7.5 In the circuit of Fig. 7.79, the capacitor voltage just before $t = 0$ is:

(a) 10 V (b) 7 V (c) 6 V
(d) 4 V (e) 0 V

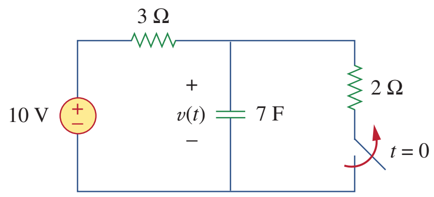

Figure 7.79
For Review Questions 7.5 and 7.6.

7.6 In the circuit in Fig. 7.79, $v(\infty)$ is:

(a) 10 V (b) 7 V (c) 6 V
(d) 4 V (e) 0 V

7.7 For the circuit in Fig. 7.80, the inductor current just before $t = 0$ is:

(a) 8 A (b) 6 A (c) 4 A
(d) 2 A (e) 0 A

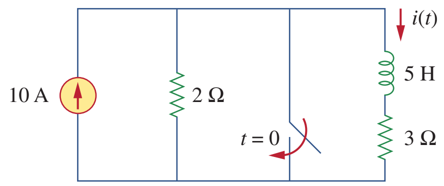

Figure 7.80
For Review Questions 7.7 and 7.8.

7.8 In the circuit of Fig. 7.80, $i(\infty)$ is:

(a) 10 A (b) 6 A (c) 4 A
(d) 2 A (e) 0 A

7.9 If v_s changes from 2 V to 4 V at $t = 0$, we may express v_s as:

(a) $\delta(t)$ V (b) $2u(t)$ V
(c) $2u(-t) + 4u(t)$ V (d) $2 + 2u(t)$ V
(e) $4u(t) - 2$ V

7.10 The pulse in Fig. 7.116(a) can be expressed in terms of singularity functions as:

(a) $2u(t) + 2u(t-1)$ V (b) $2u(t) - 2u(t-1)$ V
(c) $2u(t) - 4u(t-1)$ V (d) $2u(t) + 4u(t-1)$ V

Answers: 7.1d, 7.2b, 7.3c, 7.4b, 7.5d, 7.6a, 7.7c, 7.8e, 7.9c,d, 7.10b.

Problems

Section 7.2 The Source-Free *RC* Circuit

7.1 In the circuit shown in Fig. 7.81

$$v(t) = 56e^{-200t}\ \text{V}, \quad t > 0$$
$$i(t) = 8e^{-200t}\ \text{mA}, \quad t > 0$$

(a) Find the values of R and C.

(b) Calculate the time constant τ.

(c) Determine the time required for the voltage to decay half its initial value at $t = 0$.

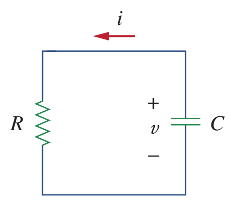

Figure 7.81
For Prob. 7.1.

7.2 Find the time constant for the *RC* circuit in Fig. 7.82.

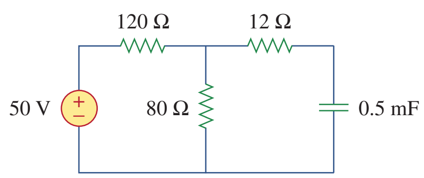

Figure 7.82
For Prob. 7.2.

7.3 Determine the time constant for the circuit in Fig. 7.83.

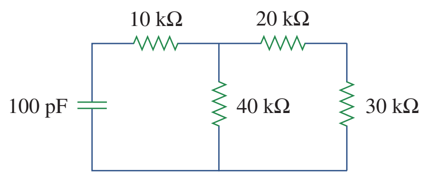

Figure 7.83
For Prob. 7.3.

7.4 The switch in Fig. 7.84 has been in position A for a long time. Assume the switch moves instantaneously from A to B at $t = 0$. Find v for $t > 0$.

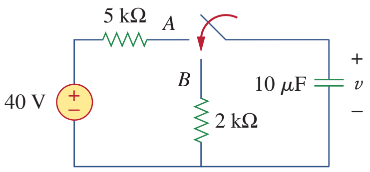

Figure 7.84
For Prob. 7.4.

7.5 Using Fig. 7.85, design a problem to help other students better understand source-free RC circuits.

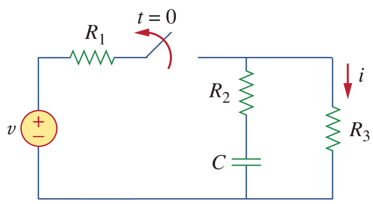

Figure 7.85
For Prob. 7.5.

7.6 The switch in Fig. 7.86 has been closed for a long time, and it opens at $t = 0$. Find $v(t)$ for $t \geq 0$.

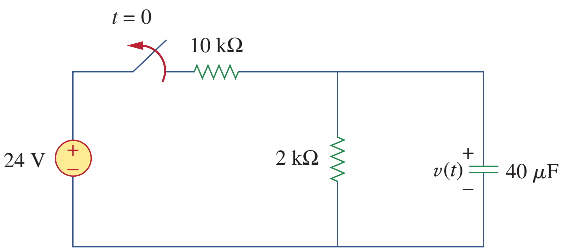

Figure 7.86
For Prob. 7.6.

7.7 Assuming that the switch in Fig. 7.87 has been in position A for a long time and is moved to position B at $t = 0$, find $v_o(t)$ for $t \geq 0$.

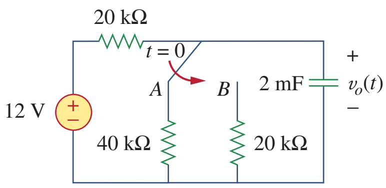

Figure 7.87
For Prob. 7.7.

7.8 For the circuit in Fig. 7.88, if

$$v = 10e^{-4t}\ \text{V} \qquad \text{and} \qquad i = 0.2\, e^{-4t}\ \text{A}, \qquad t > 0$$

(a) Find R and C.

(b) Determine the time constant.

(c) Calculate the initial energy in the capacitor.

(d) Obtain the time it takes to dissipate 50 percent of the initial energy.

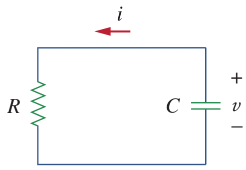

Figure 7.88
For Prob. 7.8.

7.9 The switch in Fig. 7.89 opens at $t = 0$. Find v_o for $t > 0$.

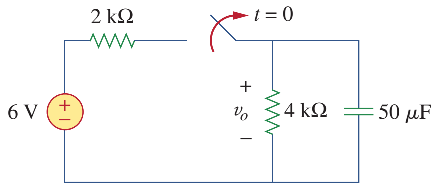

Figure 7.89
For Prob. 7.9.

7.10 For the circuit in Fig. 7.90, find $v_o(t)$ for $t > 0$. Determine the time necessary for the capacitor voltage to decay to one-third of its value at $t = 0$.

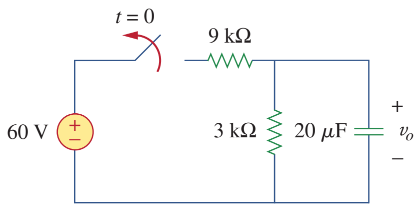

Figure 7.90
For Prob. 7.10.

Section 7.3 The Source-Free *RL* Circuit

7.11 For the circuit in Fig. 7.91, find i_o for $t > 0$.

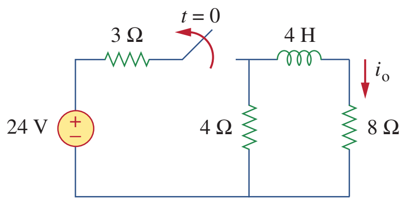

Figure 7.91
For Prob. 7.11.

7.12 Using Fig. 7.92, design a problem to help other students better understand source-free RL circuits.

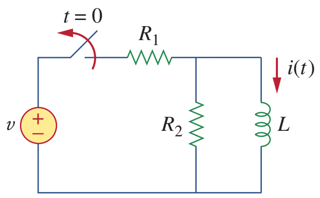

Figure 7.92
For Prob. 7.12.

7.13 In the circuit of Fig. 7.93,

$$v(t) = 20e^{-10^3 t}\text{ V}, \quad t > 0$$
$$i(t) = 4e^{-10^3 t}\text{ mA}, \quad t > 0$$

(a) Find R, L, and τ.

(b) Calculate the energy dissipated in the resistance for $0 < t < 0.5$ ms.

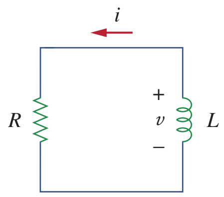

Figure 7.93
For Prob. 7.13.

7.14 Calculate the time constant of the circuit in Fig. 7.94.

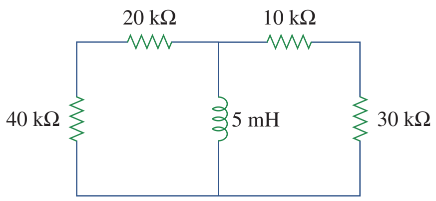

Figure 7.94
For Prob. 7.14.

7.15 Find the time constant for each of the circuits in Fig. 7.95.

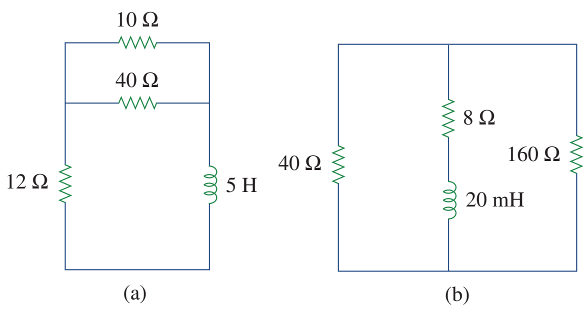

Figure 7.95
For Prob. 7.15.

7.16 Determine the time constant for each of the circuits in Fig. 7.96.

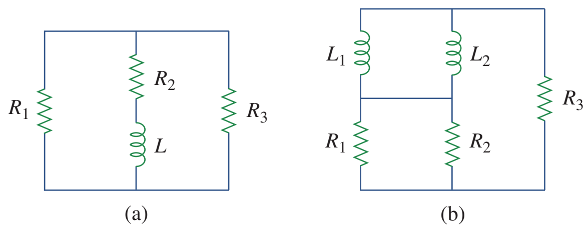

Figure 7.96
For Prob. 7.16.

7.17 Consider the circuit of Fig. 7.97. Find $v_o(t)$ if $i(0) = 2$ A and $v(t) = 0$.

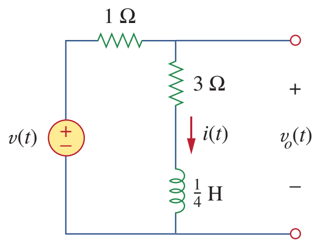

Figure 7.97
For Prob. 7.17.

7.18 For the circuit in Fig. 7.98, determine $v_o(t)$ when $i(0) = 1$ A and $v(t) = 0$.

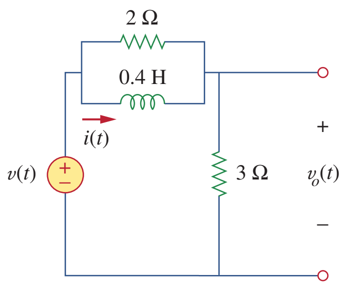

Figure 7.98
For Prob. 7.18.

7.19 In the circuit of Fig. 7.99, find $i(t)$ for $t > 0$ if $i(0) = 2$ A.

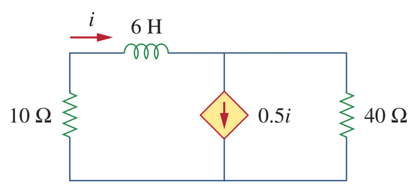

Figure 7.99
For Prob. 7.19.

7.20 For the circuit in Fig. 7.100,

$$v = 150e^{-50t}\text{ V}$$

and

$$i = 30e^{-50t}\text{ A}, \qquad t > 0$$

(a) Find L and R.

(b) Determine the time constant.

(c) Calculate the initial energy in the inductor.

(d) What fraction of the initial energy is dissipated in 10 ms?

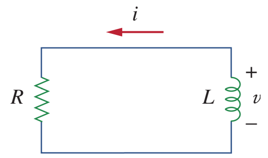

Figure 7.100
For Prob. 7.20.

7.21 In the circuit of Fig. 7.101, find the value of R for which the steady-state energy stored in the inductor will be 0.25 J.

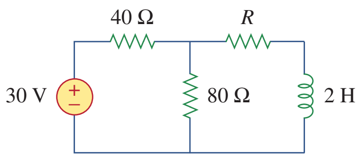

Figure 7.101
For Prob. 7.21.

7.22 Find $i(t)$ and $v(t)$ for $t > 0$ in the circuit of Fig. 7.102 if $i(0) = 20$ A.

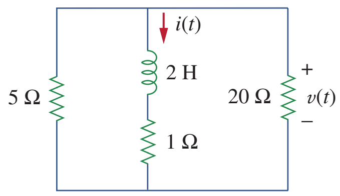

Figure 7.102
For Prob. 7.22.

7.23 Consider the circuit in Fig. 7.103. Given that $v_o(0) = 2$ V, find v_o and v_x for $t > 0$.

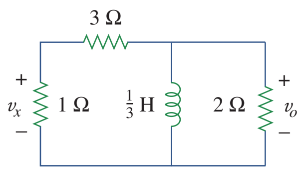

Figure 7.103
For Prob. 7.23.

Section 7.4 Singularity Functions

7.24 Express the following signals in terms of singularity functions.

(a) $v(t) = \begin{cases} 0, & t < 0 \\ -5, & t > 0 \end{cases}$

(b) $i(t) = \begin{cases} 0, & t < 1 \\ -10, & 1 < t < 3 \\ 10, & 3 < t < 5 \\ 0, & t > 5 \end{cases}$

(c) $x(t) = \begin{cases} t - 1, & 1 < t < 2 \\ 1, & 2 < t < 3 \\ 4 - t, & 3 < t < 4 \\ 0, & \text{Otherwise} \end{cases}$

(d) $y(t) = \begin{cases} 2, & t < 0 \\ -5, & 0 < t < 1 \\ 0, & t > 1 \end{cases}$

7.25 Design a problem to help other students better understand singularity functions.

7.26 Express the signals in Fig. 7.104 in terms of singularity functions.

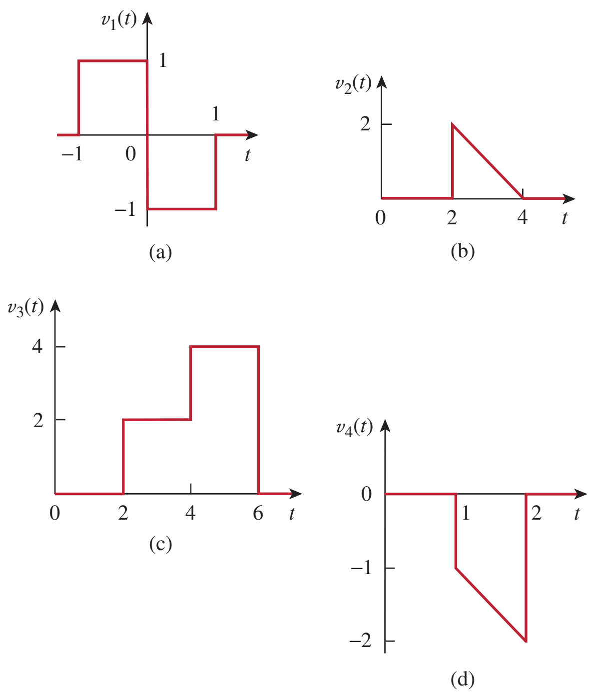

Figure 7.104
For Prob. 7.26.

7.27 Express $v(t)$ in Fig. 7.105 in terms of step functions.

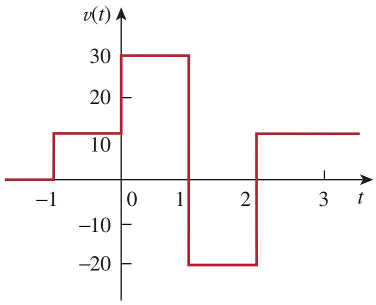

Figure 7.105
For Prob. 7.27.

7.28 Sketch the waveform represented by

$$i(t) = r(t) - r(t-1) - u(t-2) - r(t-2) + r(t-3) + u(t-4)$$

7.29 Sketch the following functions:

(a) $x(t) = 5e^{-t}u(t-1)$

(b) $y(t) = 20e^{-(t-1)}u(t)$

(c) $z(t) = 5\cos 4t\delta(t-1)$

7.30 Evaluate the following integrals involving the impulse functions:

(a) $\int_{-\infty}^{\infty} 4t^2\delta(t-1)\,dt$

(b) $\int_{-\infty}^{\infty} 4t^2 \cos 2\pi t\delta(t-0.5)\,dt$

7.31 Evaluate the following integrals:

(a) $\int_{-\infty}^{\infty} e^{-4t^2}\delta(t-2)\,dt$

(b) $\int_{-\infty}^{\infty} [5\delta(t) + e^{-t}\delta(t) + \cos 2\pi t\delta(t)]\,dt$

7.32 Evaluate the following integrals:

(a) $\int_{1}^{t} u(\lambda)\,d\lambda$

(b) $\int_{0}^{4} r(t-1)\,dt$

(c) $\int_{1}^{5} (t-6)^2\delta(t-2)\,dt$

7.33 The voltage across a 10-mH inductor is $20\delta(t-2)$ mV. Find the inductor current, assuming that the inductor is initially uncharged.

7.34 Evaluate the following derivatives:

(a) $\frac{d}{dt}[u(t-1)u(t+1)]$

(b) $\frac{d}{dt}[r(t-6)u(t-2)]$

(c) $\frac{d}{dt}[\sin 4tu(t-3)]$

7.35 Find the solution to the following differential equations:

(a) $\frac{dv}{dt} + 2v = 0, \quad v(0) = -1\text{ V}$

(b) $2\frac{di}{dt} - 3i = 0, \quad i(0) = 2$

7.36 Solve for v in the following differential equations, subject to the stated initial condition.

(a) $dv/dt + v = u(t), \quad v(0) = 0$

(b) $2\,dv/dt - v = 3u(t), \quad v(0) = -6$

7.37 A circuit is described by

$$4\frac{dv}{dt} + v = 10$$

(a) What is the time constant of the circuit?

(b) What is $v(\infty)$, the final value of v?

(c) If $v(0) = 2$, find $v(t)$ for $t \geq 0$.

7.38 A circuit is described by

$$\frac{di}{dt} + 3i = 2u(t)$$

Find $i(t)$ for $t > 0$ given that $i(0) = 0$.

Section 7.5 Step Response of an *RC* Circuit

7.39 Calculate the capacitor voltage for $t < 0$ and $t > 0$ for each of the circuits in Fig. 7.106.

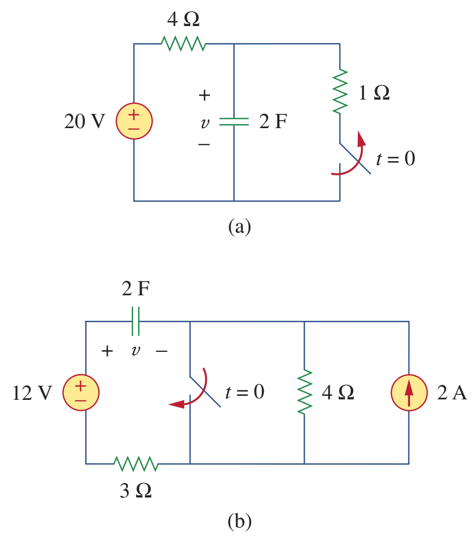

Figure 7.106
For Prob. 7.39.

7.40 Find the capacitor voltage for $t < 0$ and $t > 0$ for each of the circuits in Fig. 7.107.

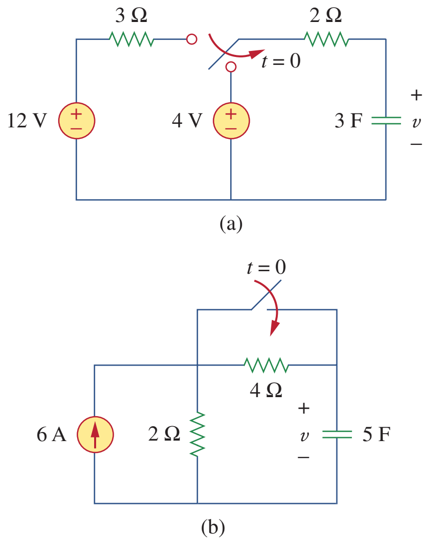

Figure 7.107
For Prob. 7.40.

7.41 Using Fig. 7.108, design a problem to help other students better understand the step response of an *RC* circuit.

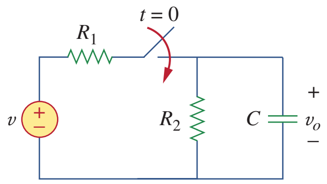

Figure 7.108
For Prob. 7.41.

7.42 (a) If the switch in Fig. 7.109 has been open for a long time and is closed at $t = 0$, find $v_o(t)$.
(b) Suppose that the switch has been closed for a long time and is opened at $t = 0$. Find $v_o(t)$.

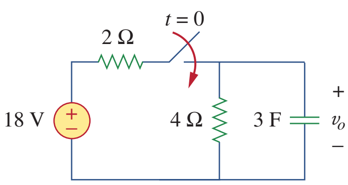

Figure 7.109
For Prob. 7.42.

7.43 Consider the circuit in Fig. 7.110. Find $i(t)$ for $t < 0$ and $t > 0$.

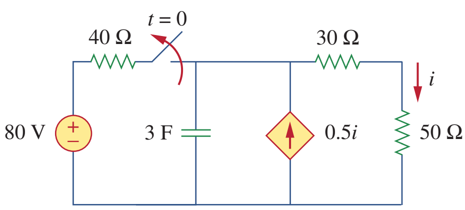

Figure 7.110
For Prob. 7.43.

7.44 The switch in Fig. 7.111 has been in position *a* for a long time. At $t = 0$, it moves to position *b*. Calculate $i(t)$ for all $t > 0$.

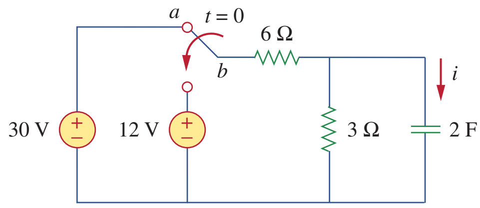

Figure 7.111
For Prob. 7.44.

7.45 Find v_o in the circuit of Fig. 7.112 when $v_s = 6u(t)$. Assume that $v_o(0) = 1$ V.

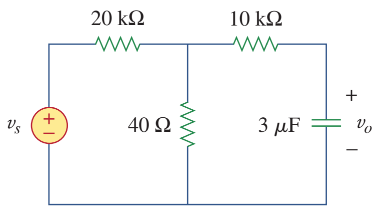

Figure 7.112
For Prob. 7.45.

7.46 For the circuit in Fig. 7.113, $i_s(t) = 5u(t)$. Find $v(t)$.

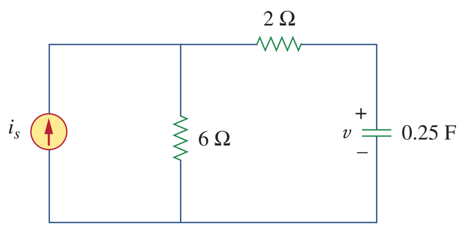

Figure 7.113
For Prob. 7.46.

7.47 Determine $v(t)$ for $t > 0$ in the circuit of Fig. 7.114 if $v(0) = 0$.

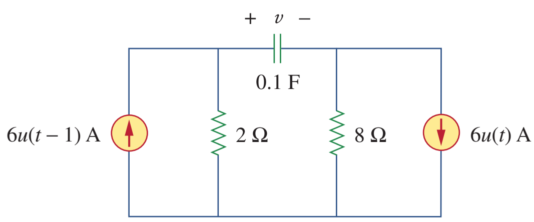

Figure 7.114
For Prob. 7.47.

7.48 Find $v(t)$ and $i(t)$ in the circuit of Fig. 7.115.

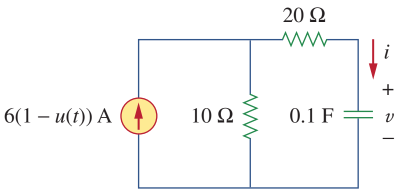

Figure 7.115
For Prob. 7.48.

7.49 If the waveform in Fig. 7.116(a) is applied to the circuit of Fig. 7.116(b), find $v(t)$. Assume $v(0) = 0$.

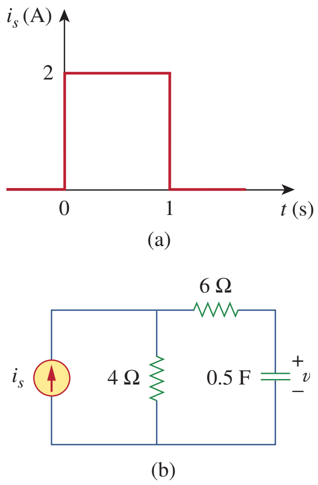

Figure 7.116
For Prob. 7.49 and Review Question 7.10.

***7.50** In the circuit of Fig. 7.117, find i_x for $t > 0$. Let $R_1 = R_2 = 1\ \text{k}\Omega$, $R_3 = 2\ \text{k}\Omega$, and $C = 0.25$ mF.

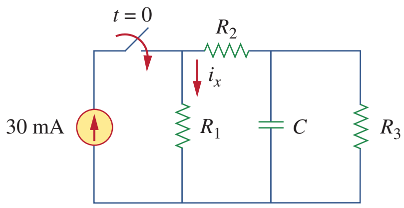

Figure 7.117
For Prob. 7.50.

Section 7.6 Step Response of an *RL* Circuit

7.51 Rather than applying the short-cut technique used in Section 7.6, use KVL to obtain Eq. (7.60).

7.52 Using Fig. 7.118, design a problem to help other students better understand the step response of an *RL* circuit.

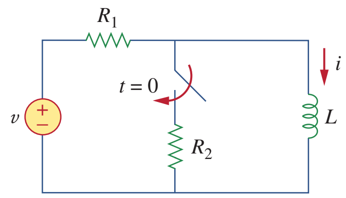

Figure 7.118
For Prob. 7.52.

7.53 Determine the inductor current $i(t)$ for both $t < 0$ and $t > 0$ for each of the circuits in Fig. 7.119.

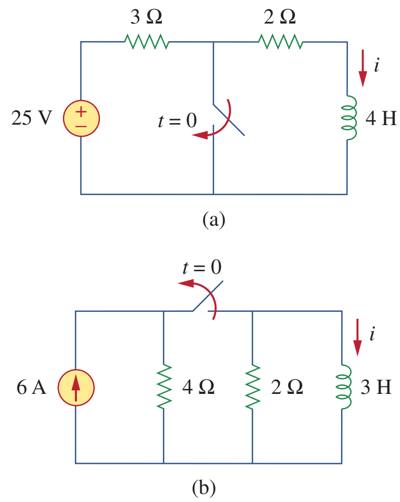

Figure 7.119
For Prob. 7.53.

7.54 Obtain the inductor current for both $t < 0$ and $t > 0$ in each of the circuits in Fig. 7.120.

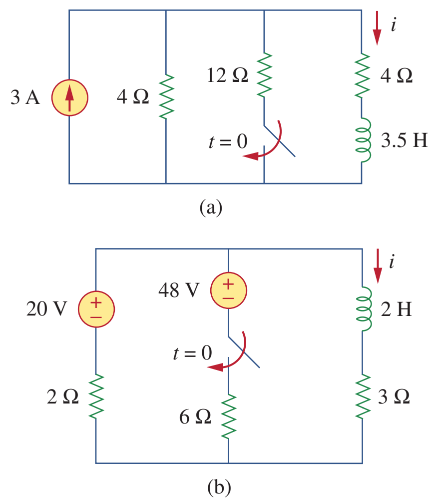

Figure 7.120
For Prob. 7.54.

* An asterisk indicates a challenging problem.

7.55 Find $v(t)$ for $t < 0$ and $t > 0$ in the circuit of Fig. 7.121.

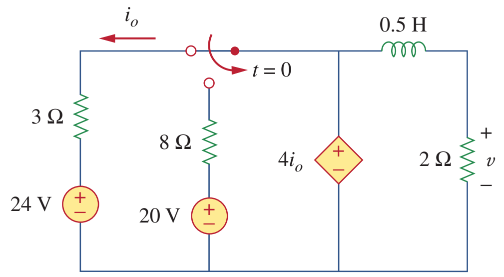

Figure 7.121
For Prob. 7.55.

7.56 For the network shown in Fig. 7.122, find $v(t)$ for $t > 0$.

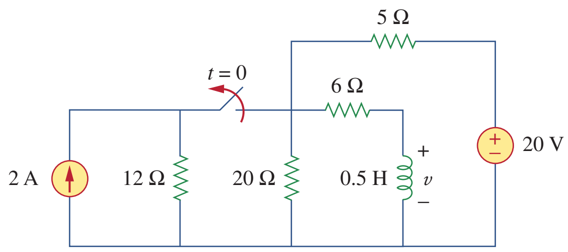

Figure 7.122
For Prob. 7.56.

***7.57** Find $i_1(t)$ and $i_2(t)$ for $t > 0$ in the circuit of Fig. 7.123.

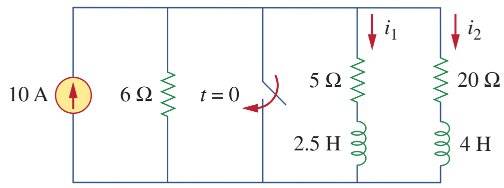

Figure 7.123
For Prob. 7.57.

7.58 Rework Prob. 7.17 if $i(0) = 10$ A and $v(t) = 20u(t)$ V.

7.59 Determine the step response $v_o(t)$ to $v_s = 9u(t)$ V in the circuit of Fig. 7.124.

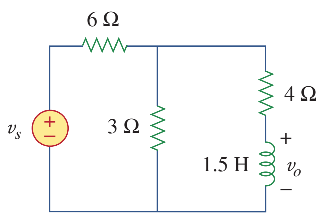

Figure 7.124
For Prob. 7.59.

7.60 Find $v(t)$ for $t > 0$ in the circuit of Fig. 7.125 if the initial current in the inductor is zero.

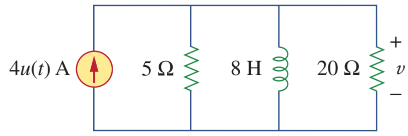

Figure 7.125
For Prob. 7.60.

7.61 In the circuit of Fig. 7.126, i_s changes from 5 A to 10 A at $t = 0$; that is, $i_s = (5 + 5u(t))$ A. Find v and i.

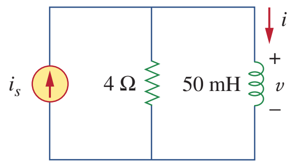

Figure 7.126
For Prob. 7.61.

7.62 For the circuit in Fig. 7.127, calculate $i(t)$ if $i(0) = 0$.

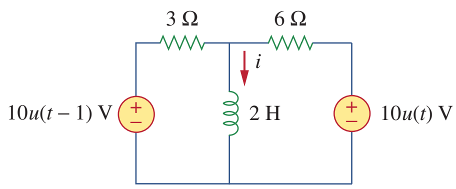

Figure 7.127
For Prob. 7.62.

7.63 Obtain $v(t)$ and $i(t)$ in the circuit of Fig. 7.128.

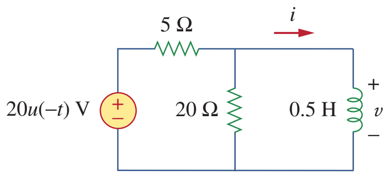

Figure 7.128
For Prob. 7.63.

7.64 Find $v_o(t)$ for $t > 0$ in the circuit of Fig. 7.129.

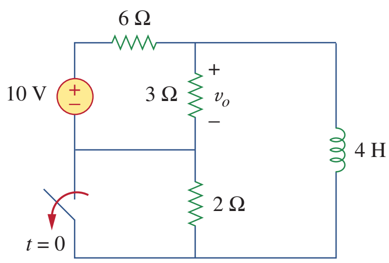

Figure 7.129
For Prob. 7.64.

7.65 If the input pulse in Fig. 7.130(a) is applied to the circuit in Fig. 7.130(b), determine the response $i(t)$.

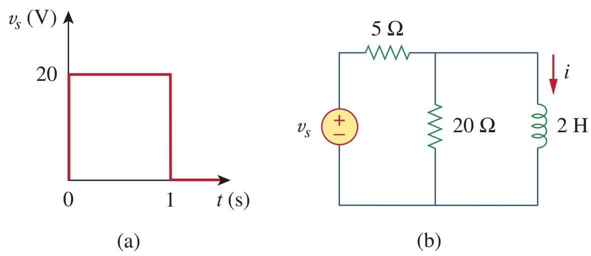

Figure 7.130
For Prob. 7.65.

Section 7.7 First-order Op Amp Circuits

7.66 Using Fig. 7.131, design a problem to help other students better understand first-order op amp circuits.

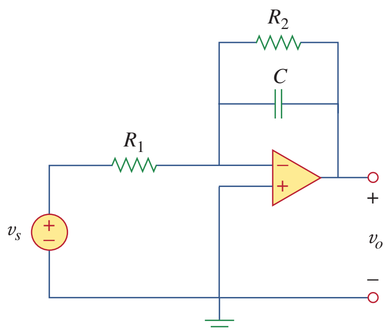

Figure 7.131
For Prob. 7.66.

7.67 If $v(0) = 10$ V, find $v_o(t)$ for $t > 0$ in the op amp circuit of Fig. 7.132. Let $R = 10$ kΩ and $C = 1$ μF.

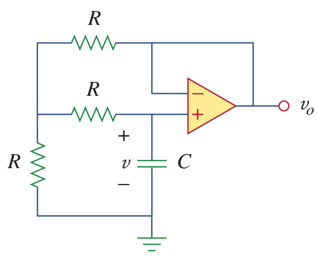

Figure 7.132
For Prob. 7.67.

7.68 Obtain v_o for $t > 0$ in the circuit of Fig. 7.133.

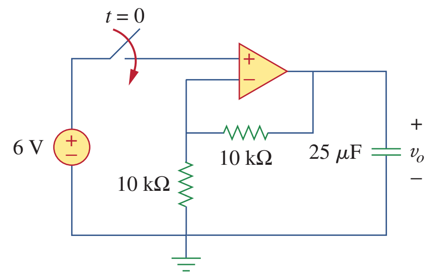

Figure 7.133
For Prob. 7.68.

7.69 For the op amp circuit in Fig. 7.134, find $v_o(t)$ for $t > 0$.

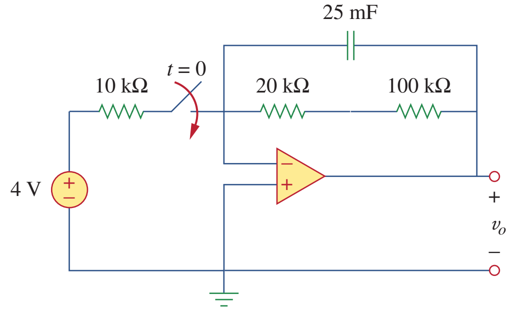

Figure 7.134
For Prob. 7.69.

7.70 Determine v_o for $t > 0$ when $v_s = 20$ mV in the op amp circuit of Fig. 7.135.

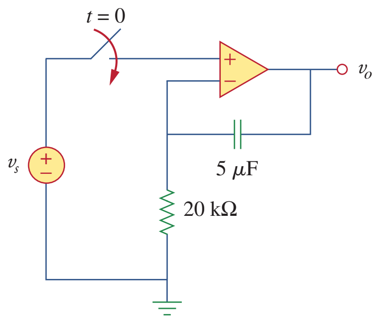

Figure 7.135
For Prob. 7.70.

7.71 For the op amp circuit in Fig. 7.136, suppose $v_0 = 0$ and $v_s = 3$ V. Find $v(t)$ for $t > 0$.

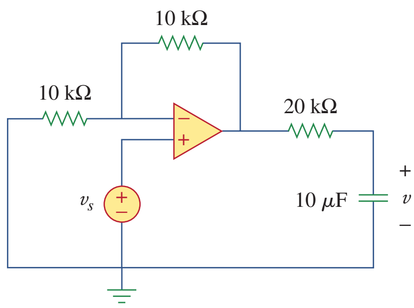

Figure 7.136
For Prob. 7.71.

7.72 Find i_o in the op amp circuit in Fig. 7.137. Assume that $v(0) = -2$ V, $R = 10$ kΩ, and $C = 10$ μF.

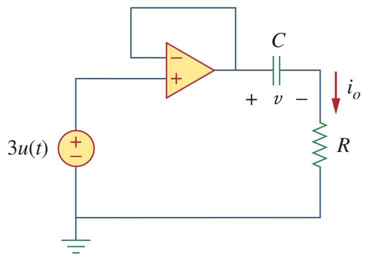

Figure 7.137
For Prob. 7.72.

7.73 For the circuit shown in Fig. 7.138, solve for $i_o(t)$.

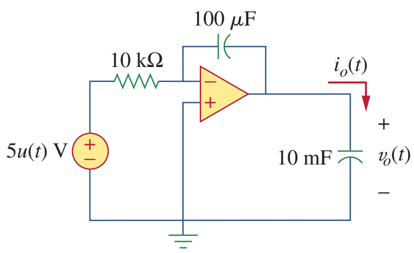

Figure 7.138
For Prob. 7.73.

7.74 Determine $v_o(t)$ for $t > 0$ in the circuit of Fig. 7.139. Let $i_s = 10u(t)$ μA and assume that the capacitor is initially uncharged.

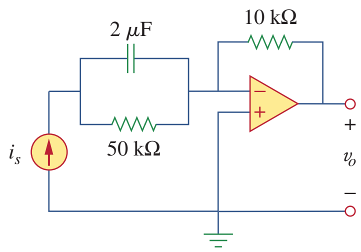

Figure 7.139
For Prob. 7.74.

7.75 In the circuit of Fig. 7.140, find v_o and i_o, given that $v_s = 4u(t)$ V and $v(0) = 1$ V.

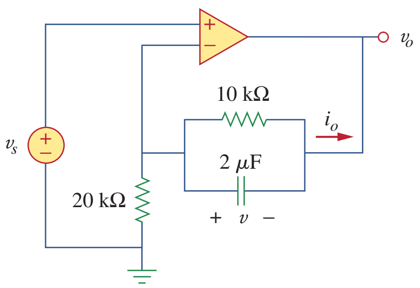

Figure 7.140
For Prob. 7.75.

Section 7.8 Transient Analysis with *PSpice*

7.76 Repeat Prob. 7.49 using *PSpice*.

7.77 The switch in Fig. 7.141 opens at $t = 0$. Use *PSpice* to determine $v(t)$ for $t > 0$.

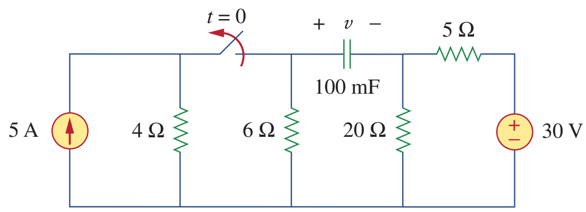

Figure 7.141
For Prob. 7.77.

7.78 The switch in Fig. 7.142 moves from position *a* to *b* at $t = 0$. Use *PSpice* to find $i(t)$ for $t > 0$.

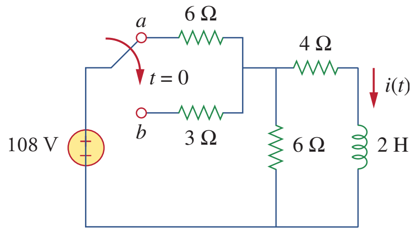

Figure 7.142
For Prob. 7.78.

7.79 In the circuit of Fig. 7.143, the switch has been in position *a* for a long time but moves instantaneously to position *b* at $t = 0$. Determine $i_o(t)$.

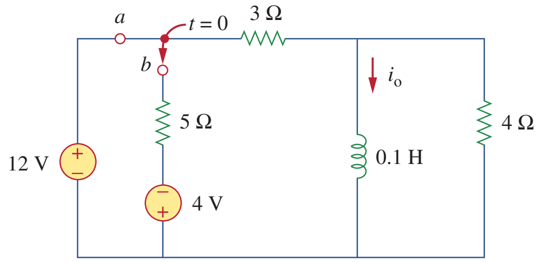

Figure 7.143
For Prob. 7.79.

7.80 In the circuit of Fig. 7.144, assume that the switch has been in position *a* for a long time, find:

(a) $i_1(0)$, $i_2(0)$, and $v_o(0)$

(b) $i_L(t)$

(c) $i_1(\infty)$, $i_2(\infty)$, and $v_o(\infty)$.

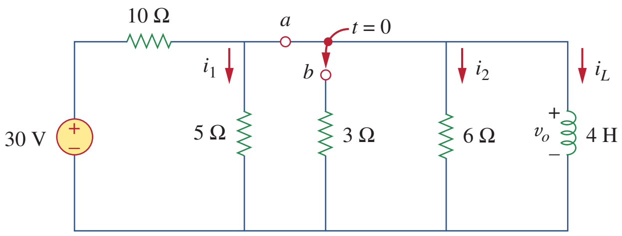

Figure 7.144
For Prob. 7.80.

7.81 Repeat Prob. 7.65 using *PSpice*.

Section 7.9 Applications

7.82 In designing a signal-switching circuit, it was found that a 100-μF capacitor was needed for a time constant of 3 ms. What value resistor is necessary for the circuit?

7.83 An *RC* circuit consists of a series connection of a 120-V source, a switch, a 34-MΩ resistor, and a 15-μF capacitor. The circuit is used in estimating the speed of a horse running a 4-km racetrack. The switch closes when the horse begins and opens when the horse crosses the finish line. Assuming that the capacitor charges to 85.6 V, calculate the speed of the horse.

7.84 The resistance of a 160-mH coil is 8 Ω. Find the time required for the current to build up to 60 percent of its final value when voltage is applied to the coil.

7.85 A simple relaxation oscillator circuit is shown in Fig. 7.145. The neon lamp fires when its voltage reaches 75 V and turns off when its voltage drops to 30 V. Its resistance is 120 Ω when on and infinitely high when off.

(a) For how long is the lamp on each time the capacitor discharges?

(b) What is the time interval between light flashes?

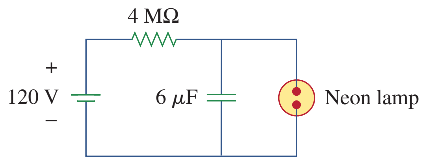

Figure 7.145
For Prob. 7.85.

7.86 Figure 7.146 shows a circuit for setting the length of time voltage is applied to the electrodes of a welding machine. The time is taken as how long it takes the capacitor to charge from 0 to 8 V. What is the time range covered by the variable resistor?

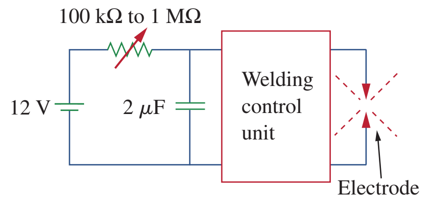

Figure 7.146
For Prob. 7.86.

7.87 A 120-V dc generator energizes a motor whose coil has an inductance of 50 H and a resistance of 100 Ω. A field discharge resistor of 400 Ω is connected in parallel with the motor to avoid damage to the motor, as shown in Fig. 7.147. The system is at steady state. Find the current through the discharge resistor 100 ms after the breaker is tripped.

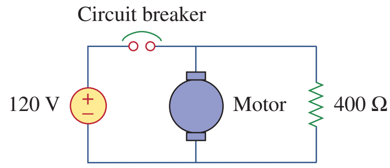

Figure 7.147
For Prob. 7.87.

Comprehensive Problems

7.88 The circuit in Fig. 7.148(a) can be designed as an approximate differentiator or an integrator, depending on whether the output is taken across the resistor or the capacitor, and also on the time constant $\tau = RC$ of the circuit and the width T of the input pulse in Fig. 7.148(b). The circuit is a differentiator if $\tau \ll T$, say $\tau < 0.1T$, or an integrator if $\tau \gg T$, say $\tau > 10T$.

(a) What is the minimum pulse width that will allow a differentiator output to appear across the capacitor?

(b) If the output is to be an integrated form of the input, what is the maximum value the pulse width can assume?

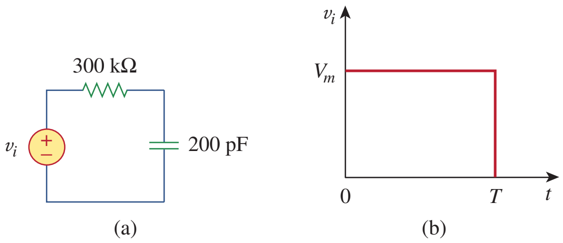

Figure 7.148
For Prob. 7.88.

7.89 An *RL* circuit may be used as a differentiator if the output is taken across the inductor and $\tau \ll T$ (say $\tau < 0.1T$), where T is the width of the input pulse. If R is fixed at 200 kΩ, determine the maximum value of L required to differentiate a pulse with $T = 10\ \mu$s.

7.90 An attenuator probe employed with oscilloscopes was designed to reduce the magnitude of the input voltage v_i by a factor of 10. As shown in Fig. 7.149, the oscilloscope has internal resistance R_s and capacitance C_s, while the probe has an internal resistance R_p. If R_p is fixed at 6 MΩ, find R_s and C_s for the circuit to have a time constant of 15 μs.

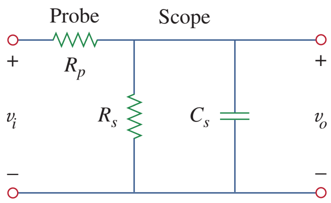

Figure 7.149
For Prob. 7.90.

7.91 The circuit in Fig. 7.150 is used by a biology student to study "frog kick." She noticed that the frog kicked a little when the switch was closed but kicked violently for 5 s when the switch was opened. Model the frog as a resistor and calculate its resistance. Assume that it takes 10 mA for the frog to kick violently.

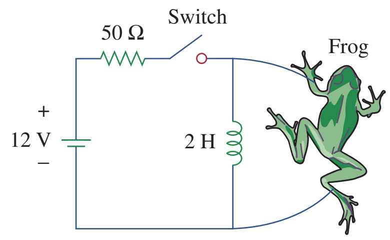

Figure 7.150
For Prob. 7.91.

7.92 To move a spot of a cathode-ray tube across the screen requires a linear increase in the voltage across the deflection plates, as shown in Fig. 7.151. Given that the capacitance of the plates is 4 nF, sketch the current flowing through the plates.

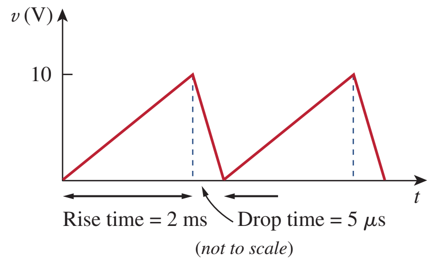

Figure 7.151
For Prob. 7.92.