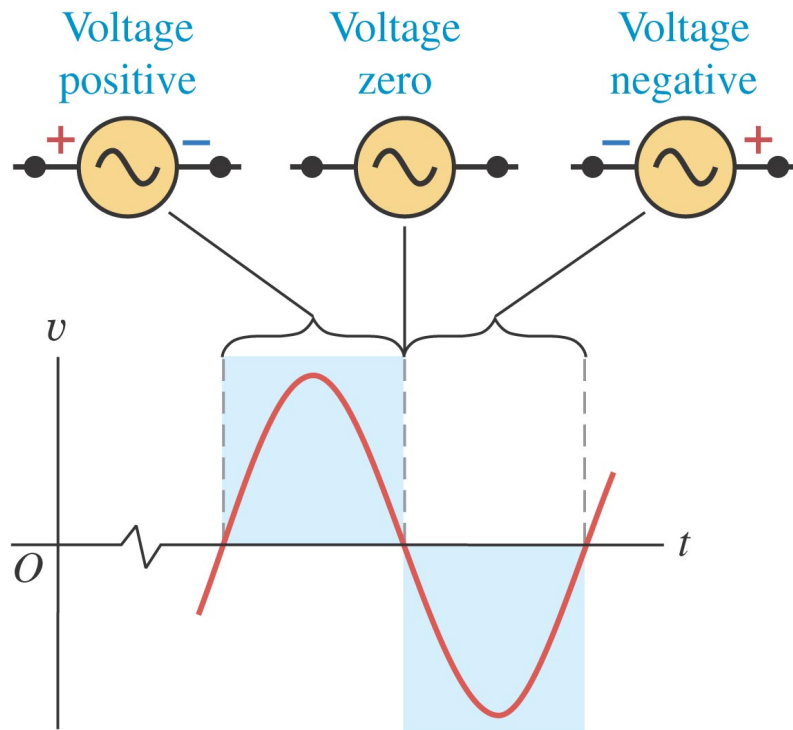
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- How does a radio tune to a particular station?
- How are ac circuits different from dc circuits?
- We shall see how resistors, capacitors, and inductors behave with a sinusoidally varying voltage source.



# Phasors and alternating currents

- Follow the text discussion of alternating current and phasors using Figures 31.1 (which shows ac voltage) and 31.2 (which shows a phasor diagram) below.

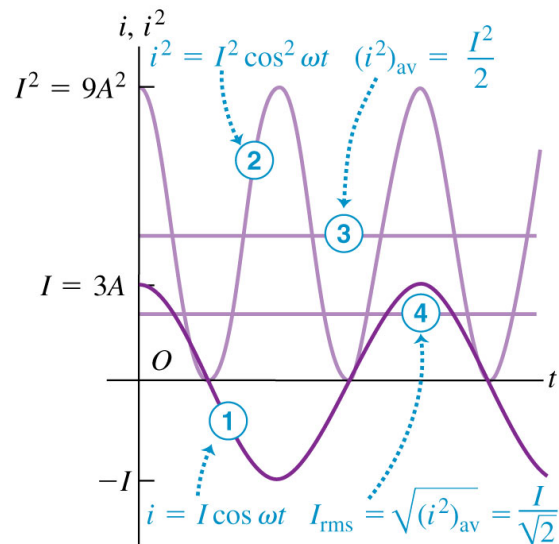


# Root-mean-square values

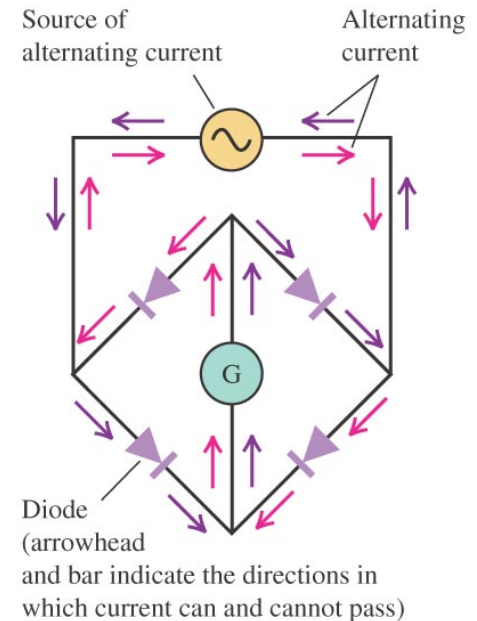
- Follow the text discussion of rectified alternating current, rms current, and rms voltage. Use Figures 31.3 (right) and 31.4 (below).

**Meaning of the rms value** of a sinusoidal quantity (here, ac current with  $I = 3\text{ A}$ ):

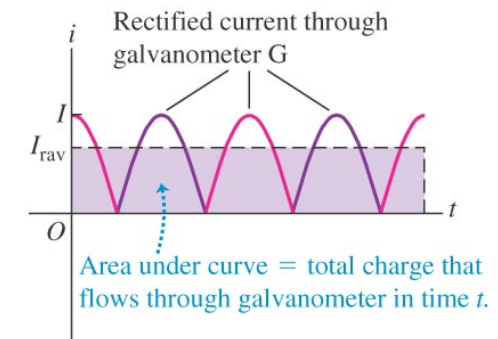
- Graph current  $i$  versus time.
- Square the instantaneous current  $i$ .
- Take the *average* (mean) value of  $i^2$ .
- Take the *square root* of that average.



(a) A full-wave rectifier circuit



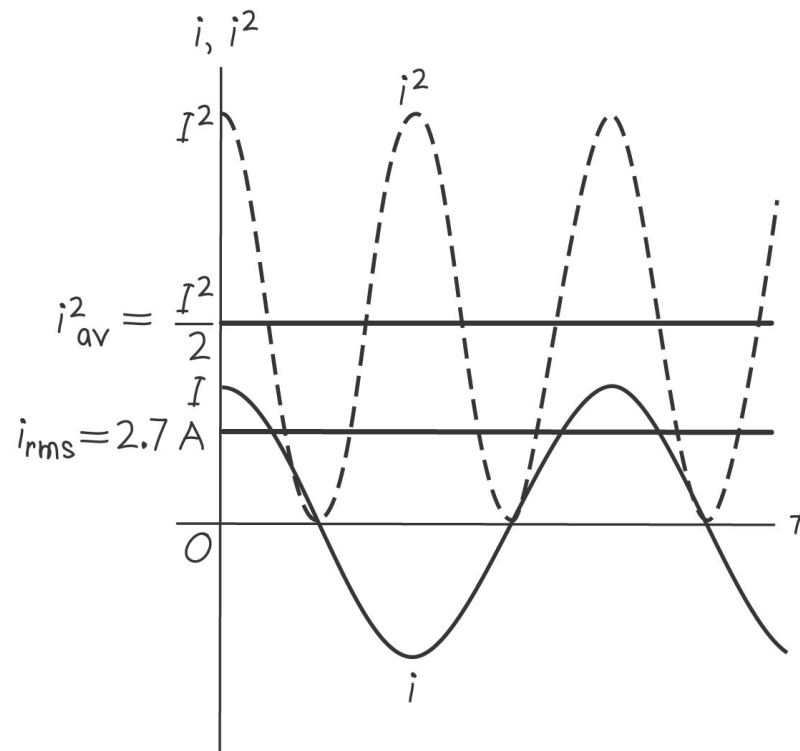
(b) Graph of the full-wave rectified current and its average value, the rectified average current  $I_{\text{rav}}$



# Current in a personal computer

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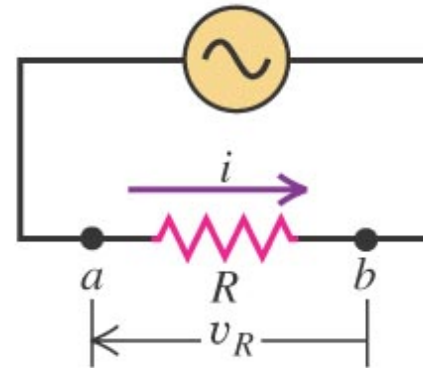
- Follow Example 31.1 using Figure 31.6 below.



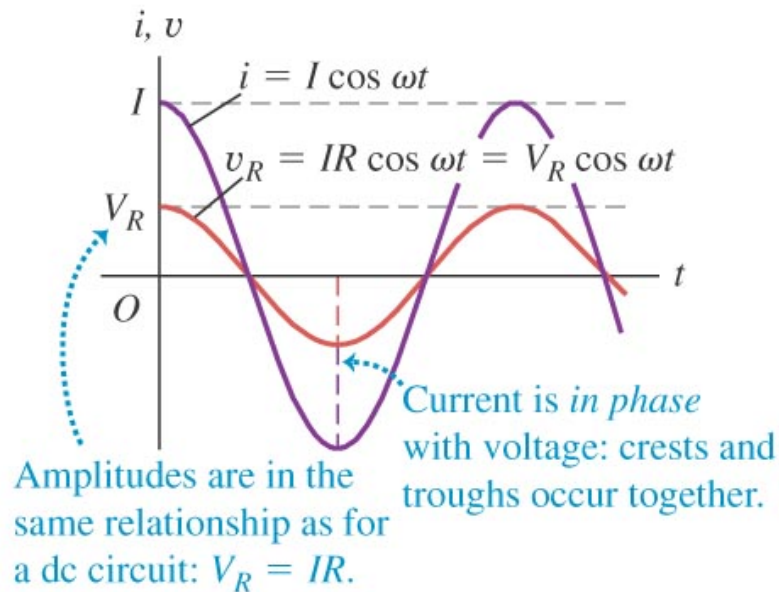
# Resistor in an ac circuit

- Ohm's Law gives the voltage amplitude across a resistor:  
 $V_R = IR$ .
- Figure 31.7 shows the circuit, the current and voltage as functions of time, and a phasor.

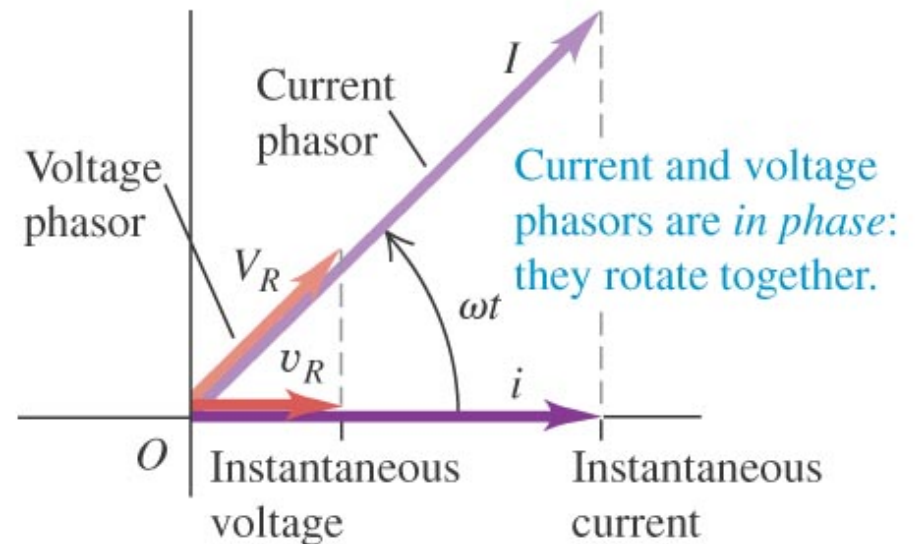
(a) Circuit with ac source and resistor



(b) Graphs of current and voltage versus time



(c) Phasor diagram

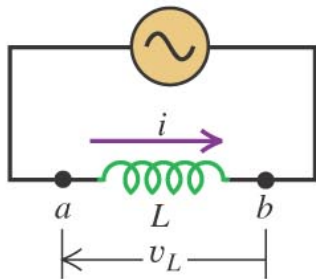




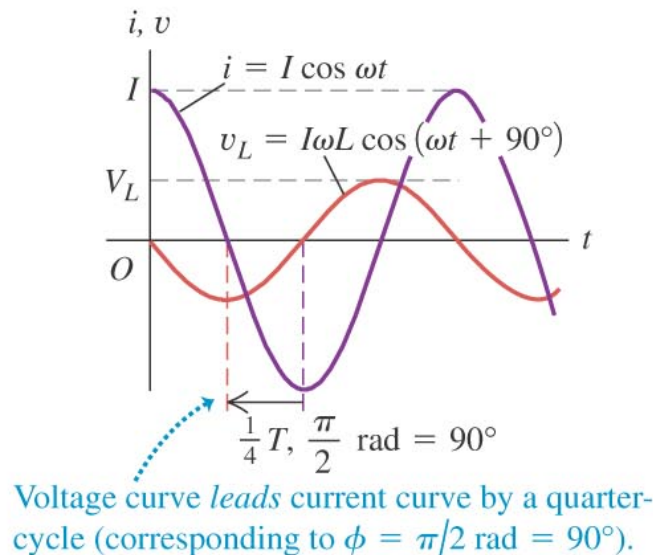
# Inductor in an ac circuit

- Follow the text analysis of an inductor in an ac circuit using Figure 31.8 below. The voltage amplitude across the inductor is  $V_L = IX_L$ .
- Follow Example 31.2.

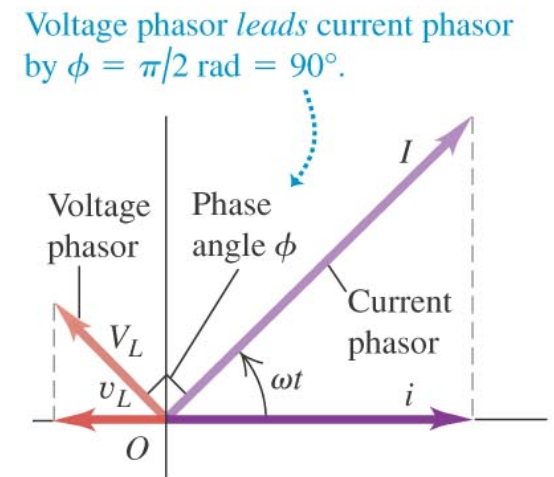
(a) Circuit with ac source and inductor



(b) Graphs of current and voltage versus time



(c) Phasor diagram

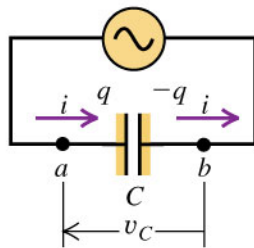




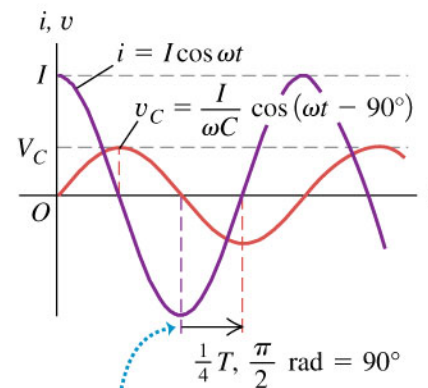
# Capacitance in an ac circuit

- Follow the text analysis of a capacitor in an ac circuit using Figure 31.9 below. The voltage amplitude across the capacitor is  $V_C = IX_C$ .

(a) Circuit with ac source and capacitor

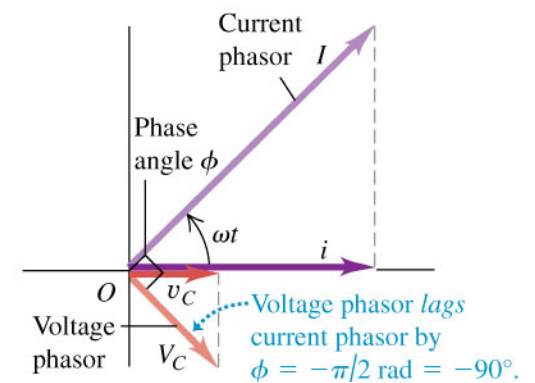


(b) Graphs of current and voltage versus time



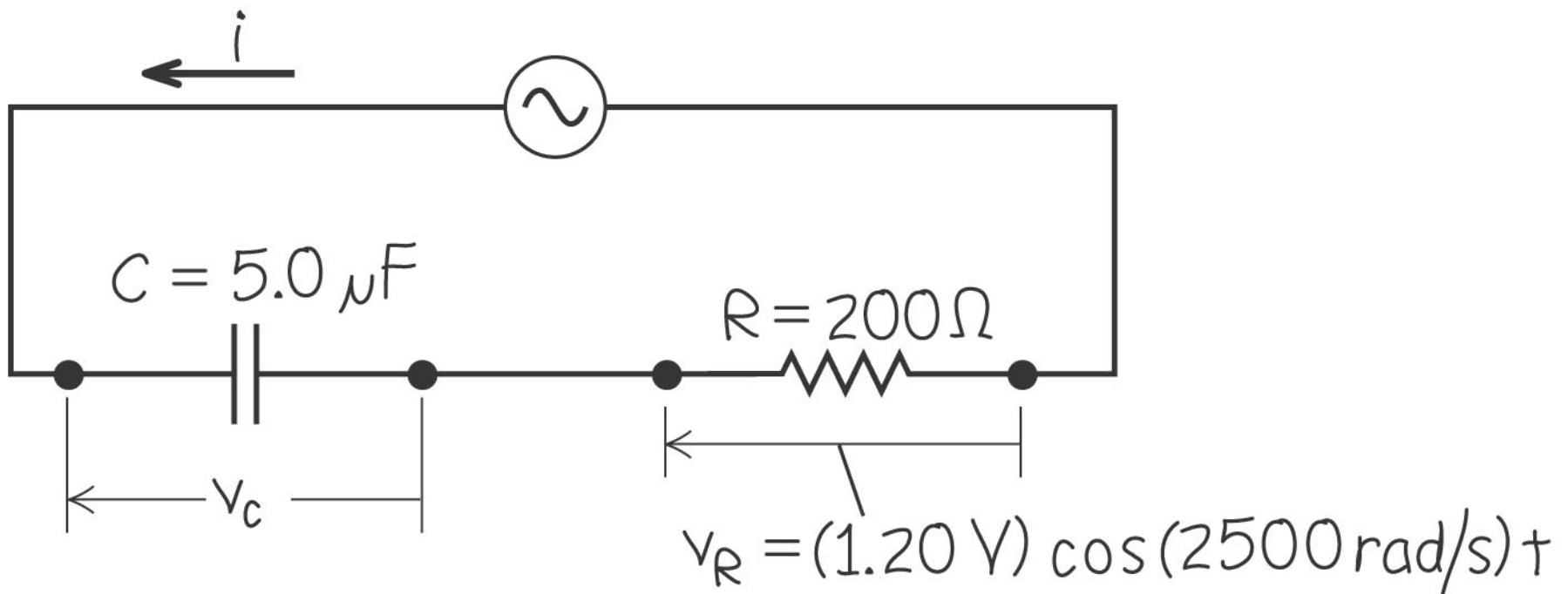
Voltage curve lags current curve by a quarter-cycle (corresponding to  $\phi = -\pi/2 \text{ rad} = -90^\circ$ ).

(c) Phasor diagram



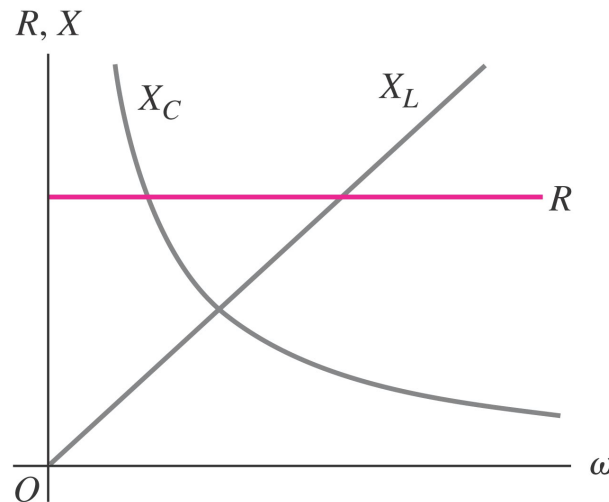
## A resistor and a capacitor in an ac circuit

- Follow Example 31.3, which combines a resistor and a capacitor in an ac circuit. Refer to Figure 31.10 below.



## Comparing ac circuit elements

- Table 31.1 summarizes the characteristics of a resistor, an inductor, and a capacitor in an ac circuit.
- Figure 31.11 (below) shows graphs of resistance and reactance.



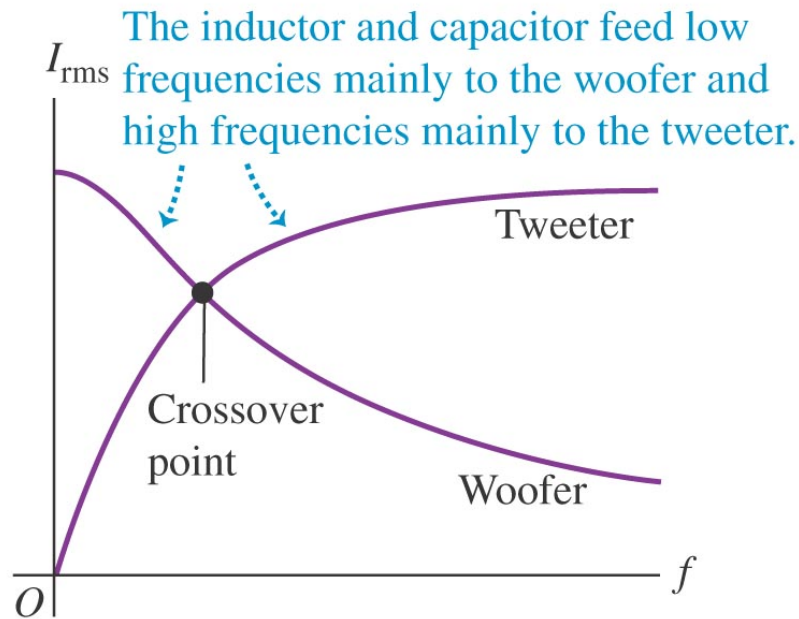
**Table 31.1** Circuit Elements with Alternating Current

Circuit Element	Amplitude Relationship	Circuit Quantity	Phase of $v$
Resistor	$V_R = IR$	$R$	In phase with $i$
Inductor	$V_L = IX_L$	$X_L = \omega L$	Leads $i$ by $90^\circ$
Capacitor	$V_C = IX_C$	$X_C = 1/\omega C$	Lags $i$ by $90^\circ$

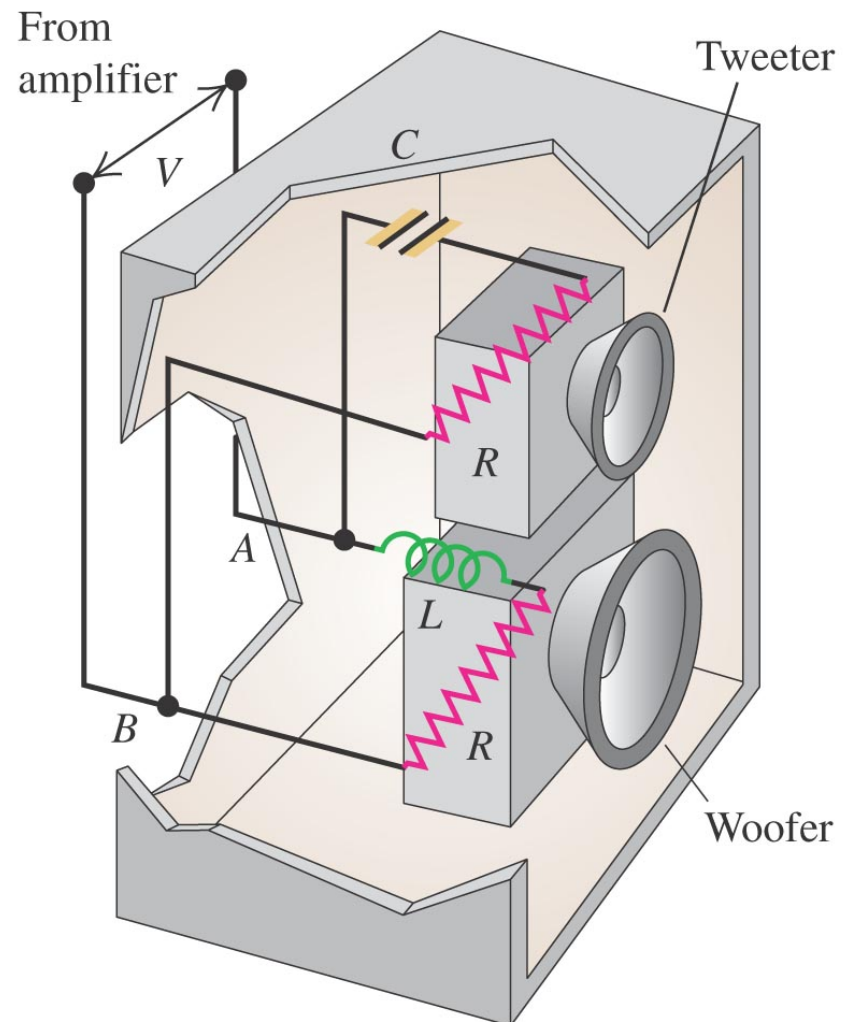
# A useful application: the loudspeaker

- The woofer (low tones) and the tweeter (high tones) are connected in parallel across the amplifier output. (See Figure 31.12 shown here.)

Graphs of rms current as functions of frequency for a given amplifier voltage



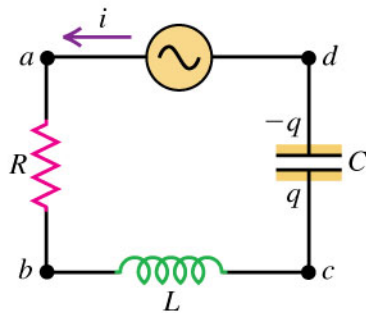
A crossover network in a loudspeaker system



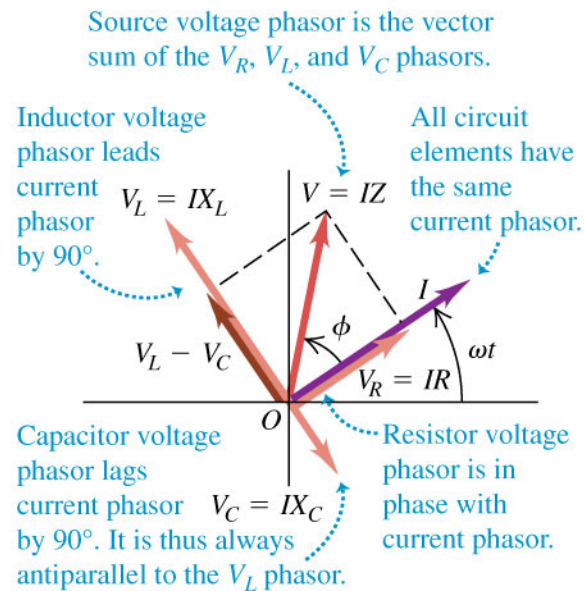
# The $L$ - $R$ - $C$ series circuit

- Follow the text analysis of the  $L$ - $R$ - $C$  series circuit, including impedance and phase angle, using Figure 31.13 below.
- The voltage amplitude across an ac circuit is  $V = IZ$ .

(a)  $L$ - $R$ - $C$  series circuit

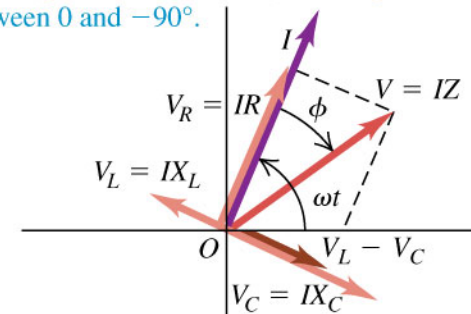


(b) Phasor diagram for the case  $X_L > X_C$



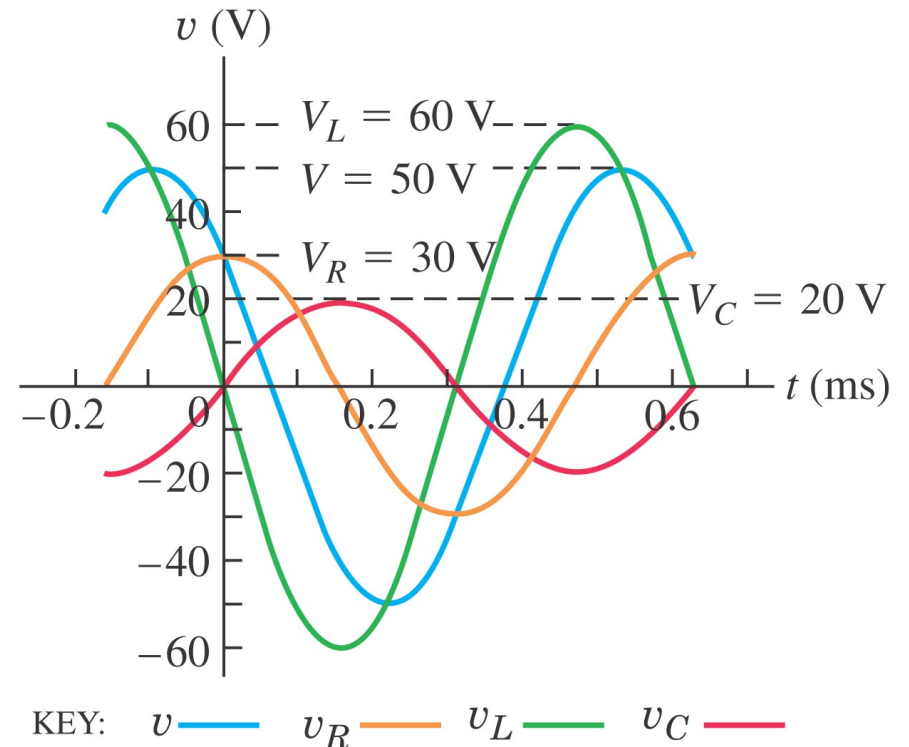
(c) Phasor diagram for the case  $X_L < X_C$

If  $X_L < X_C$ , the source voltage phasor lags the current phasor,  $X < 0$ , and  $\phi$  is a negative angle between  $0$  and  $-90^\circ$ .



## An $L$ - $R$ - $C$ series circuit

- Read Problem-Solving Strategy 31.1.
- Follow Example 31.4.
- Follow Example 31.5 using Figure 31.15 at the right.

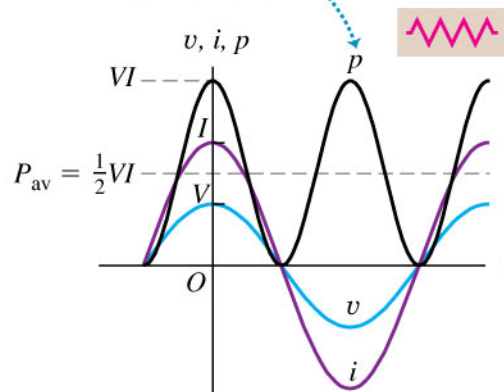


# Power in ac circuits

- Follow the text discussion of power in alternating-current circuits using Figure 31.16 below.
- Note that the net energy transfer over one cycle is zero for an inductor and a capacitor.
- Follow Example 31.6 and Example 31.7.

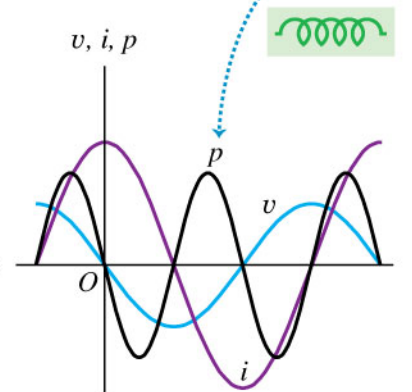
(a) Pure resistor

For a resistor,  $p = vi$  is always positive because  $v$  and  $i$  are either both positive or both negative at any instant.

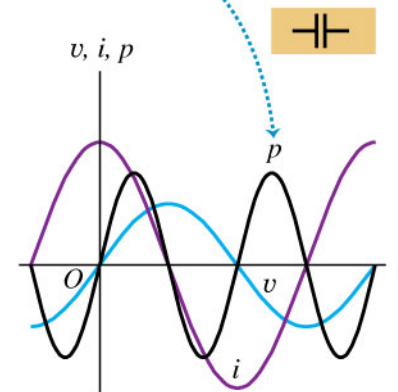


(b) Pure inductor

For an inductor or capacitor,  $p = vi$  is alternately positive and negative, and the average power is zero.

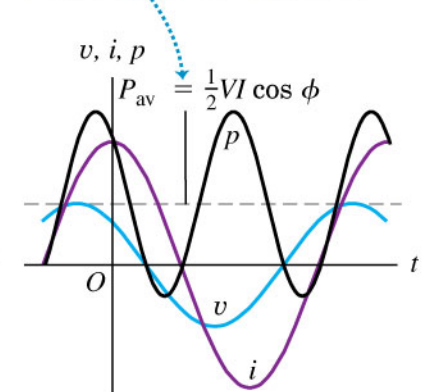


(c) Pure capacitor



(d) Arbitrary ac circuit

For an arbitrary combination of resistors, inductors, and capacitors, the average power is positive.



KEY: Instantaneous current,  $i$  —

Instantaneous voltage across device,  $v$  —

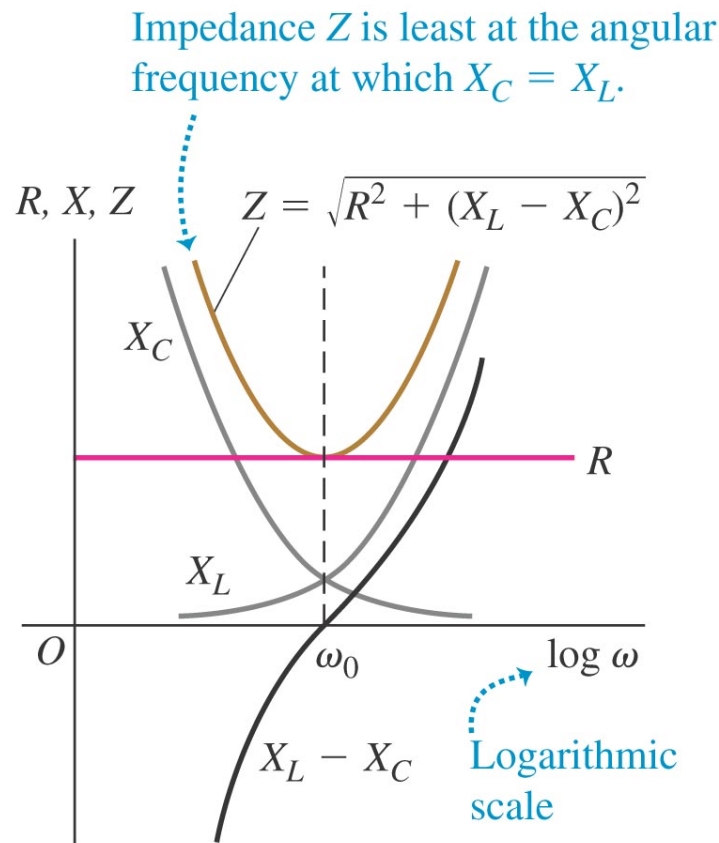
Instantaneous power input to device,  $p$  —



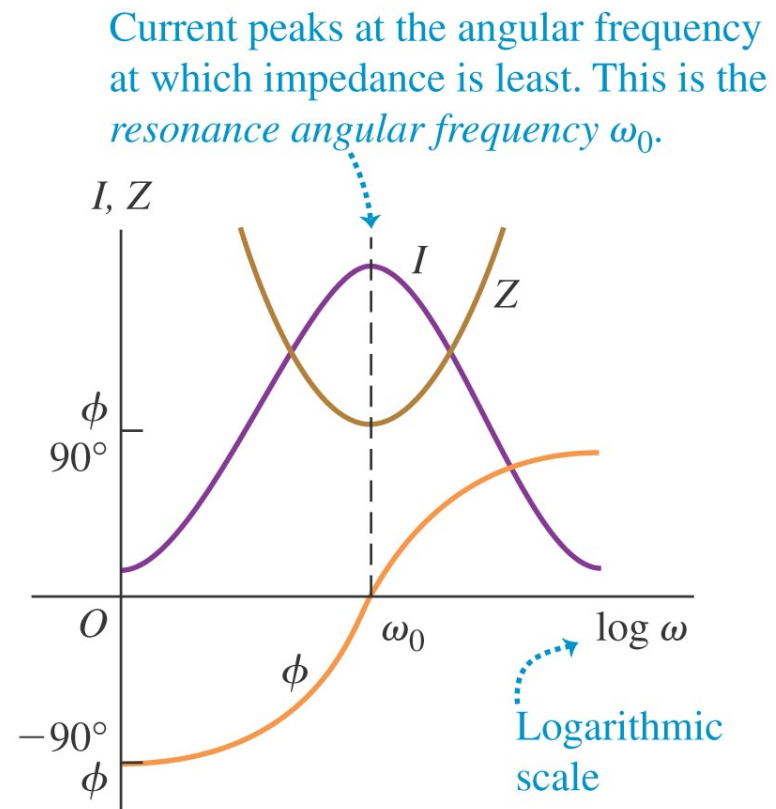
# Resonance in ac circuits

- At the *resonance angular frequency*  $\omega_0$ , the inductive reactance equals the capacitive reactance and the current amplitude is greatest. (See Figure 31.18 below.)

Reactance, resistance, and impedance as functions of angular frequency

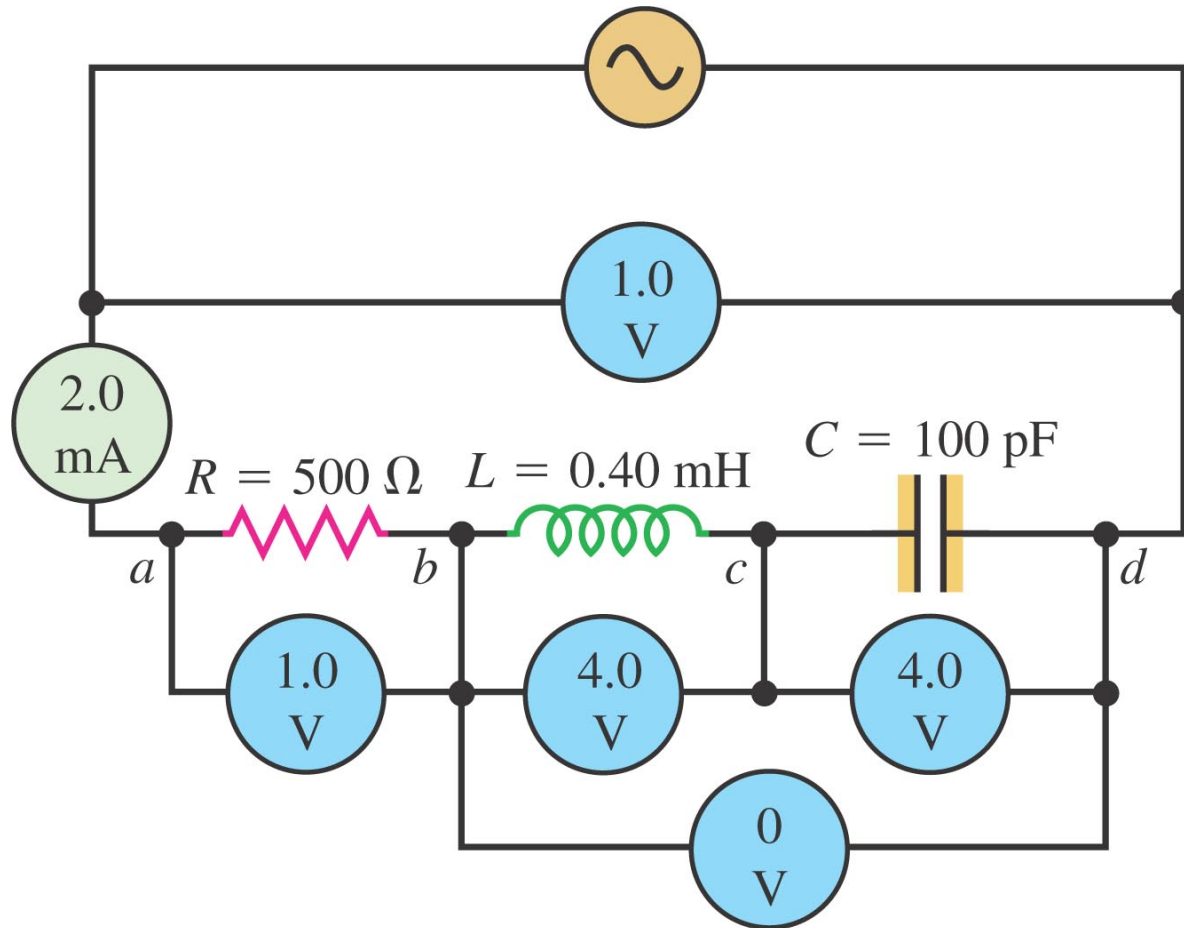


Impedance, current, and phase angle as functions of angular frequency



# Tuning a radio

- Follow Example 31.8 using Figure 31.20 below.

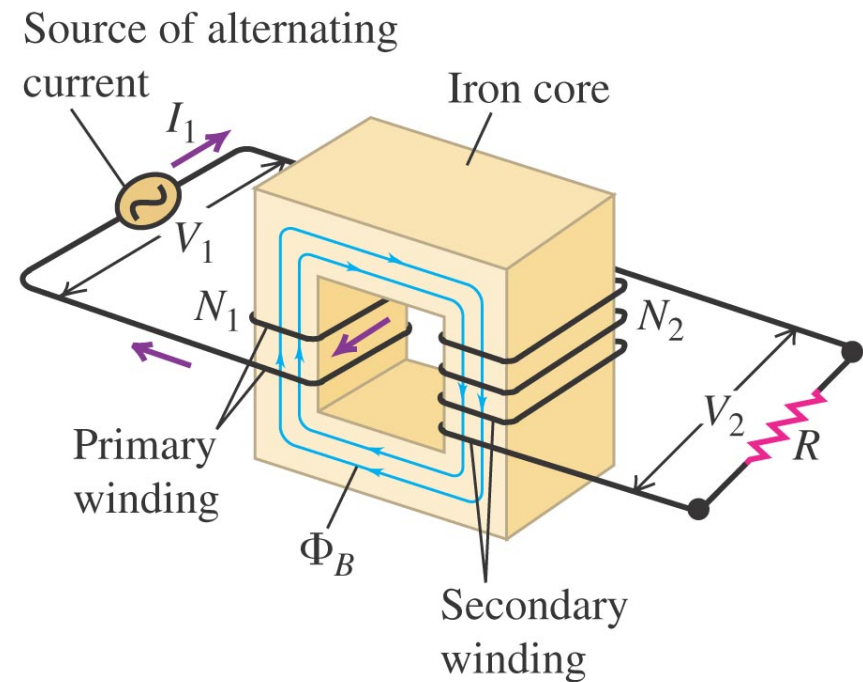


# Transformers

- Power is supplied to the *primary* and delivered from the *secondary*. See Figure 31.21 at the right.
- Terminal voltages:  
 $V_2/V_1 = N_2/N_1$ .
- Currents in primary and secondary:  
 $V_1 I_1 = V_2 I_2$ .

The induced emf *per turn* is the same in both coils, so we adjust the ratio of terminal voltages by adjusting the ratio of turns:

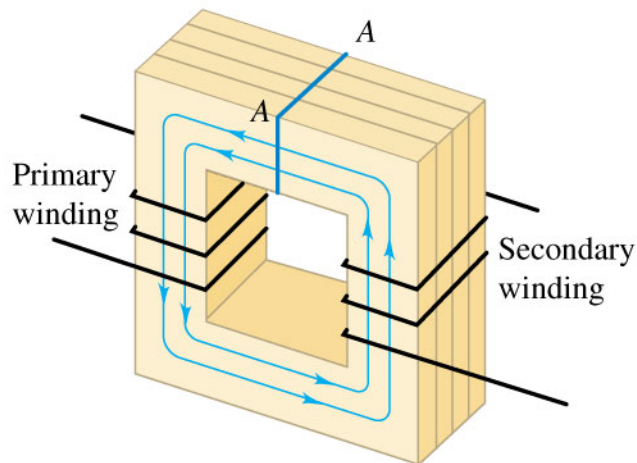
$$\frac{V_2}{V_1} = \frac{N_2}{N_1}$$



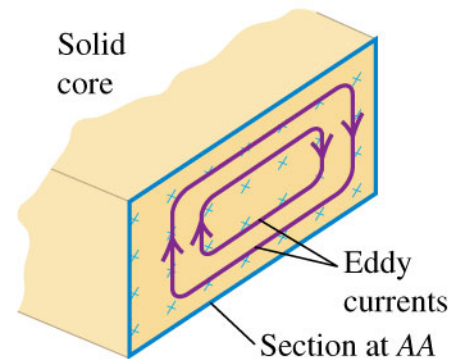
# Real transformers

- Real transformers always have some power losses, as illustrated in Figure 31.24 below.
- Follow Example 31.9.

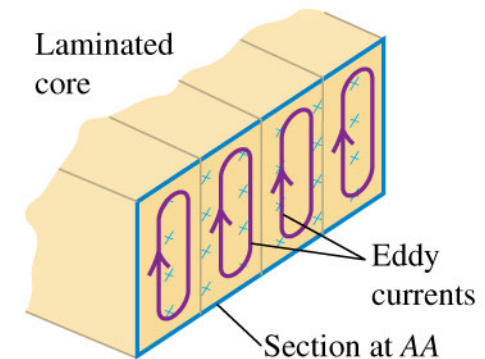
(a) Schematic transformer



(b) Large eddy currents in solid core



(c) Smaller eddy currents in laminated core

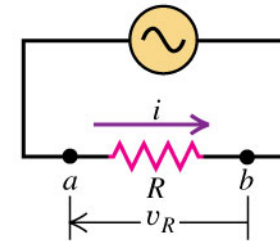




## Q31.1

A resistor is connected across an ac source as shown. For this circuit, what is the relationship between the instantaneous current  $i$  through the resistor and the instantaneous voltage  $v_{ab}$  across the resistor?

(a) Circuit with ac source and resistor



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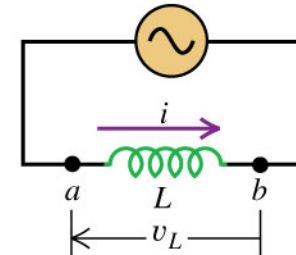
- A.  $i$  is maximum at the same time as  $v_{ab}$ .
- B.  $i$  is maximum one-quarter cycle before  $v_{ab}$ .
- C.  $i$  is maximum one-quarter cycle after  $v_{ab}$ .
- D. not enough information given to decide



## Q31.2

An inductor is connected across an ac source as shown. For this circuit, what is the relationship between the instantaneous current  $i$  through the inductor and the instantaneous voltage  $V_{ab}$  across the inductor?

(a) Circuit with ac source and inductor



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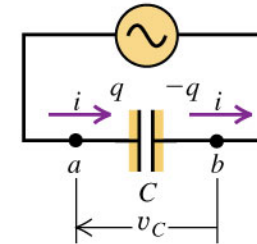
- A.  $i$  is maximum at the same time as  $V_{ab}$ .
- B.  $i$  is maximum one-quarter cycle before  $V_{ab}$ .
- C.  $i$  is maximum one-quarter cycle after  $V_{ab}$ .
- D. not enough information given to decide



### Q31.3

A capacitor is connected across an ac source as shown. For this circuit, what is the relationship between the instantaneous current  $i$  through the capacitor and the instantaneous voltage  $v_{ab}$  across the capacitor?

(a) Circuit with ac source and capacitor



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- A.  $i$  is maximum at the same time as  $v_{ab}$ .
- B.  $i$  is maximum one-quarter cycle before  $v_{ab}$ .
- C.  $i$  is maximum one-quarter cycle after  $v_{ab}$ .
- D. not enough information given to decide

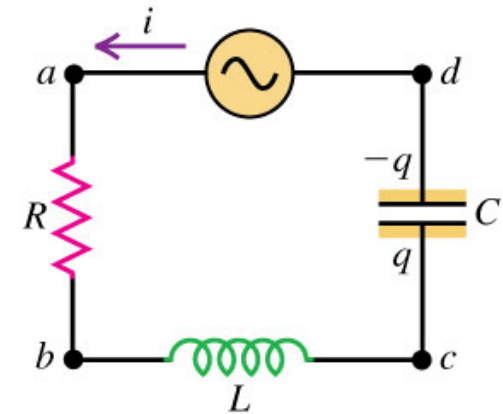




## Q31.4

An  $L$ - $R$ - $C$  series circuit as shown is operating at its resonant frequency. At this frequency, how are the values of the capacitive reactance  $X_C$ , the inductive reactance  $X_L$ , and the resistance  $R$  related to each other?

(a)  $L$ - $R$ - $C$  series circuit



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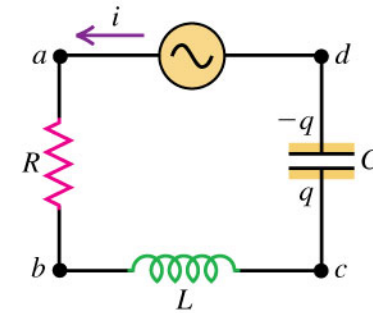
- A.  $X_L = R$ ;  $X_C$  can have any value.
- B.  $X_C = R$ ;  $X_L$  can have any value.
- C.  $X_C = X_L$ ;  $R$  can have any value.
- D.  $X_C = X_L = R$
- E. none of the above



## Q31.5

In an  $L$ - $R$ - $C$  series circuit as shown, the current has a very small amplitude if the ac source oscillates at a very high frequency. Which circuit element causes this behavior?

(a)  $L$ - $R$ - $C$  series circuit



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- A. the resistor  $R$
- B. the inductor  $L$
- C. the capacitor  $C$
- D. Misleading question—the current actually has a very *large* amplitude if the frequency is very high.

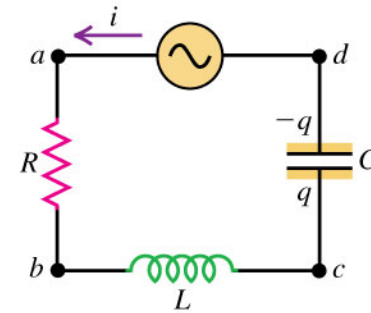


## Q31.6

In an  $L$ - $R$ - $C$  series circuit as shown, there is a phase angle between the instantaneous current through the circuit and the instantaneous voltage  $v_{ad}$  across the entire circuit. For what value of the phase angle is the *greatest* power delivered to the resistor?

- A. zero
- B.  $90^\circ$
- C.  $180^\circ$
- D.  $270^\circ$
- E. none of the above

(a)  $L$ - $R$ - $C$  series circuit



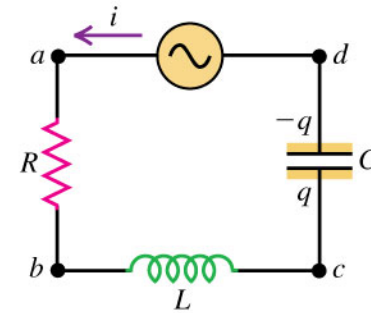
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## Q31.7

In an  $L$ - $R$ - $C$  series circuit as shown, suppose that the angular frequency of the ac source equals the resonance angular frequency. In this case, the circuit impedance

(a)  $L$ - $R$ - $C$  series circuit



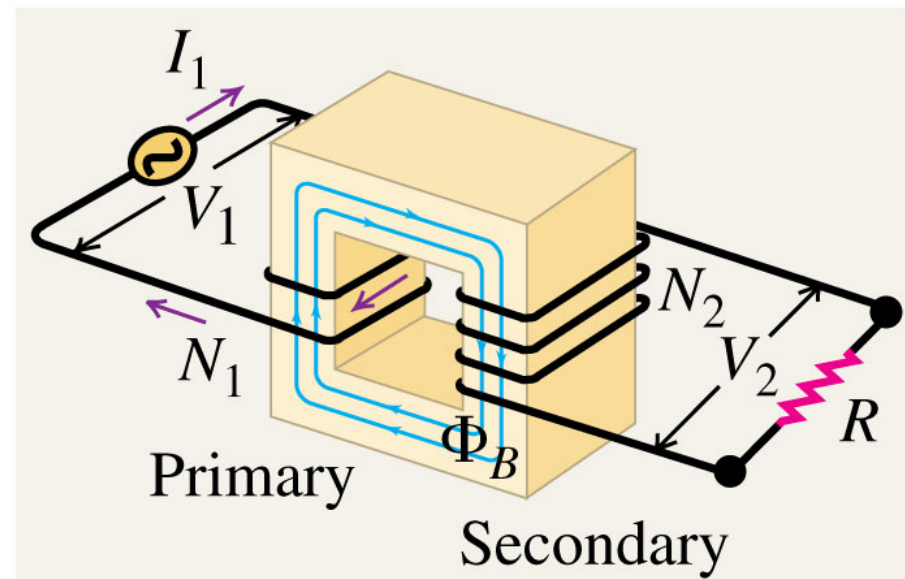
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- A. is maximum.
- B. is minimum, but not zero.
- C. is zero.
- D. is neither a maximum nor a minimum.
- E. not enough information give to decide



## Q31.8

In the transformer shown in the drawing, there are more turns in the secondary than in the primary. In this situation, the *voltage amplitude* is



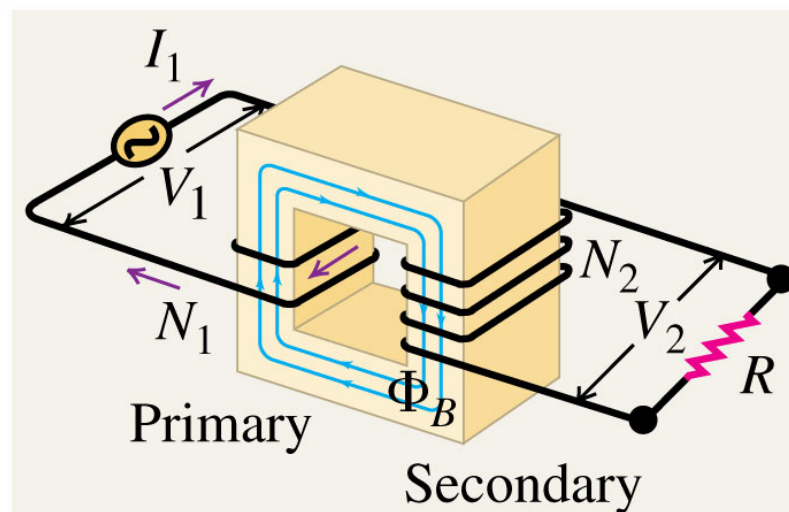
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- A. greater in the primary than in the secondary.
- B. smaller in the primary than in the secondary.
- C. the same in the primary and in the secondary.
- D. not enough information given to decide

## Q31.9



In the transformer shown in the drawing, there are more turns in the secondary than in the primary. In this situation, the *current amplitude* is



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- A. greater in the primary than in the secondary.
- B. smaller in the primary than in the secondary.
- C. the same in the primary and in the secondary.
- D. not enough information given to decide