The Language of Physics

Effective current
That constant current that generates heat in a resistor at the same rate as an alternating current. The effective value of an alternating current is equal to 70.7% of the maximum or peak value of the AC current. An AC ammeter measures the effective current in the circuit. The effective current is sometimes called the rms current (p. 689).

Effective voltage
The constant value of the voltage that produces the same effect as an alternating voltage. The effective value of an alternating voltage is equal to 70.7% of the maximum or peak value of the AC voltage. An AC voltmeter measures the effective voltage. The effective voltage is sometimes called the rms voltage (p. 689).

***RLC* series circuit**
A circuit containing a resistor, an inductor, and a capacitor in series. The voltage across the resistor is in phase with the current in the circuit. The voltage across the inductor in the circuit leads the current in the circuit by 90°, whereas the voltage across the capacitor lags the current in the circuit by 90° (p. 690).

Phase angle
A measure of how much the applied voltage leads or lags the current in an AC circuit (p. 693).

Inductive reactance
The inductive analogue to resistance in an AC circuit; that is, an inductive reactance tends to impede the flow of charge in an AC circuit. The inductive reactance is proportional to the frequency of the AC source; a high-frequency AC source causes a high reactance, whereas a low-frequency source causes a low reactance (p. 693).

Capacitive reactance
The capacitive analogue to resistance in an AC circuit; that is, a capacitive reactance tends to impede the flow of charge in an AC circuit. The capacitive reactance is inversely proportional to the frequency of the AC source; a high-frequency AC source causes a low reactance, whereas a low-frequency source causes a high reactance (p. 694).

Impedance
A measure of the opposition to the flow of charges in an AC circuit. It is composed of the resistance, inductive reactance, and the capacitive reactance of the circuit. It is the AC analogue to resistance in a DC circuit (p. 694).

Resonance
That condition in an AC circuit where the maximum current is obtained. It occurs when the inductive reactance is equal to the capacitive reactance (p. 699).

Resonant frequency
The frequency of an AC circuit that causes resonance in the circuit. It depends on the inductance and capacitance of the circuit (p. 699).

Power factor
The ratio of the power consumed in an AC circuit to the power applied to the circuit. It is also equal to the cosine of the phase angle (p. 680).

***RLC* parallel circuit**
An AC circuit in which the resistor, inductor, and capacitor are placed in parallel with each other. In such a circuit, the voltages are all in phase but the currents are out of phase with each other. The current in the capacitor leads the current in the resistor by 90°, whereas the current in the inductor lags the current in the resistor by 90° (p. 701).

Transformer
A device, based on the principle of mutual induction, that changes electrical energy at a particular voltage and current in the primary coil into a different voltage and current in the secondary coil (p. 705).

Summary of Important Equations

AC voltage
$$\mathcal{E} = \mathcal{E}_{max} \sin \omega t \quad (23.24)$$
$$V = V_{max} \sin(2\pi ft) \quad (24.6)$$

AC current
$$i = i_{max} \sin \omega t \quad (23.26)$$
$$i = i_{max} \sin(2\pi ft) \quad (24.2)$$

Relation of angular speed and frequency of sine wave
$$\omega = 2\pi f \quad (24.1)$$

Effective current in an AC circuit
$$i_{eff} = 0.707 i_{max} \quad (24.5)$$

Effective voltage in an AC circuit
$$V_{eff} = 0.707 V_{max} \quad (24.7)$$

Inductive reactance
$$X_L = 2\pi fL \quad (24.15)$$

Capacitive reactance
$$X_C = \frac{1}{2\pi fC} \quad (24.17)$$

Impedance of an AC series circuit
$$Z = \sqrt{R^2 + (X_L - X_C)^2} \quad (24.18)$$

Ohm's law for an AC circuit
$$i = \frac{V}{Z} \quad (24.19)$$

Voltage drop across a resistor
$$V_R = iR \quad (24.13)$$

Voltage drop across an inductor
$$V_L = iX_L \quad (24.14)$$

Voltage drop across a capacitor
$$V_C = iX_C \quad (24.16)$$

Total voltage in an AC series circuit
$$V = \sqrt{V_R^2 + (V_L - V_C)^2} \quad (24.11)$$

Phase angle between voltage and current in an AC series circuit
$$\phi = \tan^{-1}\left(\frac{V_L - V_C}{V_R}\right) \quad (24.12)$$

Resonant frequency of an AC series circuit
$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad (24.21)$$

Power dissipated in an AC circuit
$$P = iV \cos \phi \quad (24.22)$$

Power factor
$$\text{PF} = \cos \phi = \frac{R}{Z} \quad (24.24)$$

Power factor
$$\text{PF} = \frac{\text{Power consumed}}{\text{Power supplied}} \quad (24.25)$$

Total current in a parallel *RLC* circuit
$$I_T = \sqrt{(I_R^2 + (I_C - I_L)^2} \quad (24.26)$$

Current in resistor for parallel *RLC* circuit
$$I_R = \frac{V}{R} \quad (24.27)$$

Current in inductor for parallel *RLC* circuit
$$I_L = \frac{V}{X_L} \quad (24.28)$$

Current in capacitor for parallel *RLC* circuit
$$I_C = \frac{V}{X_C} \quad (24.29)$$

Phase angle for parallel *RLC* circuit
$$\phi = \tan^{-1}\frac{I_C - I_L}{I_R} \quad (24.30)$$

Total impedance for parallel *RLC* circuit
$$Z = \frac{V}{I_T} \quad (24.32)$$

Transformer
$$\frac{\mathcal{E}_2}{\mathcal{E}_1} = \frac{i_1}{i_2} = \frac{N_2}{N_1} \quad (24.37)$$

Questions for Chapter 24

†**1.** When Americans visit Europe, they are told to get an adapter for their personal appliances such as electric razors, hair driers, and the like. Why is this necessary? What is the difference between European electricity and American electricity?

2. What does doubling the frequency do to the inductive reactance? The capacitive reactance?

3. Can you use the d'Arsonval galvanometer to measure AC currents or voltages?

†**4.** How can you measure an AC current or voltage?

†**5.** What does increasing the area of the plates of a capacitor do to the resonant frequency in an *RLC* series circuit? How is this used in a variable capacitor of a tuned circuit?

6. What is the phase angle of an *RLC* series circuit when the inductive reactance equals the capacitive reactance? What is the power factor in this case?

†**7.** How is an *LC* circuit like a mass attached to a vibrating spring? Compare the equation for resonance for a vibrating spring and the *LC* circuit. Can you make an analogue between them?

†**8.** How can an *RLC* circuit be used to filter signals of a special frequency?

†**9.** In many transformers, the wires are wrapped around an iron core rather than a hollow air core. Why do you think this is done?

Problems for Chapter 24

24.2 The Effective Current and Voltage in an AC Circuit

1. The effective voltage in an AC circuit is measured as 50.0 V. What is the maximum value of the voltage?

2. The peak-to-peak voltage of an AC voltage is measured on an oscilloscope to be 100 V. What is the effective voltage?

3. The effective current in an AC circuit is measured to be 5.00 A. What is the maximum value of the current?

4. An AC current varies from −5.65 A to +5.65 A. Find the effective value of the current. What DC current would give the same effect?

24.3 An *RLC* Series Circuit

5. Find the inductive reactance of a 5.00-H coil when a 400-Hz AC voltage is impressed across it.

6. At what frequency will a 50.0-mH inductor have a reactance of 800 Ω?

7. A 110-V, 60.0-Hz, AC line is connected to a 6.55-mH coil. Find the current through the coil.

8. A coil has an impedance of 800 Ω and an inductive reactance of 600 Ω. Find the resistance of the coil.

9. Find the capacitive reactance of a 10.0-μF capacitor at 60.0 Hz.

10. A 55.5-V, 400-Hz, AC line is connected to a 6-pF capacitor. Find the current in the circuit.

11. At what frequency will the inductive reactance of a 2.00-H inductor be (a) 20 Ω, (b) 200 Ω, and (c) 2000 Ω? Is it easier for an inductor to pass low-frequency or high-frequency signals?

12. At what frequency will the capacitive reactance of a 5.00-μF capacitor be (a) 10 Ω, (b) 100 Ω, and (c) 1000 Ω? Is it easier for a capacitor to pass low-frequency or high-frequency signals?

13. A 2.00-mH inductor is connected to a 110-V, 60.0-Hz line. Find (a) the inductive reactance and (b) the current through the inductor.

14. A 2.00-μF capacitor is connected to a 50.0-V, 40.0-Hz, AC line. Find the current flowing in the capacitor circuit.

15. Find the impedance of a series circuit of $R = 1000$ Ω, $L = 5.00$ mH, and $C = 10.0$ μF, if the AC source is at a frequency of 60.0 Hz.

16. A resistor $R = 500$ Ω, an inductor $L = 20.0$ mH, and a capacitor $C = 6.00$ μF are connected in series. Find the impedance if the source is 110 V at 400 Hz.

†**17.** An *RLC* series circuit has $R = 1800$ Ω, $L = 4.89$ mH, $C = 4.78$ μF, and $f = 60.0$ Hz. Find (a) the phase angle between the applied voltage and the current in the circuit, (b) the phase angle between the voltage across the inductor and the applied voltage, and (c) the phase angle between the voltage across the capacitance and the applied voltage.

18. If the impedance of an *RLC* series circuit of $R = 800$ Ω, $L = 50.0$ mH, and $C = 3.00$ μF is 1178 Ω, find the phase angle between the current in the circuit and the applied voltage.

19. In an *RLC* series circuit, $R = 200$ Ω, $C = 10.0$ μF, and the frequency $f = 70.0$ Hz. What inductance would result in the potential across the *RLC* combination leading the current by 30.0°?

20. A 240-V, 50.0-Hz, AC line is connected in series with a resistor of 958 Ω and a capacitor of 9.50 μF. Find (a) the impedance of the circuit and (b) the phase angle of the circuit.

21. A 120-V, 50.0-Hz, AC line is connected to an *RL* series circuit of $R = 280$ Ω and $L = 5.75$ mH. Find the impedance of the circuit and the phase angle between the applied voltage and the current in the circuit.

22. In an *RLC* series circuit, $V_L = 12.0$ V, $V_C = 24.0$ V, and $R = 160$ Ω. If the potential across the *RLC* combination lags the current by 42.0°, find the current in the circuit.

23. A 400-Ω resistor is connected in series with an unknown inductor to a 110-V, 60.0-Hz, AC line. If the current in the circuit is 0.194 A, what is the value of the inductance of the inductor?

24.4 Resonance in an *RLC* Series Circuit

24. A 2.00-mH inductor is connected in series with a 10.0-μF capacitor to an AC line of variable frequency. At what frequency will resonance occur?

25. What value of inductance is necessary to tune an *RLC* circuit to a frequency of 106.2 MHz if the capacitor has a value of 5.00 pF?

26. At what frequency is the inductive reactance equal to the capacitive reactance if $X_L = 850$ Ω and $C = 6.00$ μF?

27. In an RLC series circuit, $\mathscr{E} = 120$ V, $C = 15.0$ pF, and the resonant frequency is 50.0 Hz. (a) Find the inductance in the circuit. (b) If the current is 10.0 mA at resonance, find the resistance in the circuit. (c) If the resonant frequency is changed to 60.0 Hz by varying the capacitance, find the new value of the capacitance.

28. If $R = 800\ \Omega$, $L = 50.0$ mH, and $C = 3.00\ \mu$F in an RLC series circuit of $\mathscr{E} = 120$ V, plot the current I as a function of the frequency, for $f =$ 100 to 800 Hz in intervals of 100 Hz. Find the resonant frequency from the graph and compare with the resonant frequency obtained from the equation.

29. A local FM radio station transmits at a frequency of 94.3 MHz. What value of capacitance is needed in a LC series circuit of $L = 1.00$ H in order to have resonance?

24.5 Power in an AC Circuit

30. A 5.00-A current flows in a series RLC circuit and leads the 120 V applied voltage by 40.0°. Find the power factor of the circuit and the power.

31. The power factor in an RLC series circuit is 0.80. If the resistance of the circuit is 60.0 Ω, find the difference between the reactances, $X_L - X_C$.

24.6 An *RLC* Parallel Circuit

†32. A 220-V, 40.0-Hz, AC line is connected across a parallel RLC circuit of $R = 900\ \Omega$, $L = 7.00$ H, and $C = 8.00\ \mu$F. Find (a) the inductive reactance, (b) the capacitive reactance, (c) the current through the resistor, (d) the current through the inductor, (e) the current through the capacitor, (f) the total current in the circuit, (g) the phase angle ϕ, and (h) the total impedance.

†33. A 110-V, 60.0-Hz, AC line is connected across a resistance of 1000 Ω, which is in parallel with an inductor of 5.00 H. Find (a) the inductive reactance, (b) the current I_R through the resistor, (c) the current I_L through the inductor, (d) the total current in the circuit, (e) the phase angle ϕ, and (f) the total impedance of the circuit.

†34. A 110-V, 60.0-Hz, AC line is connected across a 1.00-μF capacitor in parallel with a 5.00-H inductor. Find (a) the capacitive reactance, (b) the inductive reactance, (c) the current I_C through the capacitor, (d) the current I_L through the inductor, (e) the total current I_T in the circuit, (f) the phase angle ϕ, and (g) the total impedance of the circuit.

†35. A 110-V, 60.0-Hz, AC line is connected across a resistance of 500 Ω in parallel with a capacitor of 4.00 μF. Find (a) the capacitive reactance, (b) the current through R, (c) the current through C, (d) the total current in the circuit, (e) the phase angle ϕ, and (f) the total impedance of the circuit.

24.7 The Transformer

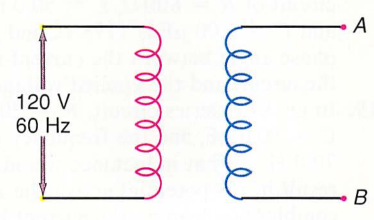
36. A transformer has 100 turns in the primary coil and 250 turns in secondary. If the primary of the transformer is connected to an alternating voltage generator of 400 V, what voltage will appear across the secondary?

37. A transformer has 100 turns in the primary coil and 250 turns in the secondary. If there is an alternating current in the primary of the transformer of 3.00 A, what current will appear in the secondary?

38. If there are 200 turns of wire in the primary of a transformer connected to a 120-V outlet, how many turns do you need in the secondary in order to produce 6.00 V there?

39. A transformer has a current in its primary winding of 2.50 A and a current in its secondary winding of 0.750 A. (a) If there are 20 turns in the primary coil, find the number of turns in the secondary coil. (b) If the resistance of the secondary coil is 100 Ω, find the applied emf in the primary coil and the induced emf in the secondary coil. (Assume 100% efficiency.)

40. Find the turns ratio for the transformer in the diagram such that a spark is given off at the points AB. The distance from point A to point B is 5.00 mm.



41. A power station generates 200 kW at 100 A and 2000 V. If the transmission line has a resistance of 10.0 Ω, how much power will be lost in transmission? If a step-up transformer of 1:10 is used, what will the power loss be then?

Additional Problems

42. RC and RL circuits are sometimes used as timing circuits; show that the units of RC and L/R have the unit of time.

†43. A 220-V, 40.0-Hz, AC line is connected across a series RLC circuit of $R = 900\ \Omega$, $L = 7.00$ H, and $C = 8.00\ \mu$F. Find (a) the inductive reactance; (b) the capacitive reactance; (c) the impedance of the circuit; (d) the current in the circuit; (e) the voltage drop across R, L, and C; (f) the total voltage across the circuit; (g) the phase angle ϕ; and (h) the resonant frequency.

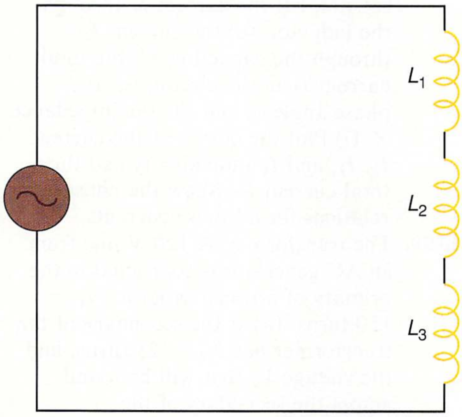
†44. A 60.0-V, 100-Hz, AC line is connected across a series RLC circuit of $R = 1000\ \Omega$, $L = 10.0$ H, and $C = 2.00\ \mu$F. Find (a) the inductive reactance, (b) the capacitive reactance, (c) the impedance of the circuit, (d) the current in the circuit, (e) the voltage drop across R, (f) the voltage drop across L, (g) the voltage drop across C, (h) the total voltage drop across the circuit, (i) the phase angle, (j) the power factor, and (k) the resonant frequency.

†45. A 110-V, 60.0-Hz, AC line is connected across a resistor of 1800 Ω, in series with a capacitor of 3.00 μF. Find (a) the capacitive reactance, (b) the impedance, (c) the current in the circuit, (d) the voltage drop across R, (e) the voltage drop across C, (f) the total voltage measured across R and C in series, (g) the phase angle ϕ, and (h) the power factor.

†46. A 120-V, 60.0-Hz, AC line is connected across a series circuit of a resistance of 500 Ω and an inductor of 10.0 H. Find (a) the inductive reactance, (b) the impedance, (c) the current in the circuit, (d) the voltage drop across R, (e) the voltage drop across L, (f) the total voltage drop across the circuit, (g) the phase angle ϕ, and (h) the power factor.

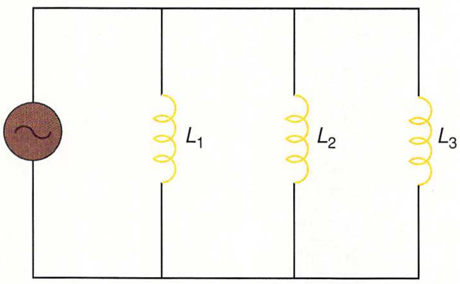
†47. Three inductors are connected in series to an AC source as shown in the diagram. The inductors are shielded so that a changing flux in one inductor does not cause a mutual inductance in another inductor. Show that the equivalent inductance of the inductors in series is given by

$$L = L_1 + L_2 + L_3$$

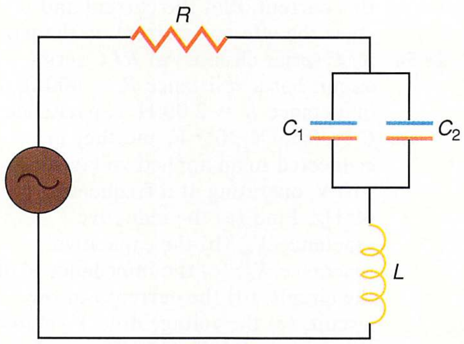


†48. Three shielded inductors are connected in parallel as shown in the diagram. The inductors are shielded so that a changing flux in one inductor does not cause a mutual inductance in another inductor. Show that the equivalent inductance of the inductors in parallel is given by

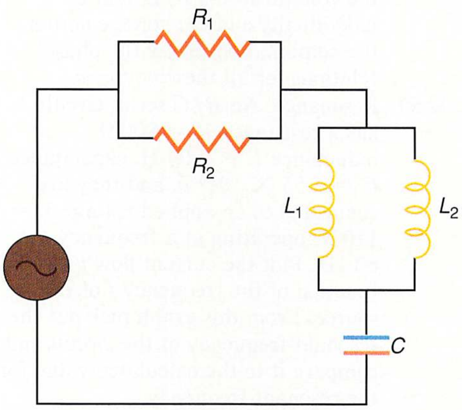
$$\frac{1}{L} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}$$



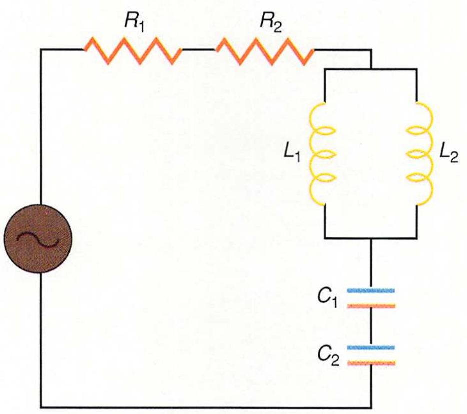
†49. In the circuit shown $R = 1300\ \Omega$, $C_1 = 5.00\ \mu F$, $C_2 = 8.00\ \mu F$, $L = 6.78$ mH, and the applied voltage is 110 V at 60.0 Hz. Find the current through each circuit element.



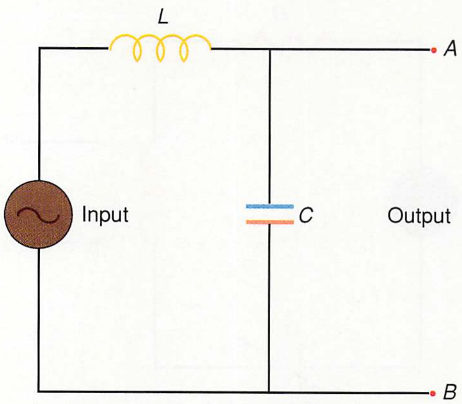
†50. In the circuit shown $R_1 = 978\ \Omega$, $R_2 = 560\ \Omega$, $L_1 = 6.78$ mH, $L_2 = 3.25$ mH, $C = 5.00\ \mu F$, and the applied voltage is 110 V at 60.0 Hz. Find the current through each circuit element.



†51. In the circuit shown $R_1 = 535\ \Omega$, $R_2 = 350\ \Omega$, $L_1 = 3.25$ mH, $L_2 = 2.56$ mH, $C_1 = 5.00\ \mu F$, $C_2 = 7.50\ \mu F$, and the applied voltage is 110 V at 60.0 Hz. Find the current through each circuit element.

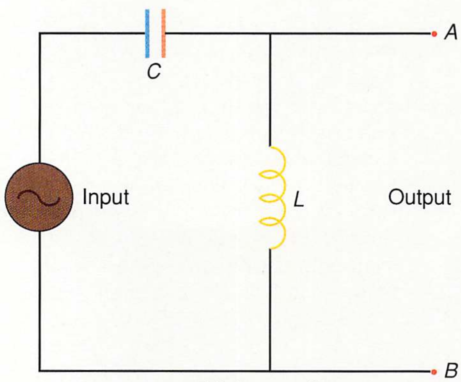


52. The diagram is an example of a low-pass filter. Show that very low-input frequencies pass through the circuit while high frequencies do not. That is, show that high-output voltages are obtained across AB for low-input frequencies, while very low-output voltages are obtained for high-input frequencies.



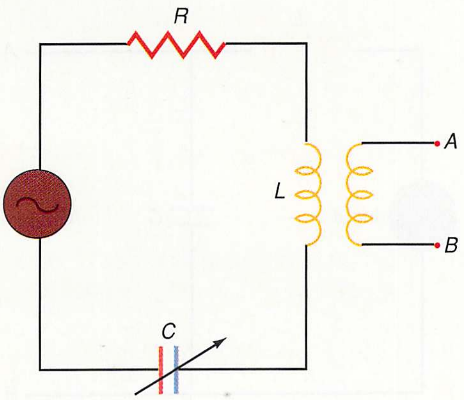
Low-pass filter

53. The diagram is an example of a high-pass filter. Show that very high-input frequencies pass through the circuit while low frequencies do not. That is, show that high-output voltages are obtained across AB for high-input frequencies, while very low-output voltages are obtained for low-input frequencies.



High-pass filter

†54. Find the turns ratio between the primary and secondary coils in the diagram, to produce a spark across AB, a distance of 5.00 mm, and find the value of C to give a spark rate of 5.00 Hz, 10.0 Hz, and 30.0 Hz. The value of the inductance is 5.00 H, $R = 500\ \Omega$, and the peak voltage is 1200 V.



Interactive Tutorials

55. Effective current in an AC circuit. An alternating current of frequency $f = 60$ Hz varies from -2.54 A to 2.54 A. Find the effective value of this current. Plot the current and show the effective current on the plot.

56. *RLC* series circuit. An *RLC* series circuit has a resistance $R = 800\ \Omega$, inductance $L = 2.00$ H, capacitance $C = 5.55 \times 10^{-6}$ F, and they are connected to an applied voltage $V = 110$ V, operating at a frequency $f = 60$ Hz. Find (a) the inductive reactance X_L, (b) the capacitive reactance X_C, (c) the impedance Z of the circuit, (d) the current i in the circuit, (e) the voltage drop V_R across the resistor, (f) the voltage drop V_L across the inductor, (g) the voltage drop V_C across the capacitor, (h) the total voltage drop across *RLC*, (i) the phase angle ϕ, and (j) the resonant frequency f_0. (k) Plot the curves of the voltage across R, L, and C individually and the voltage across the combination. Show the phase relations for all these voltages.

57. Resonance. An *RLC* series circuit has a resistance $R = 800\ \Omega$, inductance $L = 2.00$ H, capacitance $C = 5.55 \times 10^{-6}$ F, and they are connected to an applied voltage $V = 110$ V, operating at a frequency $f = 60$ Hz. Plot the current flow i as a function of the frequency f of the AC source. From this graph pick out the resonant frequency of the circuit and compare it to the calculated value for the resonant frequency.

58. *RLC* parallel circuit. An *RLC* parallel circuit has a resistance $R = 800\ \Omega$, inductance $L = 2.00$ H, capacitance $C = 5.55 \times 10^{-6}$ F, and they are connected to an applied voltage $V = 110$ V, operating at a frequency $f = 60$ Hz. Find (a) the inductive reactance X_L, (b) the capacitive reactance X_C, (c) the current I_R through the resistor, (d) the current I_L through the inductor, (e) the current I_C through the capacitor, (f) the total current I_T in the circuit, (g) the phase angle ϕ, and (h) the impedance Z. (i) Plot the curves of the current I_R, I_L, and I_C individually and the total current I_T. Show the phase relations for all these currents.

59. The transformer. A 120-V line from an AC generator is connected to the primary of a transformer of $N_1 = 150$ turns. (a) If the secondary of the transformer has $N_2 = 25$ turns, find the voltage V_2 that will be found across the secondary of the transformer. (b) If the current in the primary $i_1 = 0.05$ A, find the current i_2 in the secondary.