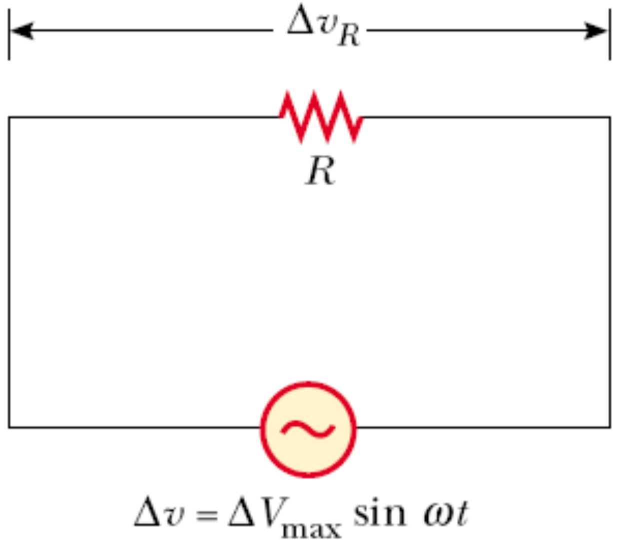
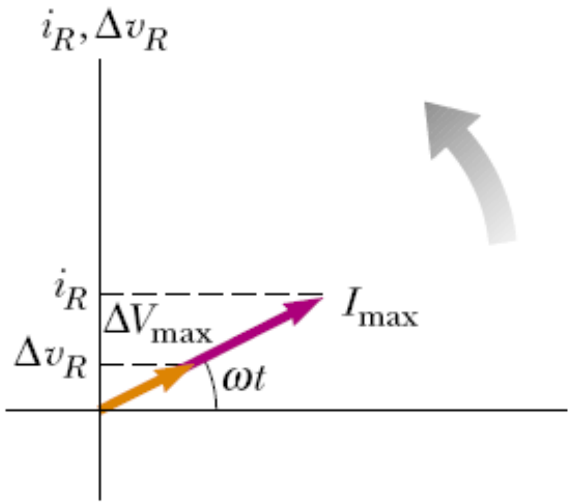
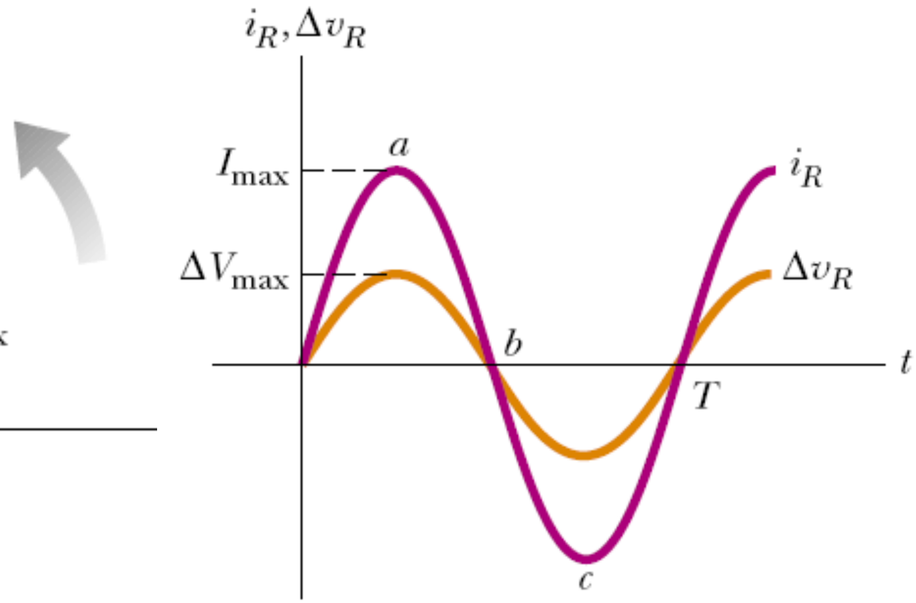
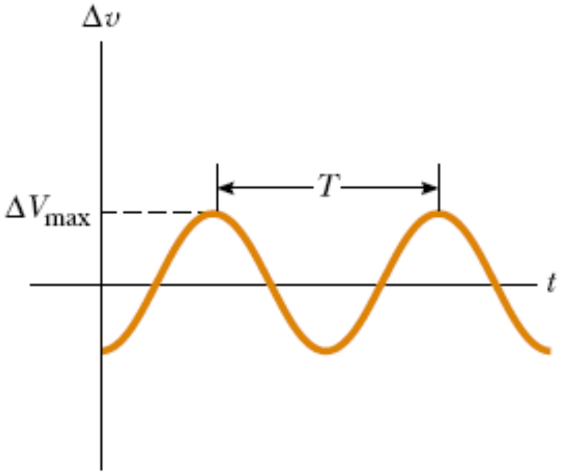
Alternating Current Circuits

CHAPTER OUTLINE









$$i_R = \frac{\Delta v_R}{R} = \frac{\Delta V_{max}}{R} \sin \omega t = I_{max} \sin \omega t$$

$$\Delta v = \Delta V_{max} \sin \omega t$$

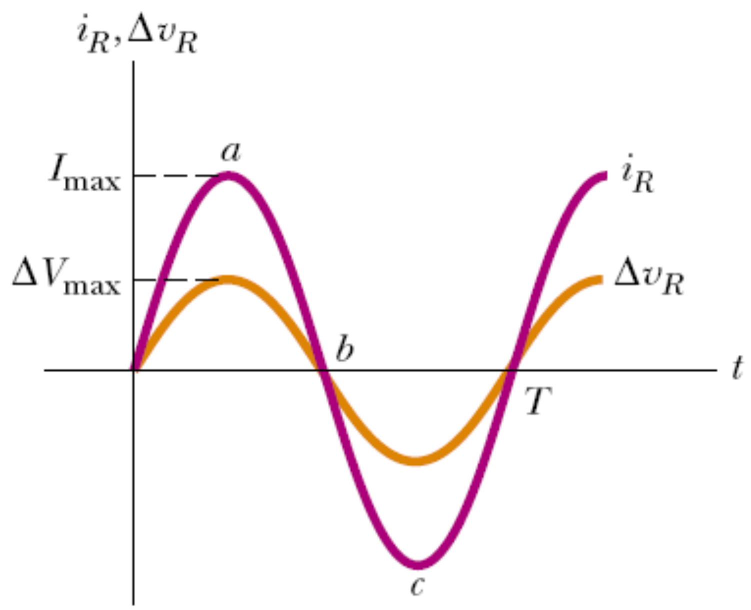
$$I_{max} = \frac{\Delta V_{max}}{R}$$

$$\omega = 2\pi f = \frac{2\pi}{T}$$

$$\Delta v = \Delta v_R = \Delta V_{max} \sin \omega t$$

$$\Delta v_R = I_{max} R \sin \omega t$$

Thus, for a sinusoidal applied voltage, the current in a resistor is always in phase with the voltage across the resistor.



For resistors in AC circuits, there are no new concepts to learn.

Resistors behave essentially the same way in both DC and AC circuits. This will not be the case for capacitors and inductors.

Quick Quiz 33.1 Consider the voltage phasor in Figure 33.4, shown at three instants of time. Choose the part of the figure that represents the instant of time at which the instantaneous value of the voltage has the largest magnitude.

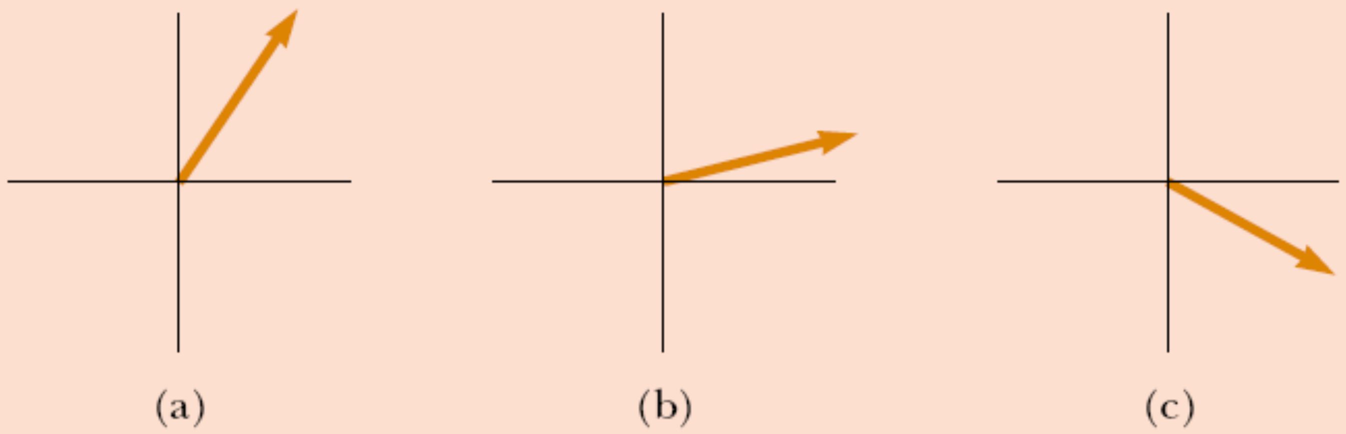


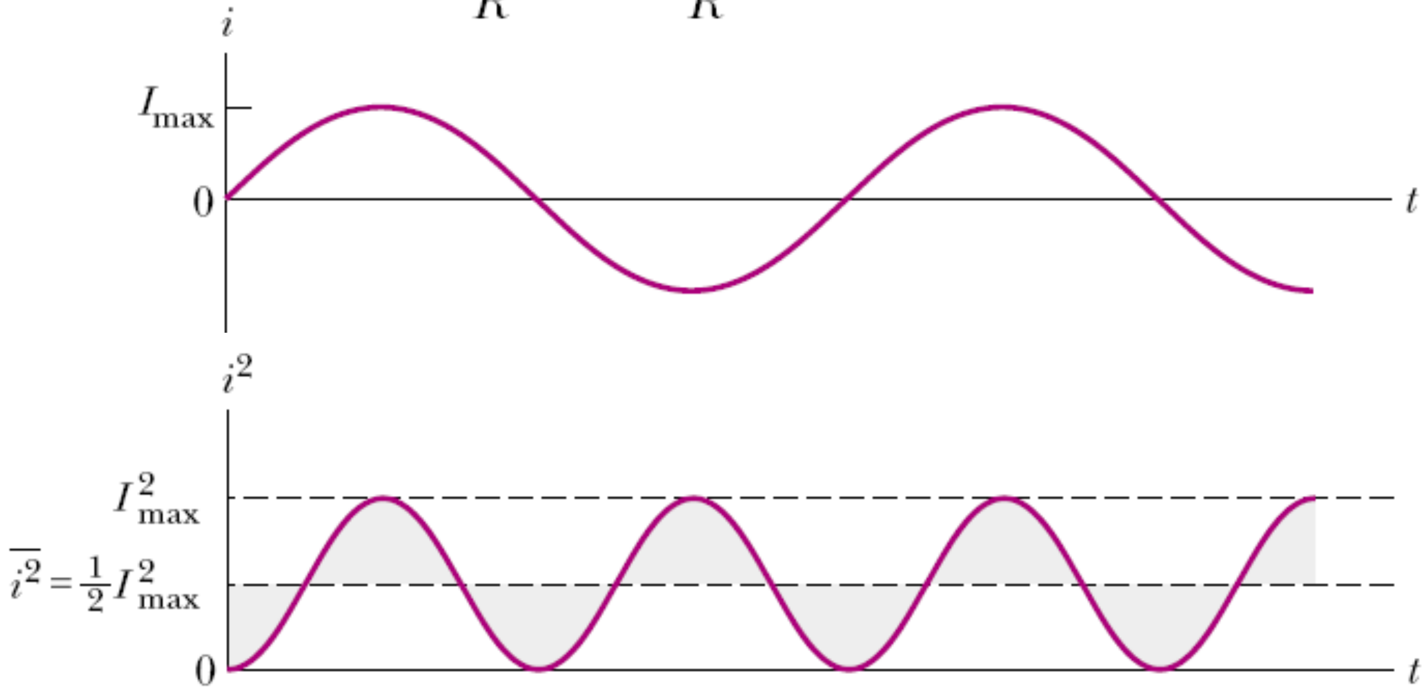
Figure 33.4 (Quick Quizzes 33.1 and 33.2) A voltage phasor is shown at three instants of time.

(a). The phasor in part (a) has the largest projection onto the vertical axis.

Quick Quiz 33.2 For the voltage phasor in Figure 33.4, choose the part of the figure that represents the instant of time at which the instantaneous value of the voltage has the smallest magnitude.

(b). The phasor in part (b) has the smallest-magnitude projection onto the vertical axis.

$$i_R = \frac{\Delta v_R}{R} = \frac{\Delta V_{\max}}{R} \sin \omega t = I_{\max} \sin \omega t$$



(b)

root-mean-square

$$I_{\text{rms}} = \sqrt{\overline{i^2}}$$

$$(\sin^2 \omega t)_{\text{av}} = (\cos^2 \omega t)_{\text{av}}$$

$$\mathscr{P}_{\text{av}} = I^2_{\text{rms}} R$$

$$\boxed{I_{\text{rms}} = \frac{I_{\max}}{\sqrt{2}} = 0.707 I_{\max}}$$

$$(\sin^2 \omega t)_{\text{av}} + (\cos^2 \omega t)_{\text{av}} = 2(\sin^2 \omega t)_{\text{av}} = 1$$

$$(\sin^2 \omega t)_{\text{av}} = \frac{1}{2}$$

$$\boxed{\Delta V_{\text{rms}} = \frac{\Delta V_{\max}}{\sqrt{2}} = 0.707\, \Delta V_{\max}}$$

Quick Quiz 33.3 Which of the following statements might be true for a resistor connected to a sinusoidal AC source? (a) $\mathcal{P}_{av} = 0$ and $i_{av} = 0$ (b) $\mathcal{P}_{av} = 0$ and $i_{av} > 0$ (c) $\mathcal{P}_{av} > 0$ and $i_{av} = 0$ (d) $\mathcal{P}_{av} > 0$ and $i_{av} > 0$.

(c). The average power is proportional to the rms current, which, as Figure 33.5 shows, is nonzero even though the average current is zero. Condition (a) is valid only for an open circuit, and conditions (b) and (d) can not be true because $i_{av} = 0$ if the source is sinusoidal.

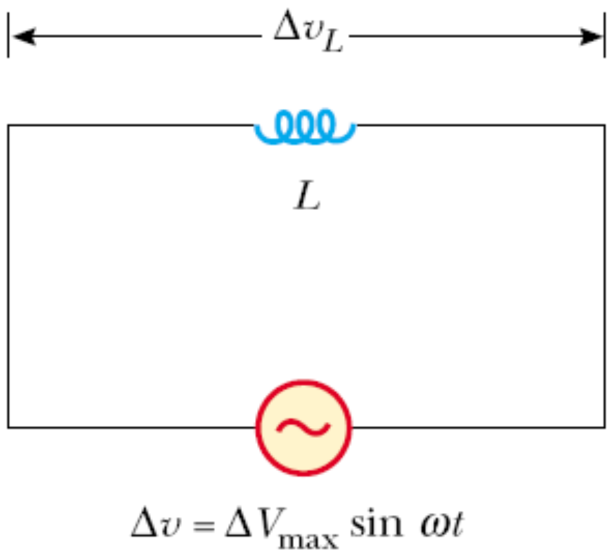
Example 33.1 What Is the rms Current?

The voltage output of an AC source is given by the expression $\Delta v = (200\text{ V})\sin \omega t$. Find the rms current in the circuit when this source is connected to a 100-Ω resistor.

$$\Delta V_{\text{rms}} = \frac{\Delta V_{\text{max}}}{\sqrt{2}} = \frac{200\text{ V}}{\sqrt{2}} = 141\text{ V}$$

$$I_{\text{rms}} = \frac{\Delta V_{\text{rms}}}{R} = \frac{141\text{ V}}{100\ \Omega} = \boxed{1.41\text{ A}}$$

Inductors in an AC Circuit

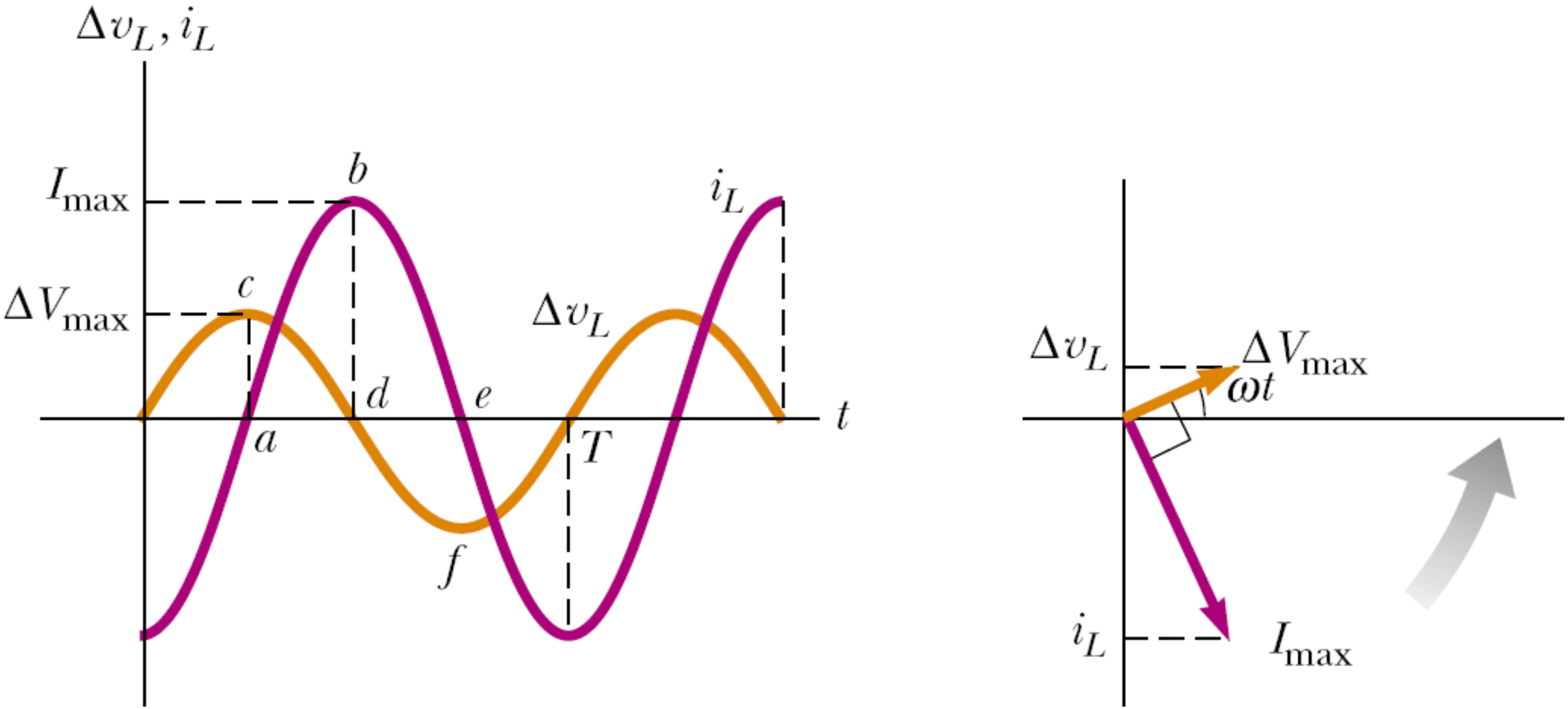


$$\Delta v - L \frac{di}{dt} = 0$$

$$\Delta v = L \frac{di}{dt} = \Delta V_{\max} \sin \omega t$$

$$di = \frac{\Delta V_{\max}}{L} \sin \omega t \, dt$$

$$i_L = \frac{\Delta V_{\max}}{L} \int \sin \omega t \, dt = -\frac{\Delta V_{\max}}{\omega L} \cos \omega t$$



$$i_L = \frac{\Delta V_{max}}{\omega L} \sin\left(\omega t - \frac{\pi}{2}\right)$$

for a sinusoidal applied voltage, the current in an inductor always lags behind the voltage across the inductor by 90° (one-quarter cycle in time).

$$I_{\max} = \frac{\Delta V_{\max}}{\omega L}$$

This looks similar to the relationship between current, voltage, and resistance in a DC circuit, $I = \Delta V/R$ (Eq. 27.8). In fact, because $I_{\max}$ has units of amperes and $\Delta V_{\max}$ has units of volts, ωL must have units of ohms. Therefore, ωL has the same units as resistance and is related to current and voltage in the same way as resistance. It must behave in a manner similar to resistance, in the sense that it represents opposition to the flow of charge. Notice that because ωL depends on the applied frequency ω, the inductor *reacts* differently, in terms of offering resistance to current, for different

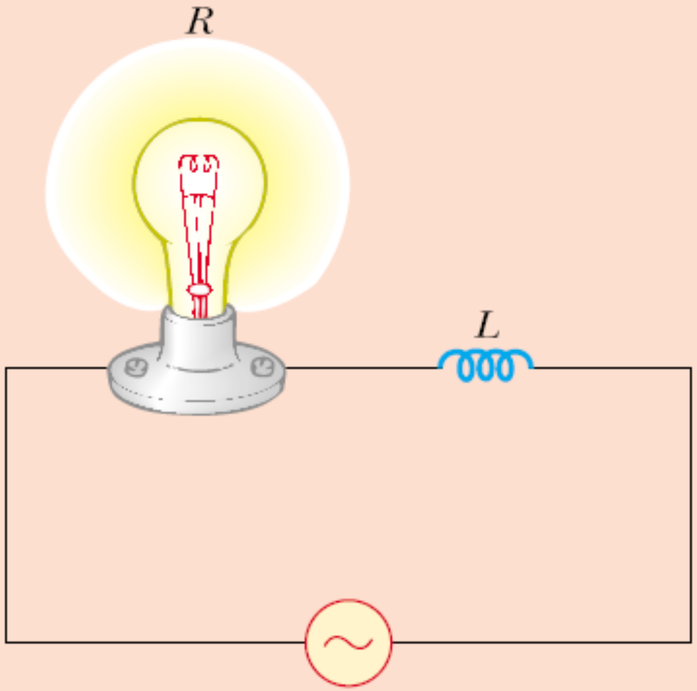
inductive reactance

$$\boxed{X_L \equiv \omega L}$$

$$\boxed{I_{\max} = \frac{\Delta V_{\max}}{X_L}}$$

$$\Delta v_L = -L\,\frac{di}{dt} = -\Delta V_{\max}\sin\omega t = -I_{\max}X_L\sin\omega t$$

Quick Quiz 33.4 Consider the AC circuit in Figure 33.8. The frequency of the AC source is adjusted while its voltage amplitude is held constant. The lightbulb will glow the brightest at (a) high frequencies (b) low frequencies (c) The brightness will be the same at all frequencies.



(b). For low frequencies, the reactance of the inductor is small so that the current is large. Most of the voltage from the source is across the bulb, so the power delivered to it is large.

Example 33.2 A Purely Inductive AC Circuit

In a purely inductive AC circuit (see Fig. 33.6), $L = 25.0$ mH and the rms voltage is 150 V. Calculate the inductive reactance and rms current in the circuit if the frequency is 60.0 Hz.

$$X_L = \omega L = 2\pi f L = 2\pi(60.0\ \text{Hz})(25.0 \times 10^{-3}\ \text{H})$$

$$= \boxed{9.42\ \Omega}$$

$$I_{\text{rms}} = \frac{\Delta V_{L,\text{rms}}}{X_L} = \frac{150\ \text{V}}{9.42\ \Omega} = \boxed{15.9\ \text{A}}$$

What If? **What if the frequency increases to 6.00 kHz? What happens to the rms current in the circuit?**

Answer If the frequency increases, the inductive reactance increases because the current is changing at a higher rate. The increase in inductive reactance results in a lower current.

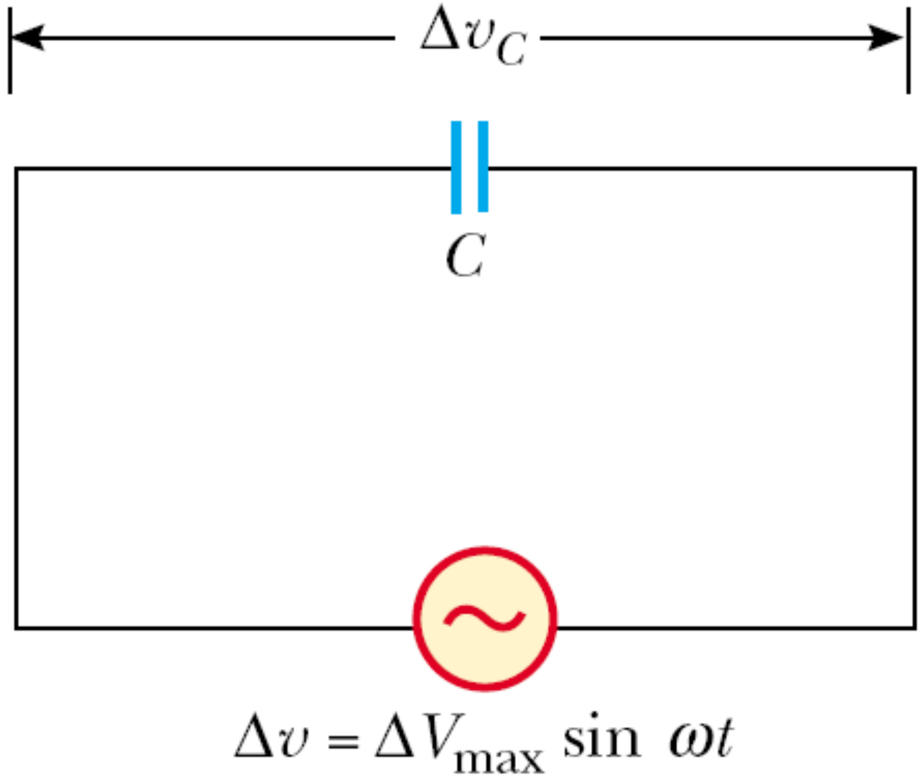
Let us calculate the new inductive reactance:

$$X_L = 2\pi(6.00 \times 10^3\ \text{Hz})(25.0 \times 10^{-3}\ \text{H}) = 942\ \Omega$$

The new current is

$$I_{\text{rms}} = \frac{150\ \text{V}}{942\ \Omega} = 0.159\ \text{A}$$

Capacitors in an AC Circuit



$$\Delta v = \Delta v_C = \Delta V_{max} \sin\ \omega t$$

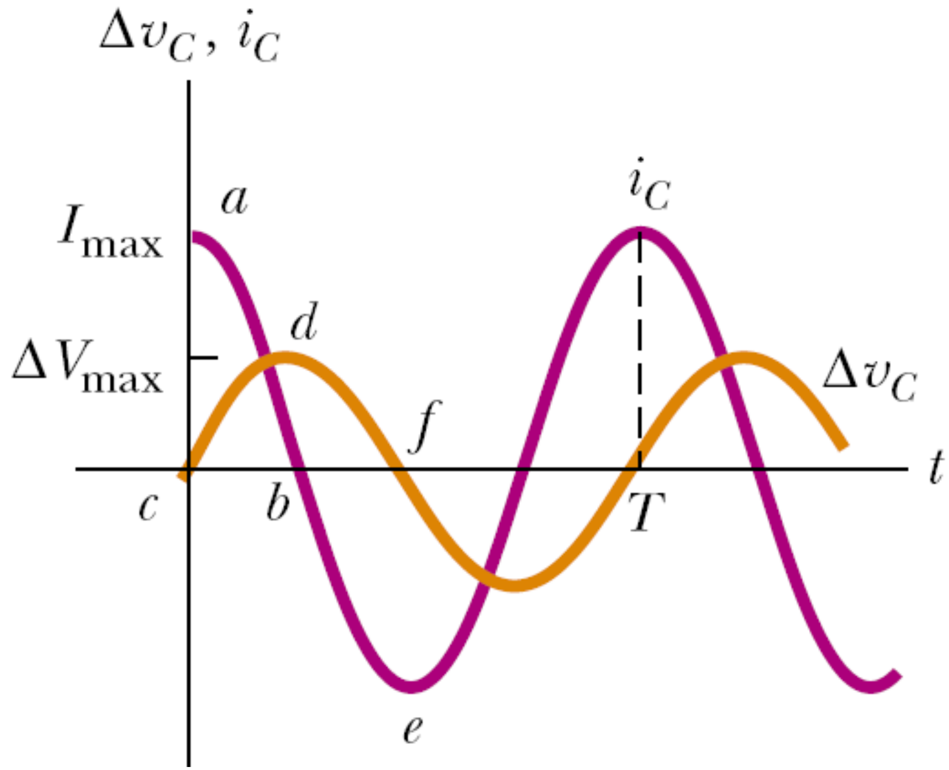
$$q = C\,\Delta V_{max} \sin\ \omega t$$

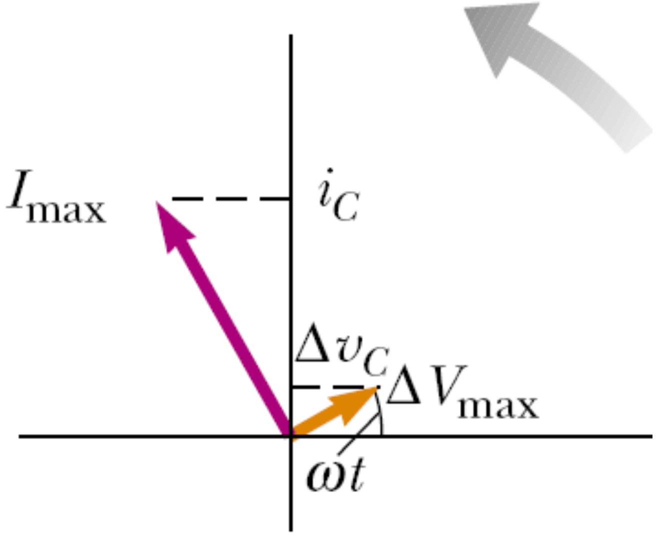
$$i_C = \frac{dq}{dt} = \omega C\,\Delta V_{max} \cos\ \omega t$$

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

$$i_C = \omega C\,\Delta V_{max} \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$\Delta v = \Delta v_C = \Delta V_{max} \sin \omega t \quad i_C = \omega C \Delta V_{max} \sin\left(\omega t + \frac{\pi}{2}\right)$$





for a sinusoidally applied voltage, the current always leads the voltage across a capacitor by 90°.

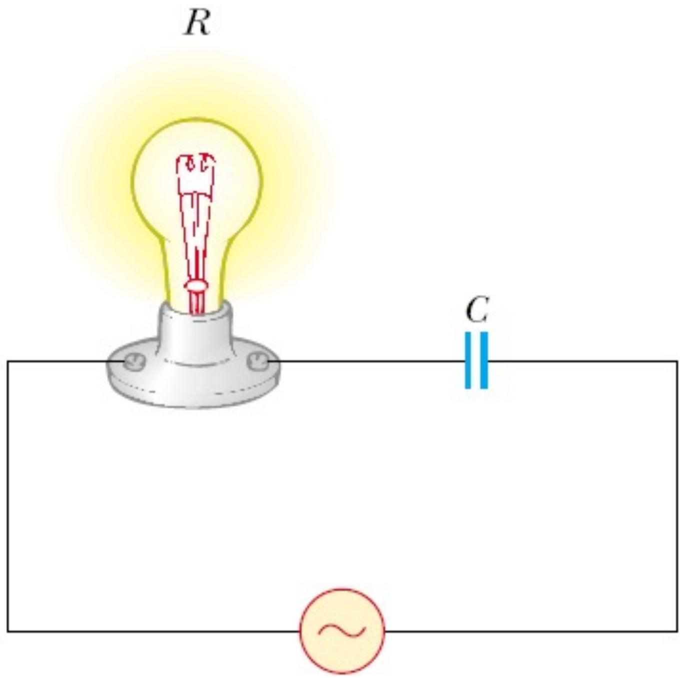
$$I_{max} = \omega C \Delta V_{max} = \frac{\Delta V_{max}}{(1/\omega C)}$$

$$X_C \equiv \frac{1}{\omega C}$$

$$I_{max} = \frac{\Delta V_{max}}{X_C}$$

capacitive reactance $\Delta v_C = \Delta V_{max} \sin \omega t = I_{max} X_C \sin \omega t$

Quick Quiz 33.5 Consider the AC circuit in Figure 33.11. The frequency of the AC source is adjusted while its voltage amplitude is held constant. The lightbulb will glow the brightest at (a) high frequencies (b) low frequencies (c) The brightness will be same at all frequencies.



(a). For high frequencies, the reactance of the capacitor is small so that the current is large. Most of the voltage from the source is across the bulb, so the power delivered to it is large.

Quick Quiz 33.6 Consider the AC circuit in Figure 33.12. The frequency of the AC source is adjusted while its voltage amplitude is held constant. The lightbulb will glow the brightest at (a) high frequencies (b) low frequencies (c) The brightness will be same at all frequencies.

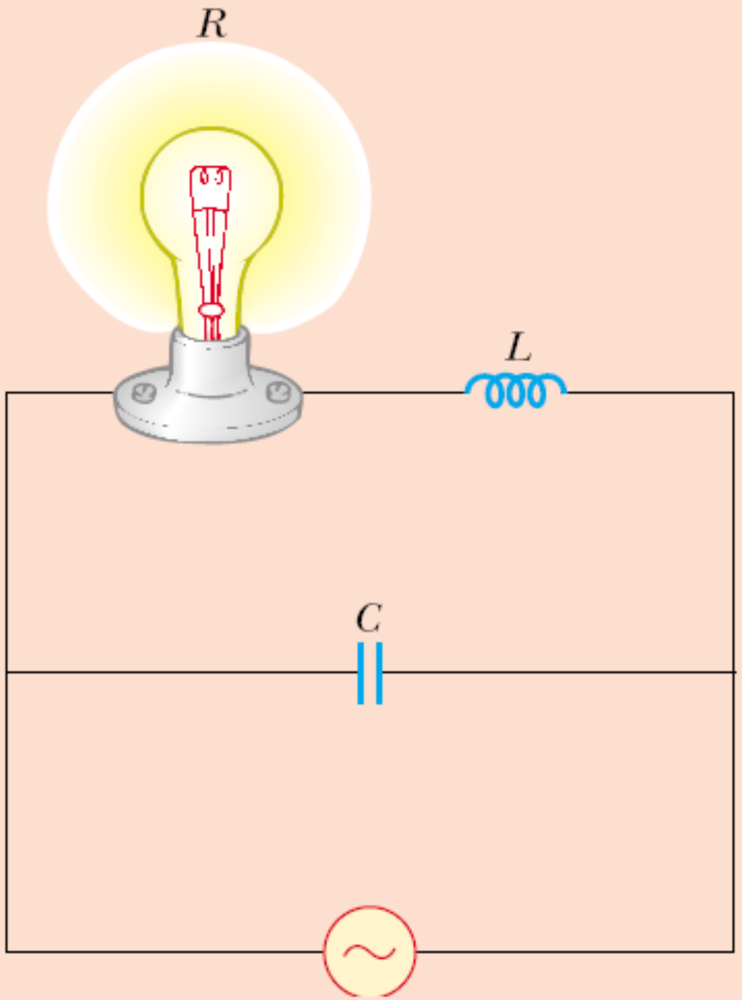


Figure 33.12 (Quick Quiz 33.6)

(b). For low frequencies, the reactance of the capacitor is large so that very little current exists in the capacitor branch. The reactance of the inductor is small so that current exists in the inductor branch and the lightbulb glows. As the frequency increases, the inductive reactance increases and the capacitive reactance decreases. At high frequencies, more current exists in the capacitor branch than the inductor branch and the lightbulb glows more dimly.

Example 33.3 A Purely Capacitive AC Circuit

An 8.00-μF capacitor is connected to the terminals of a 60.0-Hz AC source whose rms voltage is 150 V. Find the capacitive reactance and the rms current in the circuit.

$$X_C = \frac{1}{\omega C} = \frac{1}{(377\ \mathrm{s}^{-1})(8.00 \times 10^{-6}\ \mathrm{F})} = \boxed{332\ \Omega}$$

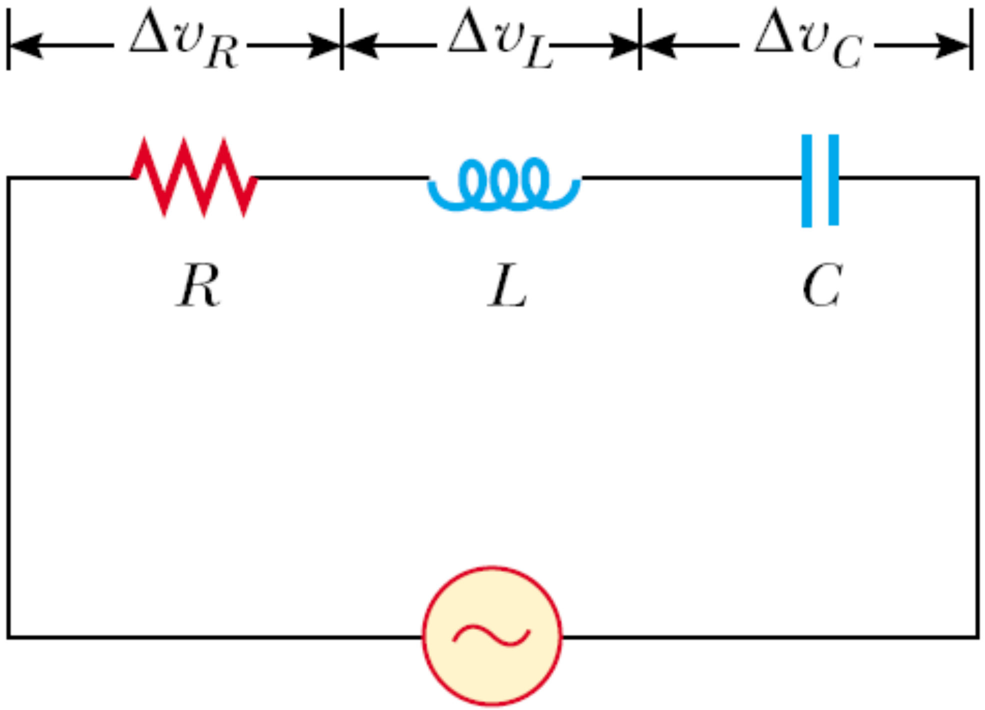
$$I_{\mathrm{rms}} = \frac{\Delta V_{\mathrm{rms}}}{X_C} = \frac{150\ \mathrm{V}}{332\ \Omega} = \boxed{0.452\ \mathrm{A}}$$

What If? What if the frequency is doubled? What happens to the rms current in the circuit?

$$X_C = \frac{1}{\omega C} = \frac{1}{2(377\ \mathrm{s}^{-1})(8.00 \times 10^{-6}\ \mathrm{F})} = 166\ \Omega$$

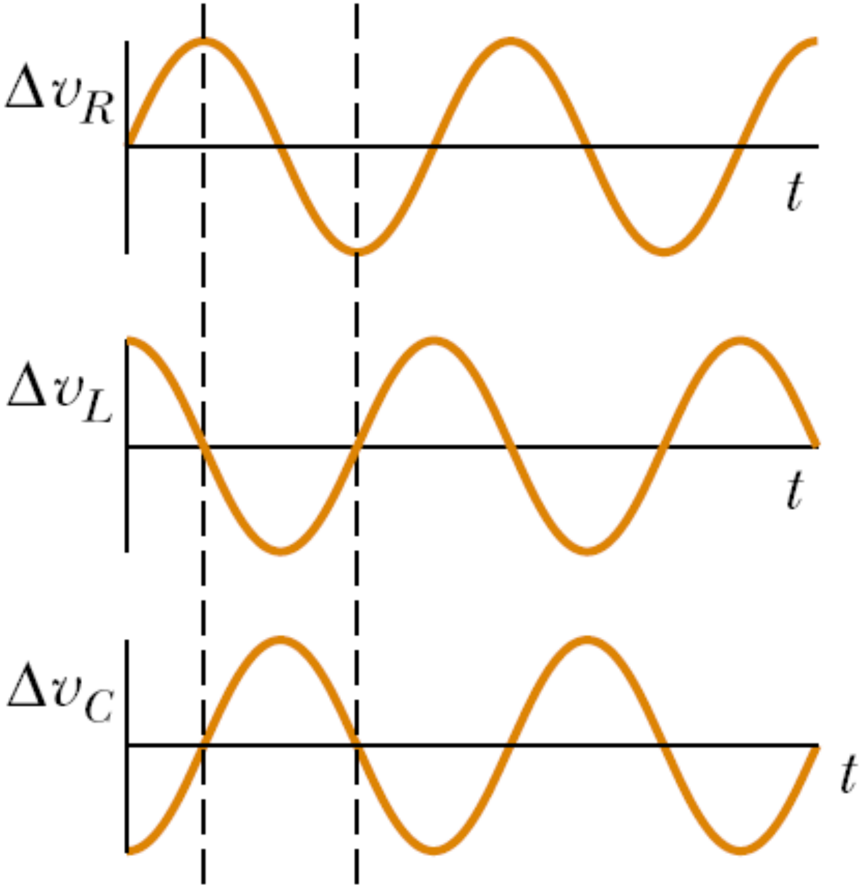
$$I_{\mathrm{rms}} = \frac{150\ \mathrm{V}}{166\ \Omega} = 0.904\ \mathrm{A}$$

The *RLC* Series Circuit



$$\Delta v = \Delta V_{\max} \sin \omega t$$

$$i = I_{\max} \sin(\omega t - \phi)$$



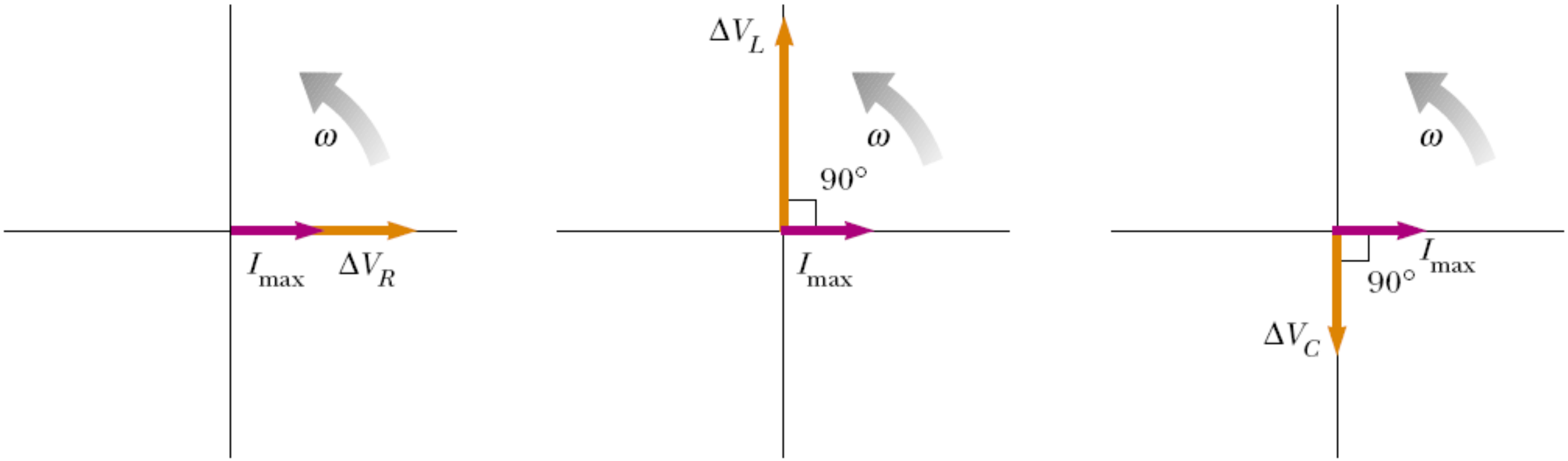
$$\Delta v_R = I_{\max} R \sin \omega t = \Delta V_R \sin \omega t$$

$$\Delta v_L = I_{\max} X_L \sin\left(\omega t + \frac{\pi}{2}\right) = \Delta V_L \cos \omega t$$

$$\Delta v_C = I_{\max} X_C \sin\left(\omega t - \frac{\pi}{2}\right) = -\Delta V_C \cos \omega t$$

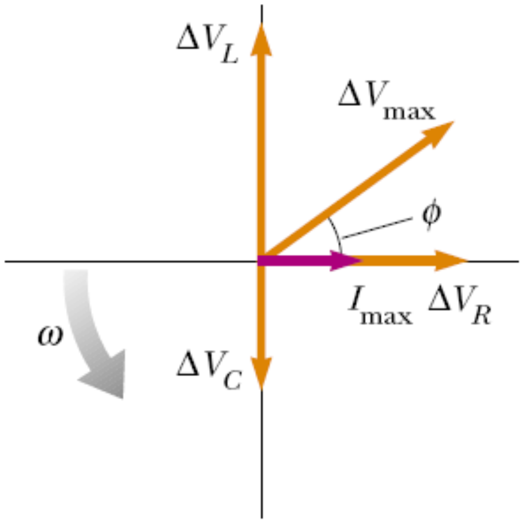
$$\Delta V_R = I_{\max} R \qquad \Delta V_L = I_{\max} X_L \qquad \Delta V_C = I_{\max} X_C$$

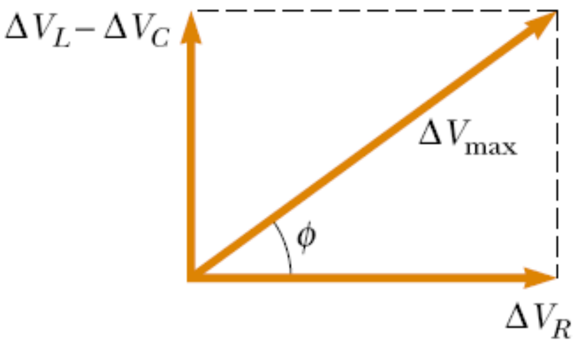
$$\Delta v = \Delta v_R + \Delta v_L + \Delta v_C$$



(a) Resistor (b) Inductor (c) Capacitor

Impedance





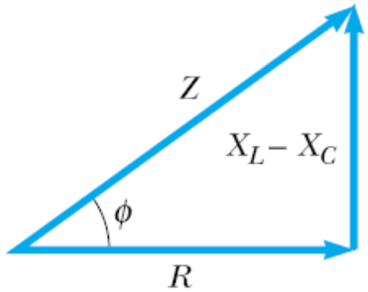


Figure 33.16 An impedance triangle for a series *RLC* circuit gives the relationship $Z = \sqrt{R^2 + (X_L - X_C)^2}$.

$$\Delta V_{max} = \sqrt{\Delta V_R{}^2 + (\Delta V_L - \Delta V_C)^2} = \sqrt{(I_{max} R)^2 + (I_{max} X_L - I_{max} X_C)^2}$$

$$\Delta V_{max} = I_{max} \sqrt{R^2 + (X_L - X_C)^2}$$

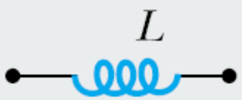
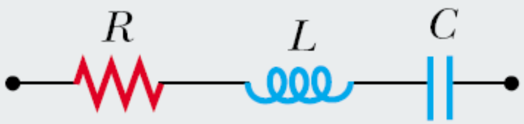
$$I_{max} = \frac{\Delta V_{max}}{\sqrt{R^2 + (X_L - X_C)^2}}$$

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

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

$$\Delta V_{max} = I_{max} Z$$

Impedance Values and Phase Angles for Various Circuit-Element Combinations[a]

Circuit Elements	Impedance Z	Phase Angle ϕ
	R	$0°$
	X_C	$-90°$
	X_L	$+90°$
	$\sqrt{R^2 + X_C{}^2}$	Negative, between $-90°$ and $0°$
	$\sqrt{R^2 + X_L{}^2}$	Positive, between $0°$ and $90°$
	$\sqrt{R^2 + (X_L - X_C)^2}$	Negative if $X_C > X_L$ Positive if $X_C < X_L$

Quick Quiz 33.7 Label each part of Figure 33.17 as being $X_L > X_C$, $X_L = X_C$, or $X_L < X_C$.

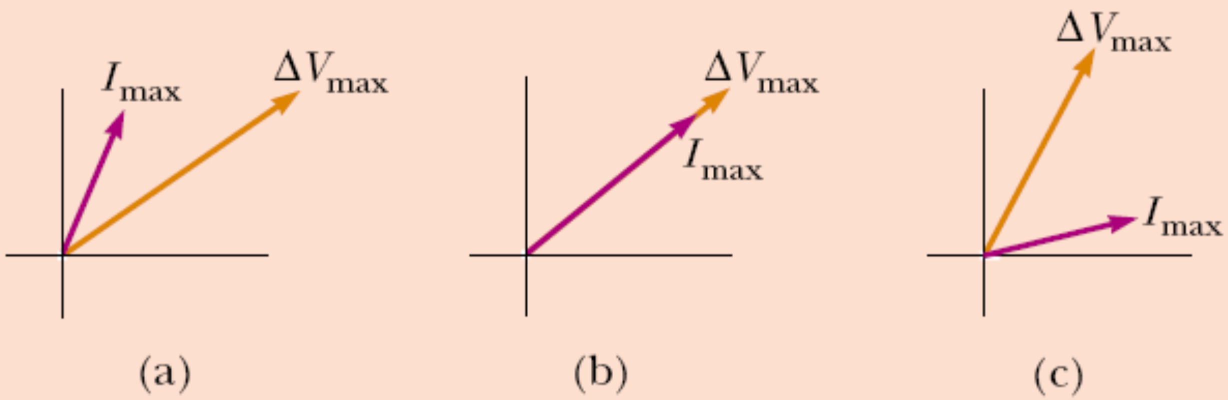
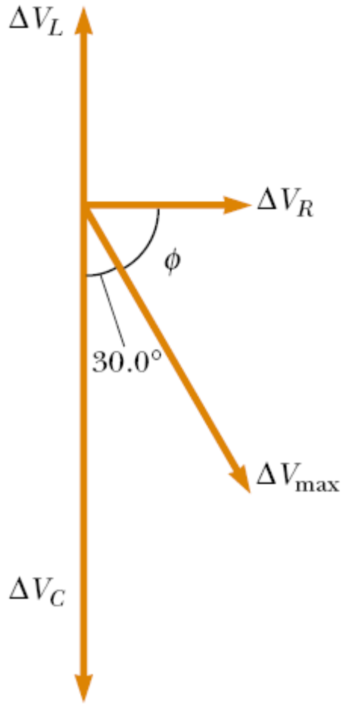


Figure 33.17 (Quick Quiz 33.7) Match the phasor diagrams to the relationships between the reactances.

(a) $X_L < X_C$. (b) $X_L = X_C$. (c) $X_L > X_C$.

Example 33.4 Finding L from a Phasor Diagram

In a series RLC circuit, the applied voltage has a maximum value of 120 V and oscillates at a frequency of 60.0 Hz. The circuit contains an inductor whose inductance can be varied, a 200-Ω resistor, and a 4.00-μF capacitor. What value of L should an engineer analyzing the circuit choose such that the voltage across the capacitor lags the applied voltage by 30.0°?



$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

$$X_L = X_C + R\tan\phi$$

$$2\pi f L = \frac{1}{2\pi f C} + R\tan\phi$$

$$L = \frac{1}{2\pi f}\left(\frac{1}{2\pi f C} + R\tan\phi\right)$$

$$L = \boxed{0.84\ \text{H.}}$$

Example 33.5 Analyzing a Series *RLC* Circuit

A series *RLC* AC circuit has $R = 425\ \Omega$, $L = 1.25$ H, $C = 3.50\ \mu$F, $\omega = 377\ \text{s}^{-1}$, and $\Delta V_{\text{max}} = 150$ V.

(A) Determine the inductive reactance, the capacitive reactance, and the impedance of the circuit.

$$X_L = \omega L = \boxed{471\ \Omega}$$

$$X_C = 1/\omega C = \boxed{758\ \Omega.}$$

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

$$= \sqrt{(425\ \Omega)^2 + (471\ \Omega - 758\ \Omega)^2} = \boxed{513\ \Omega}$$

(B) Find the maximum current in the circuit.

$$I_{\max} = \frac{\Delta V_{\max}}{Z} = \frac{150\text{ V}}{513\ \Omega} = \boxed{0.292\text{ A}}$$

(C) Find the phase angle between the current and voltage.

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right) = \tan^{-1}\left(\frac{471\ \Omega - 758\ \Omega}{425\ \Omega}\right)$$

$$= \boxed{-34.0^\circ}$$

(D) Find both the maximum voltage and the instantaneous voltage across each element.

$$\Delta V_R = I_{\max} R = (0.292\ \text{A})(425\ \Omega) = \boxed{124\ \text{V}}$$

$$\Delta V_L = I_{\max} X_L = (0.292\ \text{A})(471\ \Omega) = \boxed{138\ \text{V}}$$

$$\Delta V_C = I_{\max} X_C = (0.292\ \text{A})(758\ \Omega) = \boxed{221\ \text{V}}$$

$$\Delta v_R = \boxed{(124\ \text{V}) \sin 377t}$$

$$\Delta v_L = \boxed{(138\ \text{V}) \cos 377t}$$

$$\Delta v_C = \boxed{(-221\ \text{V}) \cos 377t}$$

What If? What if you added up the maximum voltages across the three circuit elements? Is this a physically meaningful quantity?

Answer The sum of the maximum voltages across the elements is $\Delta V_R + \Delta V_L + \Delta V_C = 484$ V. Note that this sum is much greater than the maximum voltage of the source, 150 V. The sum of the maximum voltages is a meaningless quantity because when sinusoidally varying quantities are added, *both their amplitudes and their phases* must be taken into account. We know that the maximum voltages across the various elements occur at different times. That is, the voltages must be added in a way that takes account of the different phases.

Power in an AC Circuit

$$\mathscr{P} = i\,\Delta v = I_{\max}\sin(\omega t - \phi)\,\Delta V_{\max}\sin\omega t$$
$$= I_{\max}\,\Delta V_{\max}\sin\omega t\sin(\omega t - \phi)$$

$$\sin(\omega t - \phi) = \sin\omega t\cos\phi - \cos\omega t\sin\phi$$

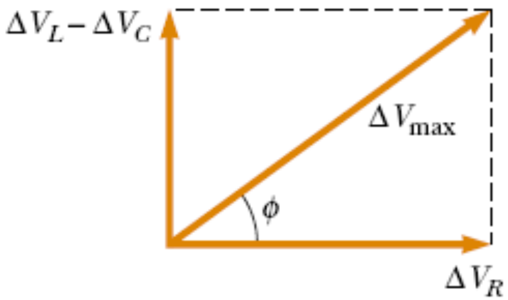
$$\mathscr{P} = I_{\max}\,\Delta V_{\max}\sin^2\omega t\cos\phi - I_{\max}\,\Delta V_{\max}\sin\omega t\cos\omega t\sin\phi$$

$$\mathscr{P}_{\text{av}} = \frac{1}{2}I_{\max}\,\Delta V_{\max}\cos\phi$$

$$\boxed{\mathscr{P}_{\text{av}} = I_{\text{rms}}\,\Delta V_{\text{rms}}\cos\phi}$$

the quantity $\cos\phi$ is called the **power factor.**

$$\mathcal{P}_{av} = I_{rms}\,\Delta V_{rms}\cos\phi = I_{rms}\left(\frac{\Delta V_{max}}{\sqrt{2}}\right)\frac{I_{max}R}{\Delta V_{max}} = I_{rms}\,\frac{I_{max}R}{\sqrt{2}}$$



$$\cos\phi = I_{max}\,R/\Delta V_{max}$$

$$I_{max} = \sqrt{2}\,I_{rms}$$

$$\Delta V_R = \Delta V_{max}\cos\phi = I_{max}\,R$$

$$\boxed{\mathcal{P}_{av} = I_{rms}^2\,R}$$

In words, **the average power delivered by the source is converted to internal energy in the resistor,** just as in the case of a DC circuit. When the load is purely resistive, then $\phi = 0$, $\cos\phi = 1$, and from Equation 33.31 we see that

$$\mathcal{P}_{av} = I_{rms}\,\Delta V_{rms}$$

Quick Quiz 33.8 An AC source drives an RLC circuit with a fixed voltage amplitude. If the driving frequency is ω_1, the circuit is more capacitive than inductive and the phase angle is $-10°$. If the driving frequency is ω_2, the circuit is more inductive than capacitive and the phase angle is $+10°$. The largest amount of power is delivered to the circuit at (a) ω_1 (b) ω_2 (c) The same amount of power is delivered at both frequencies.

(c). The cosine of $-\phi$ is the same as that of $+\phi$, so the $\cos\phi$ factor in Equation 33.31 is the same for both frequencies. The factor ΔV_{rms} is the same because the source voltage is fixed. According to Equation 33.27, changing $+\phi$ to $-\phi$ simply interchanges the values of X_L and X_C. Equation 33.25 tells us that such an interchange does not affect the impedance, so that the current I_{rms} in Equation 33.31 is the same for both frequencies.

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

$$\phi = \tan^{-1}\left(\frac{X_L - X_C}{R}\right)$$

Example 33.6 Average Power in an *RLC* Series Circuit

Calculate the average power delivered to the series *RLC* circuit described in Example 33.5.

Example 33.5 Analyzing a Series *RLC* Circuit

A series *RLC* AC circuit has $R = 425\ \Omega$, $L = 1.25$ H, $C = 3.50\ \mu$F, $\omega = 377\ \text{s}^{-1}$, and $\Delta V_{max} = 150$ V.

$$\Delta V_{rms} = \frac{\Delta V_{max}}{\sqrt{2}} = \frac{150\ \text{V}}{\sqrt{2}} = 106\ \text{V}$$

$$I_{rms} = \frac{I_{max}}{\sqrt{2}} = \frac{0.292\ \text{A}}{\sqrt{2}} = 0.206\ \text{A}$$

Because $\phi = -34.0°$, the power factor is $\cos(-34.0°)$ 0.829; hence, the average power delivered is

$$\mathcal{P}_{av} = I_{rms}\,\Delta V_{rms}\cos\phi = (0.206\ \text{A})(106\ \text{V})(0.829)$$

$$= \boxed{18.1\ \text{W}}$$

Resonance in a Series *RLC* Circuit

A series *RLC* circuit is said to be **in resonance** when the current has its maximum value. In general, the rms current can be written

$$I_{\text{rms}} = \frac{\Delta V_{\text{rms}}}{Z}$$

$$\boxed{I_{\text{rms}} = \frac{\Delta V_{\text{rms}}}{\sqrt{R^2 + (X_L - X_C)^2}}}$$

$$\boxed{\omega_0 = \frac{1}{\sqrt{LC}}}$$

Quick Quiz 33.9 The impedance of a series *RLC* circuit at resonance is (a) larger than R (b) less than R (c) equal to R (d) impossible to determine.

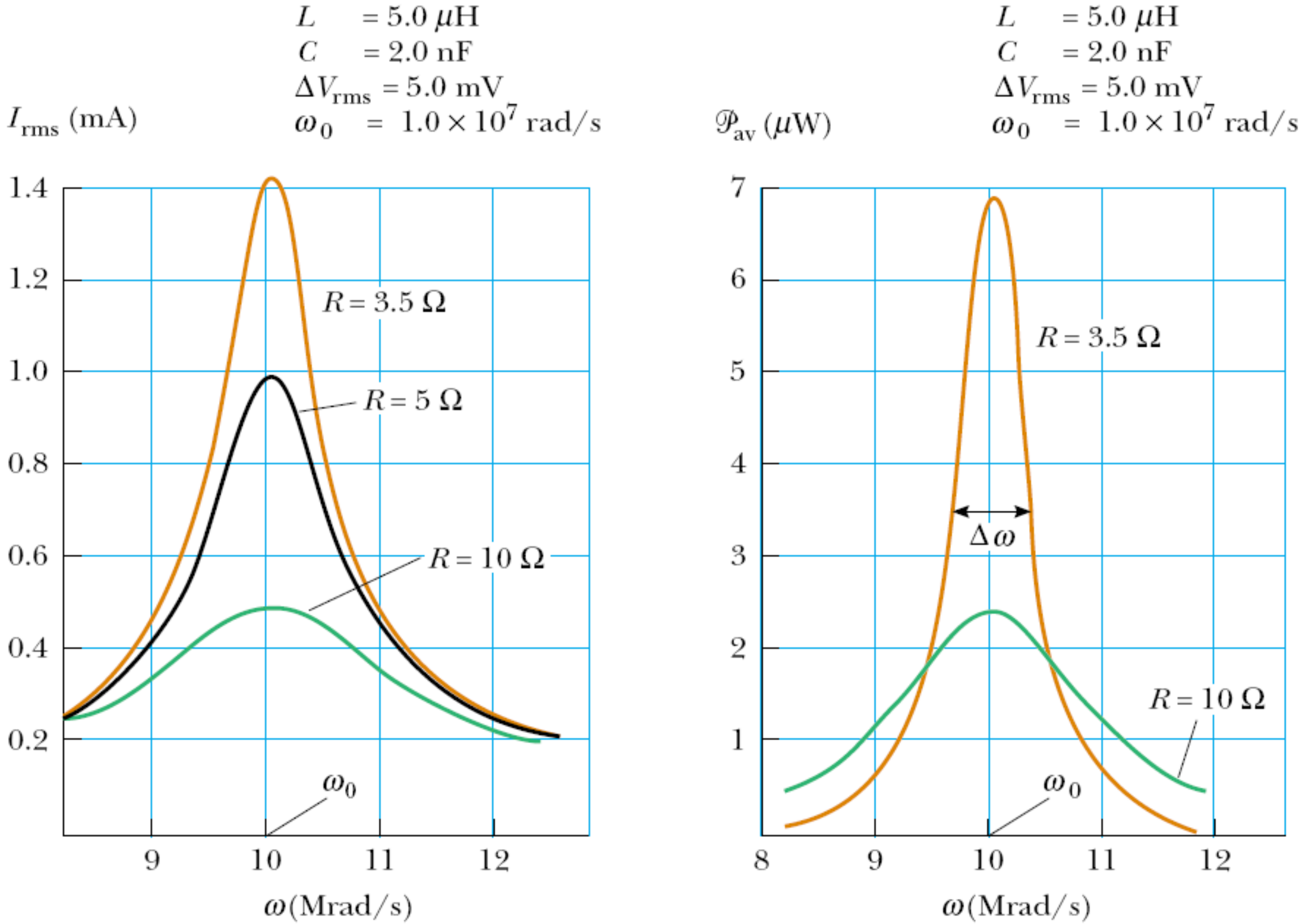
(c). At resonance, $X_L = X_C$. According to Equation 33.25, this gives us $Z = R$.

$$\mathscr{P}_{\text{av}} = I_{\text{rms}}^2 R = \frac{(\Delta V_{\text{rms}})^2}{Z^2} R = \frac{(\Delta V_{\text{rms}})^2 R}{R^2 + (X_L - X_C)^2}$$

Because $X_L = \omega L$, $X_C = 1/\omega C$, and $\omega_0{}^2 = 1/LC$, we can express the term $(X_L - X_C)^2$ as

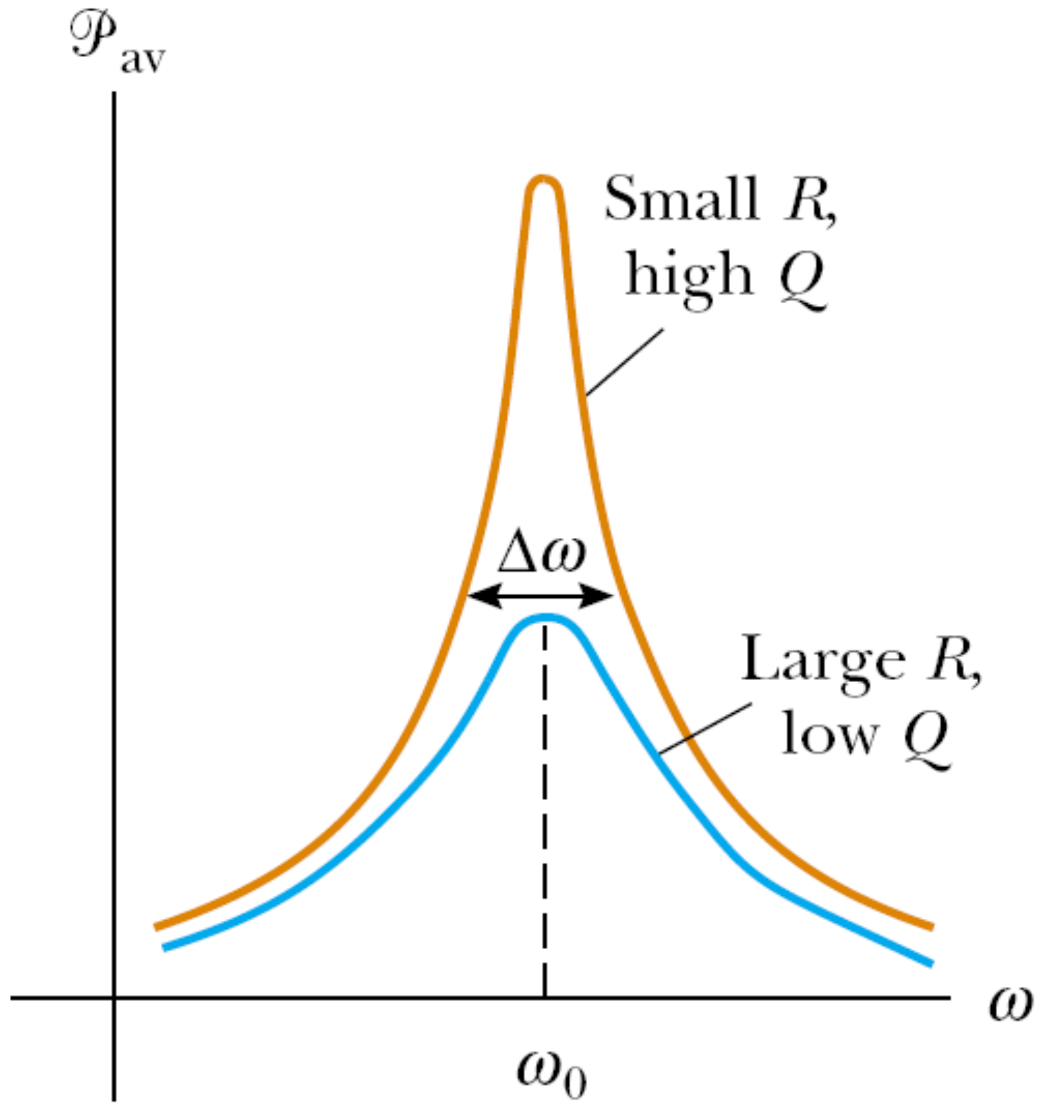
$$(X_L - X_C)^2 = \left(\omega L - \frac{1}{\omega C}\right)^2 = \frac{L^2}{\omega^2}(\omega^2 - \omega_0{}^2)^2$$

$$\mathscr{P}_{\text{av}} = \frac{(\Delta V_{\text{rms}})^2 R\omega^2}{R^2\omega^2 + L^2(\omega^2 - \omega_0{}^2)^2}$$


L = 5.0 μH
C = 2.0 nF
ΔV_rms = 5.0 mV
ω_0 = 1.0 × 10^7 rad/s
I_rms (mA)
R = 3.5 Ω
R = 5 Ω
R = 10 Ω
ω_0
ω(Mrad/s)
L = 5.0 μH
C = 2.0 nF
ΔV_rms = 5.0 mV
ω_0 = 1.0 × 10^7 rad/s
𝒫_av (μW)
R = 3.5 Ω
Δω
R = 10 Ω
ω_0
ω(Mrad/s)

$$Q = \frac{\omega_0}{\Delta\omega}$$

$$Q = \frac{\omega_0 L}{R}$$



Quick Quiz 33.10 An airport metal detector (see page 1003) is essentially a resonant circuit. The portal you step through is an inductor (a large loop of conducting wire) within the circuit. The frequency of the circuit is tuned to its resonance frequency when there is no metal in the inductor. Any metal on your body increases the effective inductance of the loop and changes the current in it. If you want the detector to detect a small metallic object, should the circuit have (a) a high quality factor or (b) a low quality factor?

(a). The higher the quality factor, the more sensitive the detector. As you can see from Figure 33.19, when $Q = \omega_0/\Delta\omega$ is high, a slight change in the resonance frequency (as might happen when a small piece of metal passes through the portal) causes a large change in current that can be detected easily.

Example 33.7 A Resonating Series *RLC* Circuit

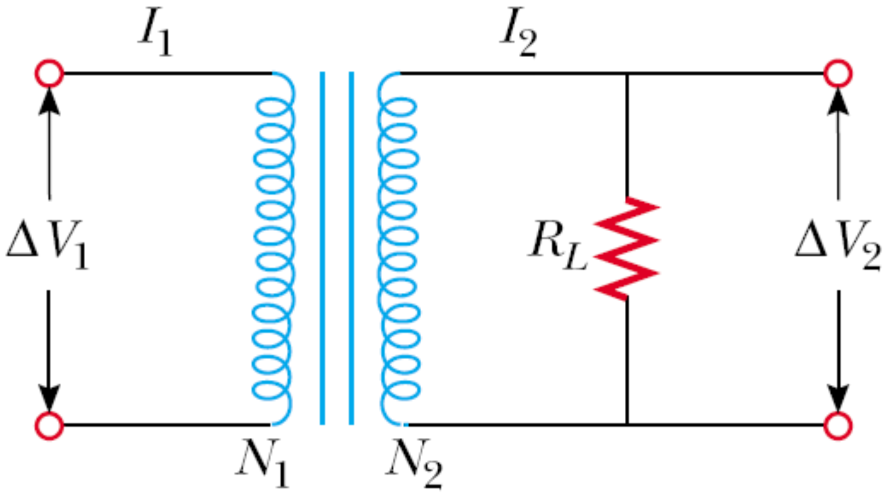
Consider a series RLC circuit for which $R = 150\ \Omega$, $L = 20.0$ mH, $\Delta V_{\mathrm{rms}} = 20.0$ V, and $\omega = 5\,000\ \mathrm{s}^{-1}$. Determine the value of the capacitance for which the current is a maximum.

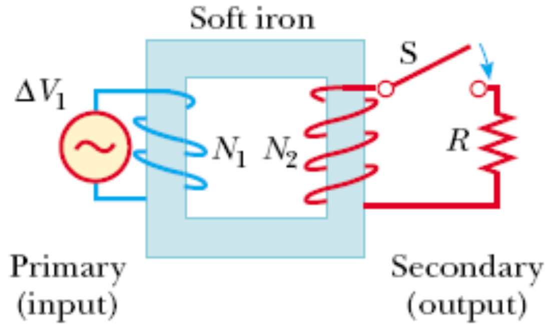
$$\omega_0 = 5.00 \times 10^3\ \mathrm{s}^{-1} = \frac{1}{\sqrt{LC}}$$

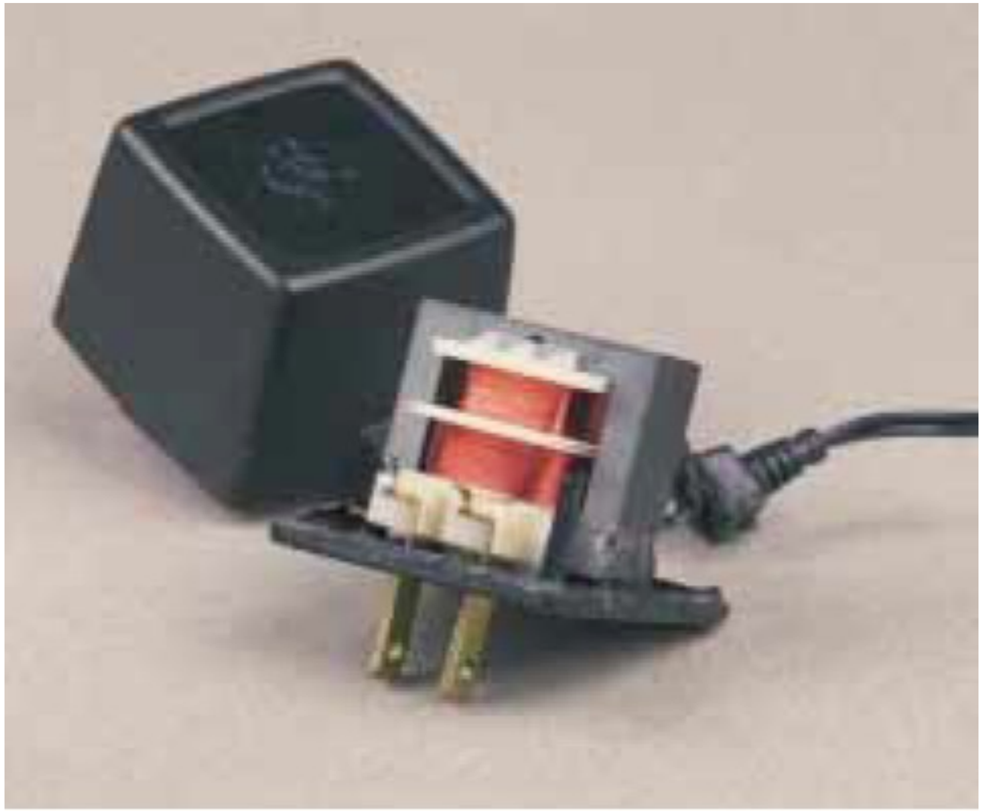
$$C = \frac{1}{\omega_0{}^2 L} = \frac{1}{(5.00 \times 10^3\ \mathrm{s}^{-1})^2(20.0 \times 10^{-3}\ \mathrm{H})}$$

$$= \boxed{2.00\ \mu\mathrm{F}}$$

The Transformer and Power Transmission







$$\Delta V_1 = -N_1 \frac{d\Phi_B}{dt}$$

$$\Delta V_2 = -N_2 \frac{d\Phi_B}{dt}$$

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

$$I_1 \Delta V_1 = I_2 \Delta V_2$$

$$R_{\text{eq}} = \left(\frac{N_1}{N_2}\right)^2 R_L$$

Example 33.8 The Economics of AC Power

An electricity-generating station needs to deliver energy at a rate of 20 MW to a city 1.0 km away.

(A) If the resistance of the wires is 2.0 Ω and the energy costs about 10¢/kWh, estimate what it costs the utility company for the energy converted to internal energy in the wires during one day. A common voltage for commercial power generators is 22 kV, but a step-up transformer is used to boost the voltage to 230 kV before transmission.

$$I_{\text{rms}} = \frac{\mathcal{P}_{\text{av}}}{\Delta V_{\text{rms}}} = \frac{20 \times 10^6 \text{ W}}{230 \times 10^3 \text{ V}} = 87 \text{ A}$$

$$\mathcal{P}_{\text{av}} = I_{\text{rms}}^2 R = (87 \text{ A})^2 (2.0 \ \Omega) = 15 \text{ kW}$$

Over the course of a day, the energy loss due to the resistance of the wires is $(15\ \text{kW})(24\ \text{h}) = 360\ \text{kWh}$, at a cost of $\boxed{\$36.}$

(B) Repeat the calculation for the situation in which the power plant delivers the energy at its original voltage of 22 kV.

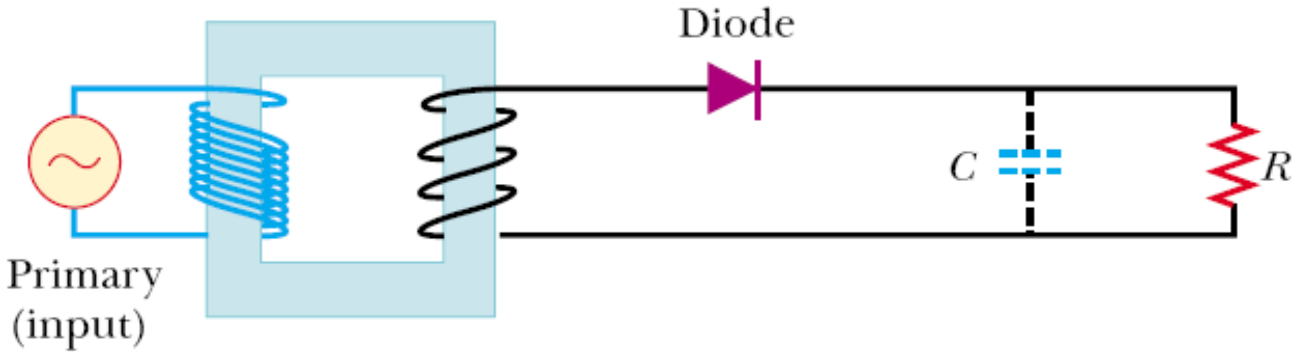
$$I_{\text{rms}} = \frac{\mathcal{P}_{\text{av}}}{\Delta V_{\text{rms}}} = \frac{20 \times 10^6\ \text{W}}{22 \times 10^3\ \text{V}} = 910\ \text{A}$$

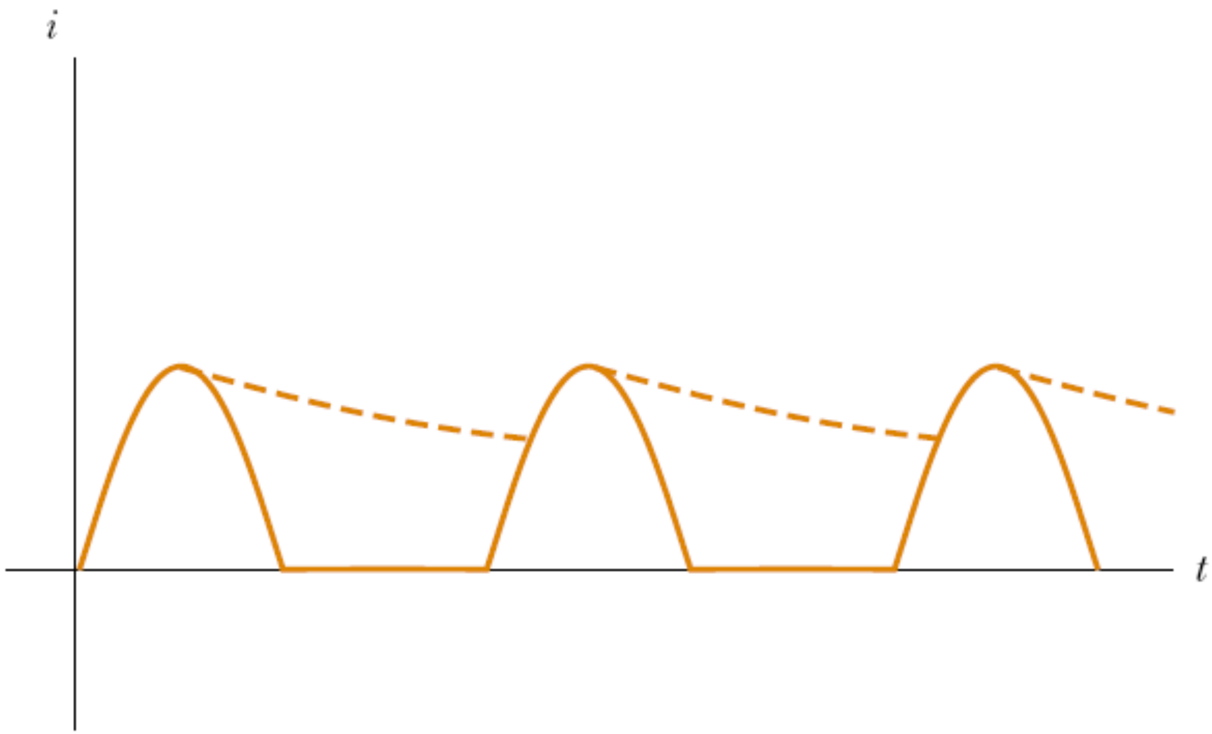
$$\mathcal{P}_{\text{av}} = I_{\text{rms}}^2 R = (910\ \text{A})^2(2.0\ \Omega) = 1.7 \times 10^3\ \text{kW}$$

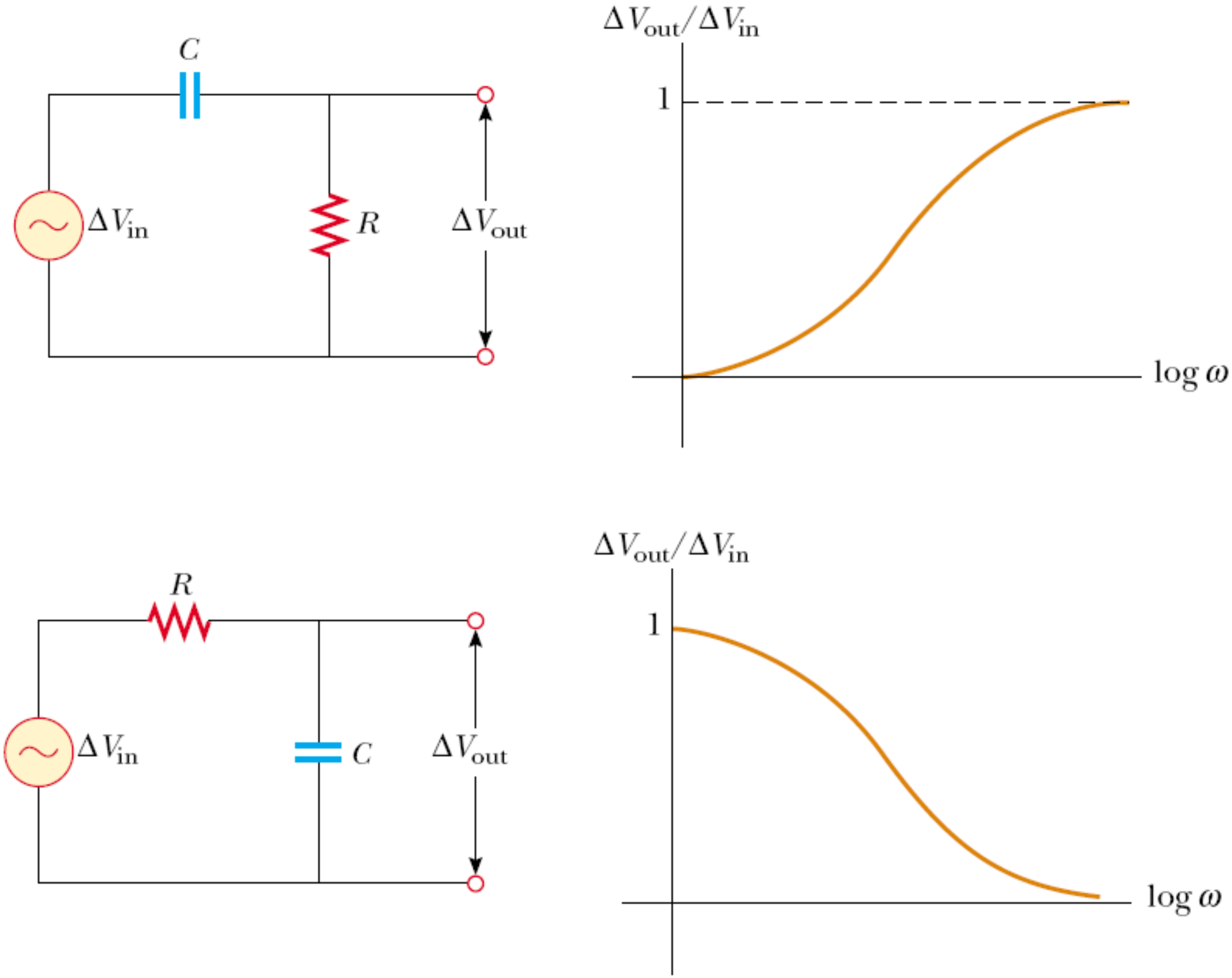
$$\text{Cost per day} = (1.7 \times 10^3\ \text{kW})(24\ \text{h})(\$0.10/\text{kWh})$$

$$= \boxed{\$4\,100}$$

Rectifiers and Filters







C
ΔV_in
R
ΔV_out
ΔV_out/ΔV_in
1
log ω
R
ΔV_in
C
ΔV_out
ΔV_out/ΔV_in
1
log ω

Quick Quiz 33.11 Suppose you are designing a high-fidelity system containing both large loudspeakers (woofers) and small loudspeakers (tweeters). If you wish to deliver low-frequency signals to a woofer, what device would you place in series with it? (a) an inductor (b) a capacitor (c) a resistor. If you wish to deliver high-frequency signals to a tweeter, what device would you place in series with it? (d) an inductor (e) a capacitor (f) a resistor.

(a) and (e). The current in an inductive circuit decreases with increasing frequency (see Eq. 33.9). Thus, an inductor connected in series with a woofer blocks high-frequency signals and passes low-frequency signals. The current in a capacitive circuit increases with increasing frequency (see Eq. 33.17). When a capacitor is connected in series with a tweeter, the capacitor blocks low-frequency signals and passes high-frequency signals.