circuit designs using criteria such as cost, power consumption, and parts count.

- Charge \( (q) \) and energy \( (w) \) are the basic physical variables involved in electrical phenomena. Current \( (i) \), voltage \( (v) \), and power \( (p) \) are the derived variables used in circuit analysis and design. In the SI system, charge is measured in coulombs \( (C) \), energy in joules \( (J) \), current in amperes \( (A) \), voltage in volts \( (V) \), and power in watts \( (W) \).
- **Current** is defined as \( dq/dt \) and is a measure of the flow of electrical charge. **Voltage** is defined as \( dw/dq \) and is a measure of the rate at which energy is being transferred. Power is related to current and voltage as \( p = vi \).
- The **reference marks** (arrows and plus/minus signs) assigned to a device are reference directions, not indications of the way a circuit responds. The actual direction of the response is determined by comparing the reference direction and the algebraic sign of the answer.
- In the **passive sign convention**, the current reference arrow is directed toward the terminal with the positive voltage reference mark. Under this convention, the device power is positive when it absorbs power and negative when it delivers power. When current and voltage have the same (opposite) algebraic signs, the device is absorbing (delivering) power.
- Engineers use computational software, such as MATLAB, to increase the speed and accuracy of calculations. Engineers use simulation software, such as OrCAD, to model the behavior of circuits. Software is useful for performing circuit simulations and for expanding the complexity of problems that can be solved in a reasonable amount of time. Learning and exploiting the advantages of computational and simulation software are critical skills for engineers, and MATLAB and OrCAD are common tools for electrical and computer engineers.

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**Problems**

**Objective 1-1 Electrical Symbols and Units (Sect. 1-2)**

Given an electrical quantity described in terms of words, scientific notation, or decimal prefix notation, convert the quantity to an alternate description.

See Exercise 1-1

1-1 Express the following quantities to the nearest standard prefix using no more than three digits.

(a) 1,000,000 Hz
(b) 102.5 \times 10^5 W
(c) 0.333 \times 10^{-7} s
(d) 10 \times 10^{-12} F

1-2 Express the following quantities to the nearest standard prefix using no more than three digits.

(a) 0.000222 H
(b) 20.5 \times 10^6 J
(c) 72.25 \times 10^9 C
(d) 3.264 \Omega

1-3 An amper-hour \((Ah)\) meter measures the time-integral of the current in a conductor. During an 8-hour period, a certain meter records 3300 Ah. Find the number of coulombs that flowed through the meter during the recording period.

1-4 Electric power companies measure energy consumption in kilowatt-hours, denoted kWh. One kilowatt-hour is the amount of energy transferred by 1 kW of power in a period of 1 hour. A power company billing statement reports a user’s total energy usage to be 2500 kWh. Find the number of joules used during the billing period.

1-5 Fill in the blanks in the following statements.

(a) To convert capacitance from picofarads to microfarads, multiply by ___.
(b) To convert resistance from megohms to kilohms, multiply by ___.
(c) To convert voltage from millivolts to volts, multiply by ___.
(d) To convert energy from megajoules to joules, multiply by ___.

**Objective 1-2 Circuit Variables (Sect. 1-3)**

Given any two of the three signal variables \((i, v, p)\) or the two basic variables \((q, w)\), find the magnitude and direction (sign) of the unspecified variables.

See Examples 1-1, 1-2, 1-3 and Exercises 1-2, 1-3, 1-4

1-6 A wire carries a constant current of 30 mA. How many coulombs flow past a given point in the wire in 5 s?

1-7 The net positive charge flowing through a device is \(q(t) = 20 + 4t\) mC. Find the current through the device.
1-8 Figure P1–8 shows a plot of the net positive charge flowing in a wire versus time. Sketch the corresponding current during the same period of time.

![Figure P1–8](image)

1-9 The net negative charge flowing through a device varies as \( q(t) = 3t^2 \) C. Find the current through the device at \( t = 0 \) s, \( t = 0.5 \) s, and \( t = 1 \) s.

1-10 A cell-phone charger outputs 9.6 V and is protected by a 50 mA fuse. A 1.5 W cell phone is connected to it to be charged. Will the fuse blow?

1-11 For \( 0 \leq t \leq 5 \) s, the current through a device is \( i(t) = 4t \) A. For \( 5 < t \leq 10 \) s, the current is \( i(t) = 40 - 4t \) A, and \( i(t) = 0 \) A for \( t > 10 \) s. Sketch \( i(t) \) versus time and find the total charge flowing through the device between \( t = 0 \) s and \( t = 10 \) s.

1-12 The charge flowing through a device is \( q(t) = 1 - e^{-1000t} \) μC. How long will it take the current to reach 200 μA?

1-13 The 12-V automobile battery in Figure P1–13 has an output capacity of 100 ampere-hours (Ah) when connected to a head lamp that absorbs 200 watts of power. The car engine is not running and therefore not charging the battery. Assume the battery voltage remains constant.

(a) Find the current supplied by the battery and determine how long can the battery power the headlight.

(b) A 100 W device is connected through the utility port. How long can the battery power both the headlight and the device?

![Figure P1–13](image)

1-14 An incandescent lamp absorbs 100 W when connected to a 120-V source. A energy-efficient compact fluorescent lamp (CFL) producing the same amount of light absorbs 16 W when connected to the same source. How much cheaper is it to operate the CFL versus the incandescent bulb over 1,000 hours when electricity costs 7.8 cents/kWh?

1-15 The current through a device is zero for \( t < 0 \) and is \( i(t) = 3e^{-2t} \) A for \( t \geq 0 \). Find the charge \( q(t) \) flowing through the device for \( t \geq 0 \).

1-16 A string of holiday lights is protected by a 5-A fuse and has 25 bulbs, each of which is rated at 7 W. How many strings can be connected end-to-end across a 120 V circuit without blowing a fuse?

1-17 When illuminated the \( i \)– relationship for a photocell is \( i = e^{t} - 10 \) A. For \( t = -2, 2 \) and \( 3 \) V find the device power and state whether it is absorbing or delivering power.

1-18 A new 6 V Alkaline lantern battery delivers 237.5 kJ of energy during its lifetime. How long will the battery last in an application that draws 15 mA continuously. Assume the battery voltage is constant.

1-19 The maximum power a device can dissipate is 0.25 W. Determine the maximum current allowed by the device power rating when the voltage is 9 V.

1-20 Traffic lights are being converted from incandescent bulbs to LED arrays to save operating and maintenance costs. Typically each incandescent light uses three 100-W bulbs, one for each color R, Y, G. A competing LED array consists of 61 LEDs with each LED requiring 9 V and drawing 20 mA of current. There are three arrays per light – R, Y, G. A small city has 1560 traffic signals. Since one light is always on 24/7, how much can a city save in one year if the city buys their electricity at 7.2¢ per kWh?

1-21 Two electrical devices are connected as shown in Figure P1–21. Using the reference marks shown in the figure, find the power transferred and state whether the power is transferred from A to B or B to A when

(a) \( v = +11 \) V and \( i = -1.1 \) A

(b) \( v = +80 \) V and \( i = +20 \) mA

(c) \( v = -120 \) V and \( i = -12 \) mA

(d) \( v = -1.5 \) V and \( i = -600 \) mA

![Figure P1–21](image)

1-22 Figure P1–22 shows an electric circuit with a voltage and a current variable assigned to each of the six devices. The device voltages and currents are observed to be

<table>
<thead>
<tr>
<th>( v ) (V)</th>
<th>( i ) (A)</th>
<th>( v ) (V)</th>
<th>( i ) (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device 1</td>
<td>15</td>
<td>-1</td>
<td>Device 4</td>
</tr>
<tr>
<td>Device 2</td>
<td>5</td>
<td>1</td>
<td>Device 5</td>
</tr>
<tr>
<td>Device 3</td>
<td>10</td>
<td>2</td>
<td>Device 6</td>
</tr>
</tbody>
</table>
Find the power associated with each device and state whether the device is absorbing or delivering power. Use the power balance to check your work.

\[ P = \sum_{\text{device}} (i \cdot v) \]

**FIGURE P1-22**

1-23 Figure P1-22 shows an electric circuit with a voltage and a current variable assigned to each of the six devices. Use power balance to find \( i \) when \( v_1 = 20 \, \text{V}, i_1 = -2 \, \text{A}, P_2 = 20 \, \text{W}, P_3 = 10 \, \text{W}, i_4 = 1 \, \text{A}, \) and \( P_6 = 2.5 \, \text{W} \). Is device 4 absorbing or delivering power?

1-24 Suppose in Figure P1-22 a ground is connected to the minus (−) side of element 6 and another to the junction of elements 2, 3 and 4. Further, assume that the voltage \( v_4 \) is 5 V and \( v_1 \) is 10 V. What are the voltages \( v_2, v_3, v_5 \) and \( v_6 \)?

1-25 For \( t \geq 0 \) the voltage across and power absorbed by a two-terminal device are \( v(t) = 2e^{-t} \, \text{V} \) and \( p(t) = 40e^{-2t} \, \text{mW} \). Find the total charge delivered to the device for \( t \geq 0 \).

**Objective 1-3 Software Introduction**

(See Sect. 1-4, Web Appendix C)

Given a simple computational problem, use MATLAB as an appropriate engineering tool to solve the problem. (We will introduce OrCAD problems starting in Chapter 2.) Examples and Exercises throughout the text. See Web Appendix C.

1-26 Repeat Problem 1-22 using MATLAB to perform the calculations. Create a vector for the voltage values, \( v = [15 \ 5 \ 10 \ -10 \ 20 \ 20] \), and a vector for the current values, \( i = [-1 \ 1 \ 2 \ -1 \ -3 \ 2] \). Compute the corresponding vector for the power values, \( \mathbf{p} \), using element-by-element multiplication \( \times \) and then use the \texttt{sum} command to verify the power balance.

1-27 Using the passive sign convention, the voltage across a device is \( v(t) = 170 \cos(377t) \, \text{V} \) and the current through the device is \( i(t) = -2 \sin(377t) \, \text{A} \). Using MATLAB, create a short script (m-file) to assign a value to the time variable, \( t \), and then calculate the voltage, current, and power at that time. Run the script for \( t = 5 \, \text{ms} \) and \( t = 10 \, \text{ms} \) and for each result state whether the device is absorbing or delivering power.

**Integrating Problems**

1-28 Power Ratio (PR) in dB (A)

A stereo amplifier takes the output of a CD player, for example, and increases the power to an audible level. Suppose the output of the CD player is 50 mW and the desired audible output is 100 W per stereo channel, find the power ratio of the amplifier per channel in decibels (dB), where the power ratio in dB is

\[ PR_{\text{dB}} = 10 \log_{10}(P_2/P_1) \]

1-29 AC to DC Converter (A)

A manufacturer's data sheet for the converter in Figure P1-29 states that the output voltage is \( v_{dc} = 5 \, \text{V} \) when the input voltage \( v_{ac} = 120 \, \text{V} \). When the load draws a current \( i_{dc} = 40 \, \text{A} \), the input power is \( P_{in} = 300 \, \text{W} \). Find the efficiency of the converter.

**Figure P1-29**

1-30 Charge-Storage Device (A)

A capacitor is a two-terminal device that can store electric charge. In a linear capacitor the amount of charge stored is proportional to the voltage across the device. For a particular device the proportionality is \( q(t) = 10^{-7} \cdot t \). If \( (t) = 0 \) for \( t < 0 \) and \( (t) = 10(1 - e^{-2000}) \) for \( t \geq 0 \), find the energy stored in the device at \( t = 200 \, \text{ms} \).

1-31 Computer Data Sheet (A)

A manufacturer's data sheet for a notebook computer lists the power supply requirements as 7.5 A @ 5 V, 2 A @ 15 V, 2.5 A @ -15 V, 2.25 A @ -5 V and 0.5 A @ 12 V. The data sheet also states that the overall power consumption is 115 W. Are these data consistent? Explain.
Problems

Objective 2-1 Element Constraints (Sect. 2-1)

Given a two-terminal element with one or more electrical variables specified, use the element i-v constraint to find the magnitude and direction of the unknown variables. See Examples 2-1, 2-2, 2-3, and 2-4 and Exercises 2-1, 2-2, and 2-3.

2-1 The current through a 56-kΩ resistor is 2.2 mA. Find the voltage across the resistor.

2-2 The voltage across a particular resistor is 6.23 V and the current is 2.75 mA. What is the actual resistance of the resistor? Using the inside back cover, what is the likely standard value of the resistor?

2-3 A 100-kΩ resistor dissipates 100 mW. Find the current through the resistor.

2-4 The conductance of a particular resistor is 0.5 mS. Find the current through the resistor when connected across a 5-V source.

2-5 In Figure P2-5 the resistor dissipates 25 mW. Find Rs.

![FIGURE P2-5](image)

2-6 In Figure P2-6 find Rs and the power delivered to the resistor.

![FIGURE P2-6](image)

2-7 A resistor found in the lab has three orange stripes followed by a gold stripe. An ohmmeter measures its resistance as 34.9 kΩ. Is the resistor properly color coded? (See inside back cover for color code.)

2-8 The i-v characteristic of a nonlinear resistor is \( v = 82i + 0.18i^2 \).

(a) Calculate \( v \) and \( p \) for \( i = \pm 0.5, \pm 1, \pm 2, \pm 5, \) and \( \pm 10 \) A. 
(b) Find the maximum error in \( v \) when the device is treated as an 82-Ω linear resistance on the range \( |i| < 0.5 \) A.

2-9 A 100-kΩ resistor has a power rating of 0.125 W. Find the maximum voltage that can be applied to the resistor.

2-10 A certain type of film resistor is available with resistance values between 10 Ω and 100 MΩ. The maximum ratings for all resistors of this type are 500 V and 0.25 W. Show that the voltage rating is the controlling limit for \( R > 1 \) MΩ, and that the power rating is the controlling limit when \( R < 1 \) MΩ.

2-11 Figure P2-11 shows the circuit symbol for a class of two-terminal devices called diodes. The i-v relationship for a specific pn junction diode is \( i = 2 \times 10^{-16} (e^{50v} - 1) \) A.

![FIGURE P2-11](image)

(a) Use this equation to find \( i \) and \( p \) for \( v = 0, \pm 0.1, \pm 0.2, \pm 0.4, \) and \( \pm 0.8 \) V. Use these data to plot the i-v characteristic of the element.
(b) Is the diode linear or nonlinear, bilateral or nonbilateral, and active or passive?
(c) Use the diode model to predict \( i \) and \( p \) for \( v = 5 \) V. Do you think the model applies to voltages in this range? Explain.
(d) Repeat (c) for \( v = -5 \) V.

2-12 A thermistor is a temperature-sensing element composed of a semiconductor material that exhibits a large change in resistance proportional to a small change in temperature. A particular thermistor has a resistance of 5 kΩ at 25 °C. Its resistance is 340 Ω at 100 °C. Assuming a straight-line relationship between these two values, at what temperature will the thermistor's resistance equal 1 kΩ?

Objective 2-2 Connection Constraints (Sect. 2-2)

Given a circuit composed of two-terminal elements:
(a) Identify nodes and loops in the circuit
(b) Identify elements connected in series and in parallel.
(c) Use Kirchhoff's laws (KCL and KVL) to find selected signal variables.

See Examples 2-5, 2-6, and 2-7 and Exercises 2-4, 2-5, 2-6, 2-7, and 2-8

2-13 In Figure P2-13 \( i_2 = -5 \) A and \( i_3 = 2 \) A. Find \( i_1 \) and \( i_4 \).

![FIGURE P2-13](image)