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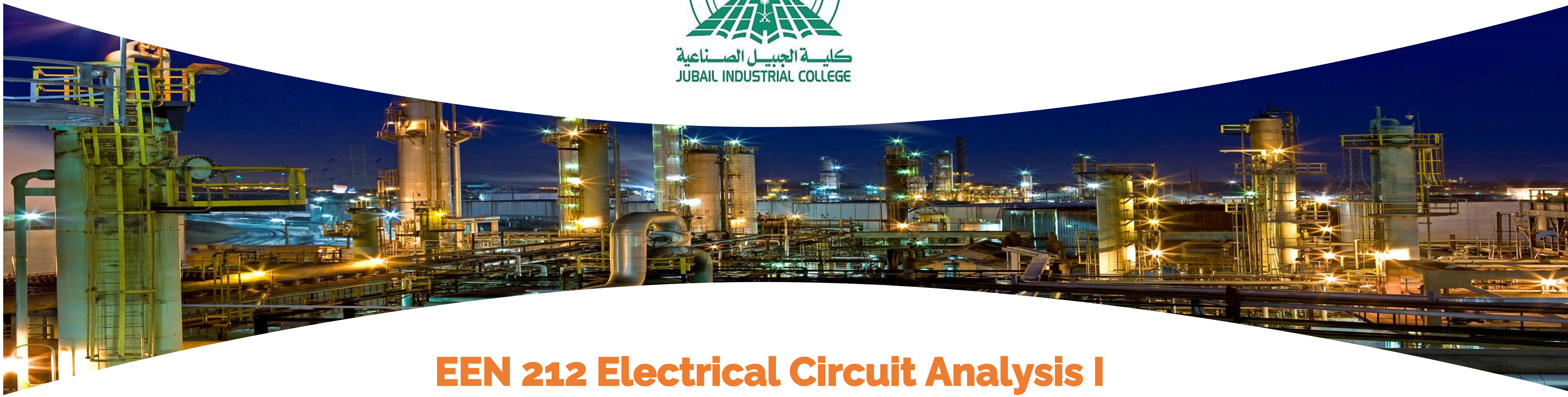

EEN 212 Electrical Circuit Analysis I
Week 1

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"Successful and unsuccessful people do not vary greatly in their abilities. They vary in their desires to reach their potential." – John Maxwell

Introduction
Chapter 1

NOTE: These illustration slides have been adopted from the following Books :

1. [Reference 1] Electric Circuits, James Nilsson and Susan Riedel,10th edition, Prentice Hall, 2015.
2. [Reference 2] Robert L. Boylestad " Introductory Circuit Analysis " Twelfth Edition Pearson [ISBN 0-13-214240-6]
3. [Reference 3] Sadiku MN, Alexander CK. Fundamentals of electric circuits. McGraw-Hill Higher Education; 2007.

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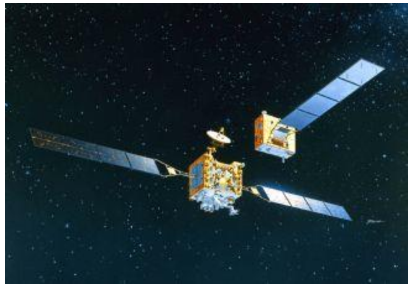
Electrical Engineering: An Overview



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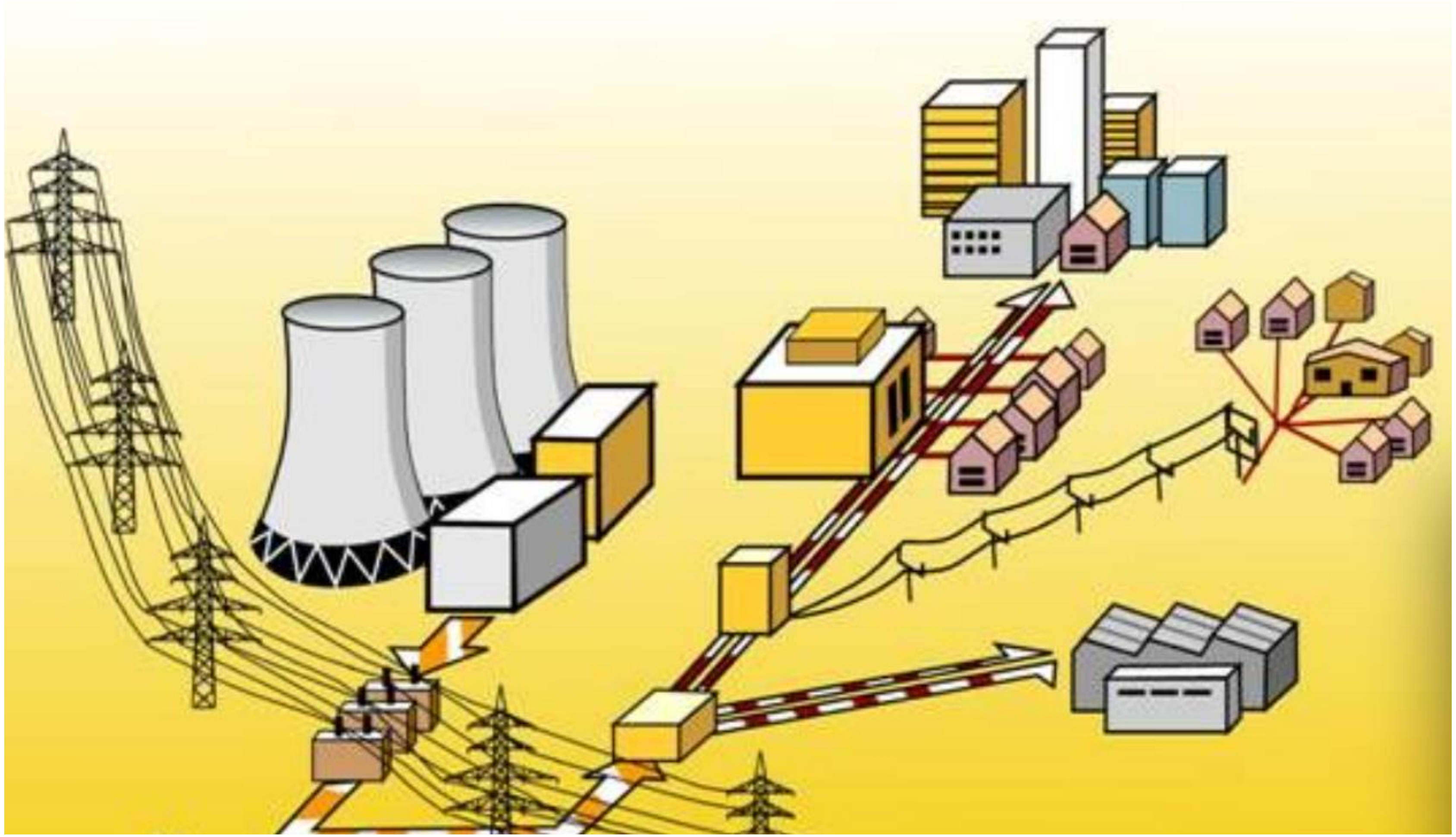
Power Systems



Anything in Common?

- An **electric circuit** is a *mathematical model* that approximates the behavior of an actual electrical system.

- Here, we use circuit theory, rather than electromagnetic field theory, to study a physical system represented by an electric circuit, based on the following three assumptions:
  - Electrical effects happen instantaneously throughout a system (***lumped-parameter system***)
  - The net charge on every component in the system is always zero
  - There is no magnetic coupling between the components in a system

Problem Solving

- Identify what's given and what's to be found.
- Sketch a circuit diagram or other visual model.
- Think of several solution methods and decide on a way of choosing among them.
- Calculate a solution.
- Use your creativity.
- Test your solution.

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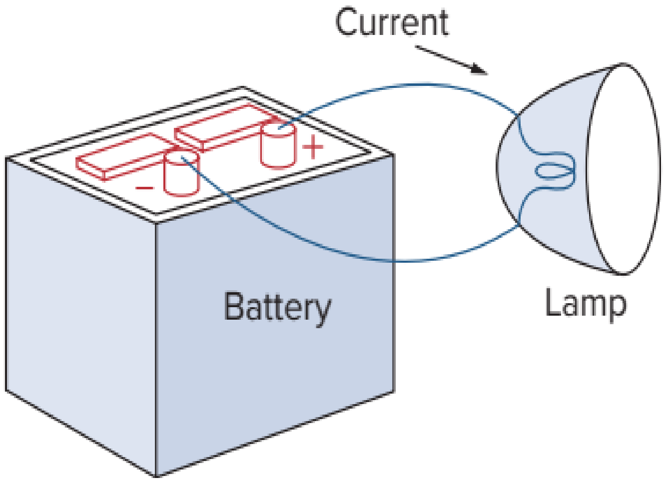
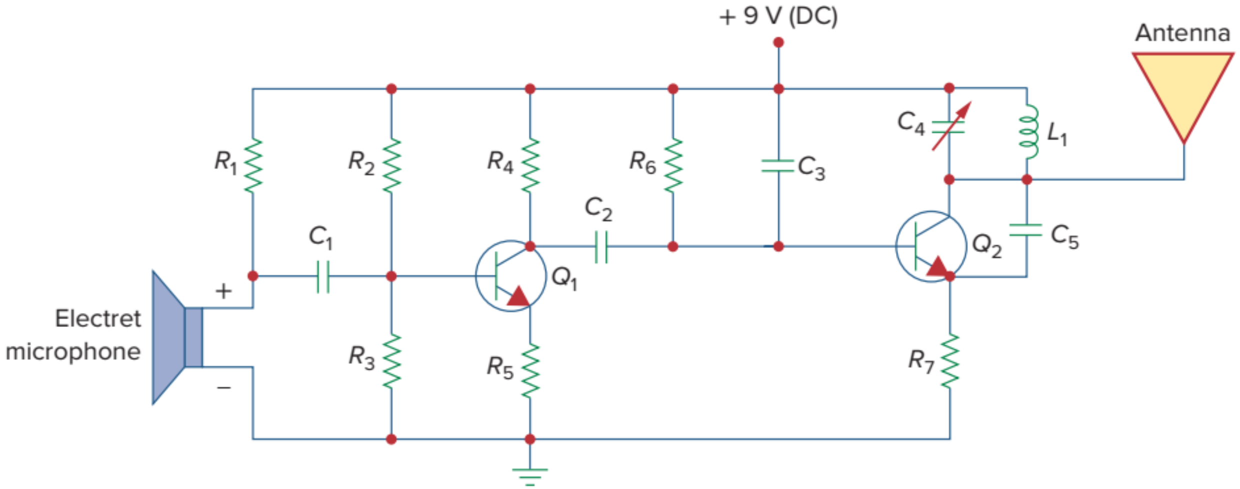
Examples of an electrical circuit





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SI units

TABLE 1.1

Six basic SI units and one derived unit relevant to this text.

Quantity	Basic unit	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Thermodynamic temperature	kelvin	K
Luminous intensity	candela	cd
Charge	coulomb	C

Powers of 10:

$$1 = 10^0 \qquad 1/10 = 0.1 = 10^{-1}$$
$$10 = 10^1 \qquad 1/100 = 0.01 = 10^{-2}$$
$$100 = 10^2 \qquad 1/1000 = 0.001 = 10^{-3}$$
$$1000 = 10^3 \qquad 1/10{,}000 = 0.0001 = 10^{-4}$$

Multiplication Factors	SI Prefix	SI Symbol
1 000 000 000 000 000 000 = 10^{18}	exa	E
1 000 000 000 000 000 = 10^{15}	peta	P
1 000 000 000 000 = 10^{12}	tera	T
1 000 000 000 = 10^{9}	giga	G
1 000 000 = 10^{6}	mega	M
1 000 = 10^{3}	kilo	k
0.001 = 10^{-3}	milli	m
0.000 001 = 10^{-6}	micro	μ
0.000 000 001 = 10^{-9}	nano	n
0.000 000 000 001 = 10^{-12}	pico	p
0.000 000 000 000 001 = 10^{-15}	femto	f
0.000 000 000 000 000 001 = 10^{-18}	atto	a

Units Examples

EXAMPLE 1.12

a. $1{,}000{,}000 \text{ ohms} = 1 \times 10^6 \text{ ohms}$
$\qquad = \mathbf{1\ megohm = 1\ M\Omega}$

b. $100{,}000 \text{ meters} = 100 \times 10^3 \text{ meters}$
$\qquad = \mathbf{100\ kilometers = 100\ km}$

c. $0.0001 \text{ second} = 0.1 \times 10^{-3} \text{ second}$
$\qquad = \mathbf{0.1\ millisecond = 0.1\ ms}$

d. $0.000001 \text{ farad} = 1 \times 10^{-6} \text{ farad}$
$\qquad = \mathbf{1\ microfarad = 1 \mu F}$

EXAMPLE 1.14 Convert 20 kHz to megahertz.

Solution: In the power-of-ten format:

$$20 \text{ kHz} = 20 \times 10^3 \text{ Hz}$$

The conversion requires that we find the multiplying factor to appear in the space below:

Increase by 3

$$20 \times 10^3 \text{ Hz} \Rightarrow \underline{\quad\quad} \times 10^6 \text{ Hz}$$

Decrease by 3

Since the power of ten will be *increased* by a factor of *three*, the multiplying factor must be *decreased* by moving the decimal point *three* places to the left, as shown below:

$$\underbrace{020.}_{3} = 0.02$$

and $\qquad 20 \times 10^3 \text{ Hz} = 0.02 \times 10^6 \text{ Hz} = \mathbf{0.02\ MHz}$

Charge and Current

Charge is an electrical property of the atomic particles of which matter consists, measured in coulombs (C).

- From physics, an atom consists of electrons, protons and neutrons.
- The charge on an electron $\boldsymbol{e} = 1.602 \times 10^{-19} C$
- How many electrons we need for 1 C? Ans 6.242×10^{18} electrons
  (1 C is a large unit of charges)
- The physic law of conservation applys to the electric charge

Electric Current

We now consider the flow of electric char ges. A unique feature of electric char ge or electricity is the f act that it is mobile; that is, it can be transferred from one place to another , where it can be con verted to another form of energy.

Electric current is the time rate of change of charge, measured in amperes (A).

Eclectic current is the rate of change of eclectic charges with respect to time :

$$i = \frac{dq}{dt}$$

$$\boxed{I = \frac{Q}{t}}$$

I = amperes (A)
Q = coulombs (C)
t = time (s)

Concept of moving charges

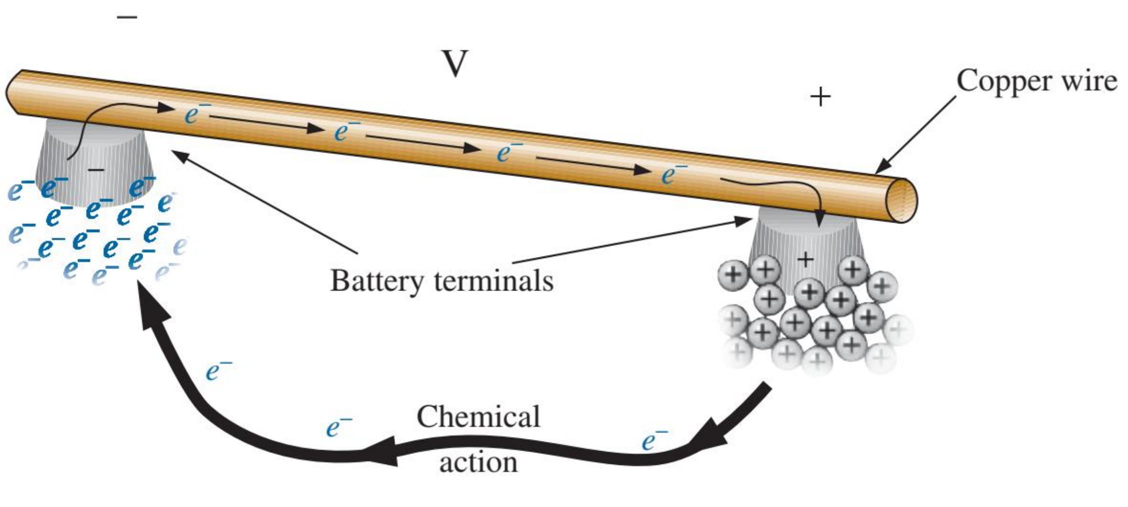


FIG. 2.9

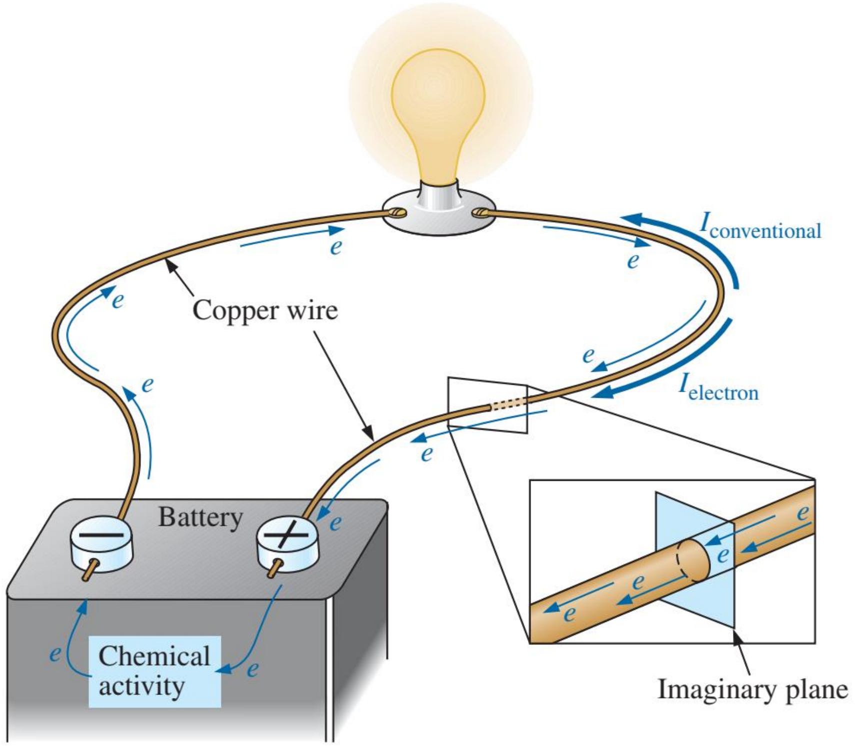


FIG. 2.10
Basic electric circuit.

if 6.242 × 10^{18} electrons (1 coulomb) pass through the imaginary plane in Fig. 2.10 in 1 second, the flow of charge, or current, is said to be 1 ampere (A).

Examples

EXAMPLE 2.3 The charge flowing through the imaginary surface in Fig. 2.10 is 0.16 C every 64 ms. Determine the current in amperes.

Solution: Eq. (2.8):

$$I = \frac{Q}{t} = \frac{0.16\ \text{C}}{64 \times 10^{-3}\ \text{s}} = \frac{160 \times 10^{-3}\ \text{C}}{64 \times 10^{-3}\ \text{s}} = \mathbf{2.50\ A}$$

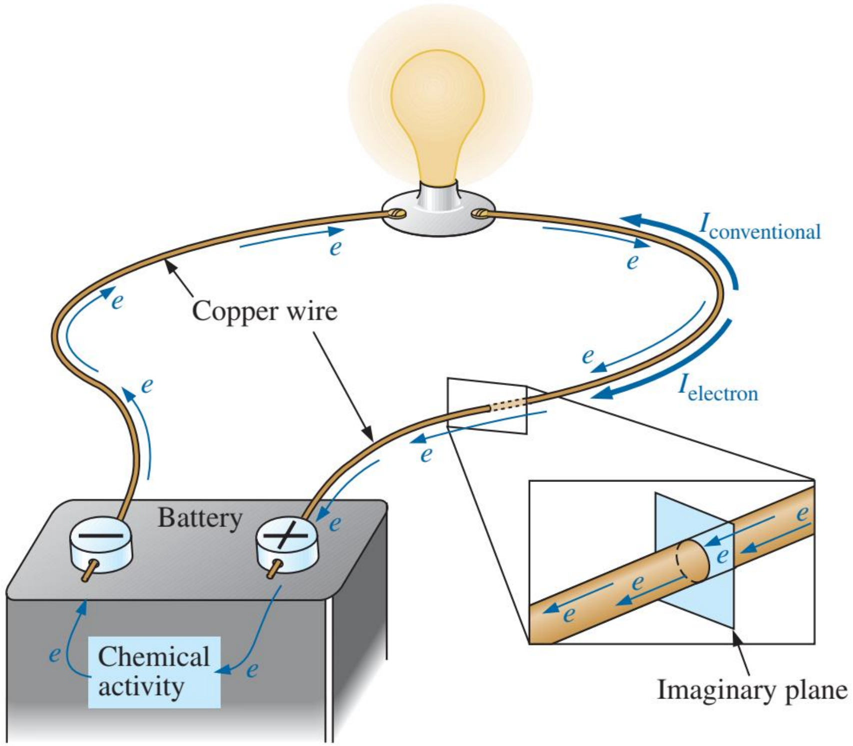


FIG. 2.10
Basic electric circuit.

EXAMPLE 2

The total char ge entering a terminal is gi ven by $q = 5t \sin 4\pi t$ mC. Calculate the current at $t = 0.5$ s.

Solution:

$$i = \frac{dq}{dt} = \frac{d}{dt}(5t \sin 4\pi t)\ \text{mC/s} = (5 \sin 4\pi t + 20\pi t \cos 4\pi t)\ \text{mA}$$

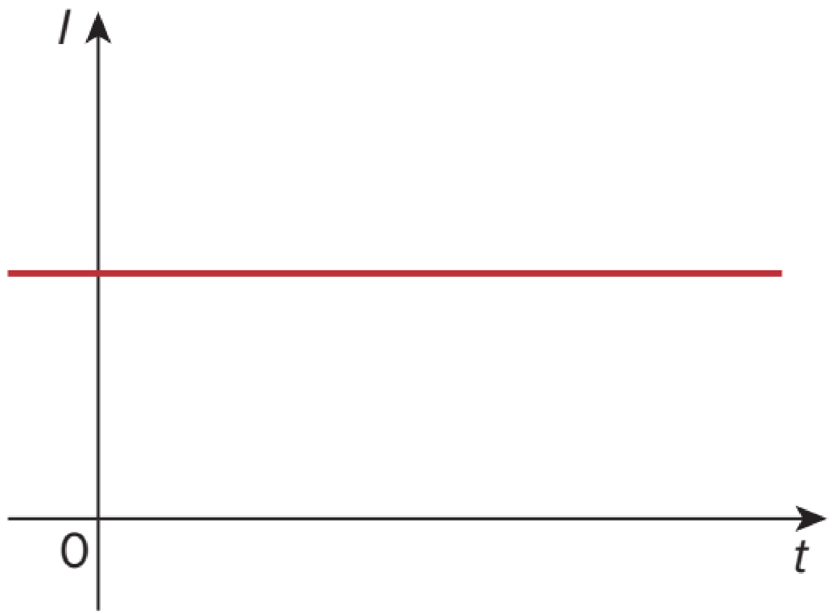
At $t = 0.5$,

$$i = 5 \sin 2\pi + 10\pi \cos 2\pi = 0 + 10\pi = 31.42\ \text{mA}$$

Electric Current

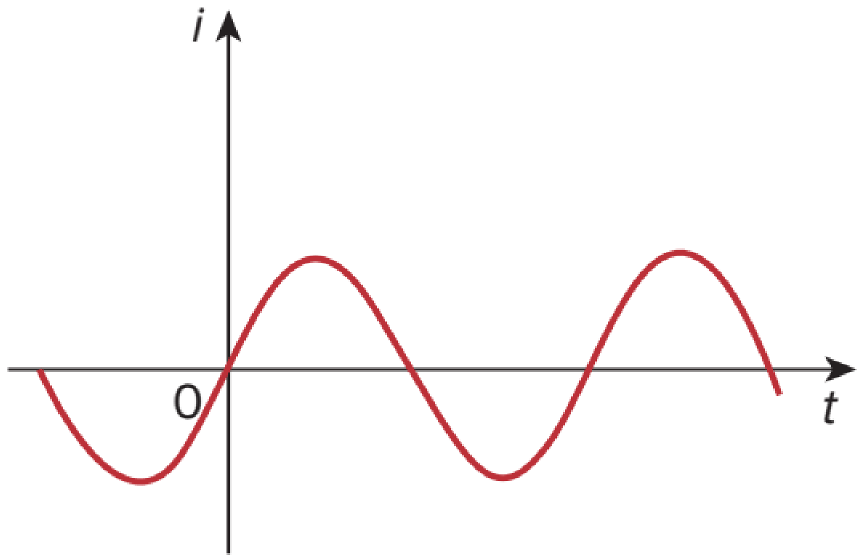
- The current is measured in Amperes (A)

$$1\,A = \frac{1\,C}{1\,s}$$



A **direct current** (dc) flows only in one direction and can be constant or time varying.

An **alternating current** (ac) is a current that changes direction with respect to time.



Measuring Current

- Using Ammeter
- Connected in series

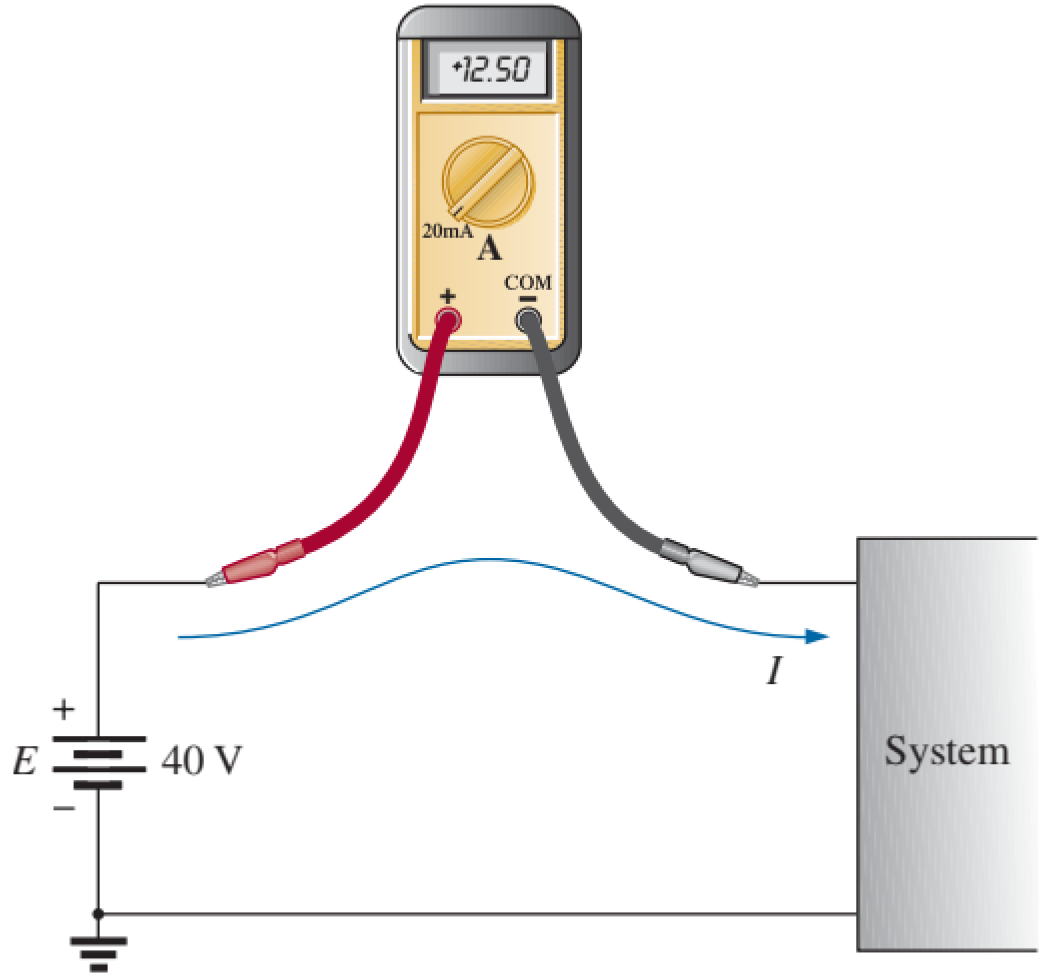


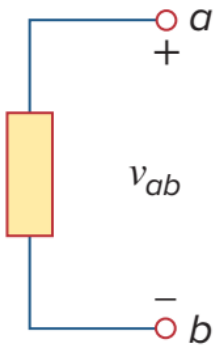
FIG. 2.30

Ammeter connection for an up-scale (+) reading.

Voltage

- To move electrons in a conductor some work or energy is required
- This work is performed by external electromotive force (emf)
- This energy is known as potential difference of voltage difference (between two points)
- The voltage (potential difference) V_{ab} between points a and b in an electrical circuit is the energy or work required to move a unit charge from point b to point a
- $V_{ab} = \frac{dw}{dq}$ (w work or energy in Joules , q charge in C)

$$1 \text{ volt} = 1 \text{ joule/coulomb} = 1 \text{ newton-meter/coulomb}$$

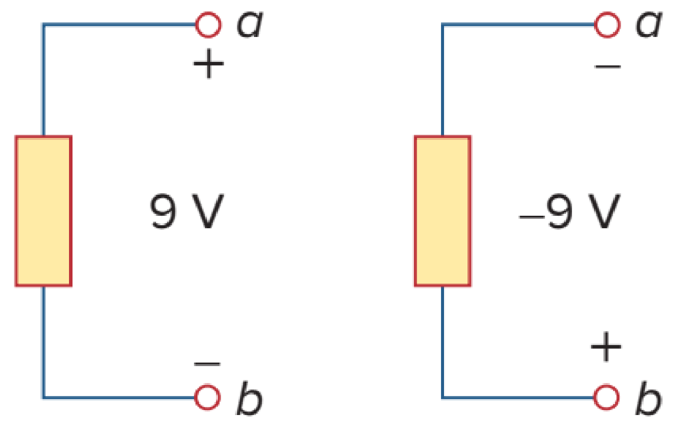


Voltage

Voltage (or **potential difference**) is the energy required to move a unit charge from a reference point (−) to another point (+), measured in volts (V).

The v_{ab} can be interpreted in two ways: (1) Point a is at a potential of v_{ab} volts higher than point b, or (2) the potential at point a with respect to point b is v_{ab}. It follows logically that in general

$$v_{ab} = -v_{ba}$$



Measuring voltage

- Using voltmeter
- Connected in parallel

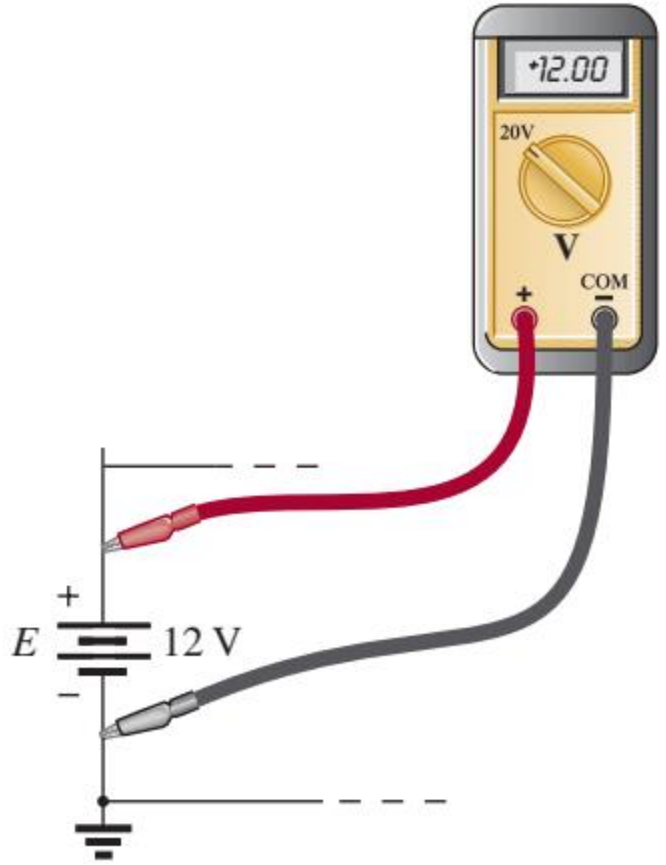


FIG. 2.29
Voltmeter connection for an up-scale (+) reading.

Electrical Power

Power is the time rate of expending or absorbing energy, measured in watts (W).

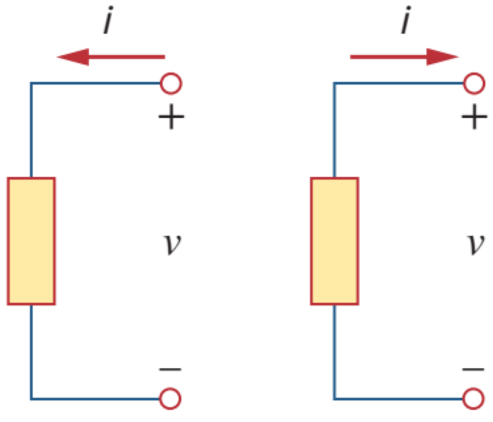
$$P = \frac{dW}{dt}$$

where p is power in watts (W), w is energy in joules (J), and t is time in seconds (s). From Eqs. (1.1), (1.3), and (1.5), it follows that

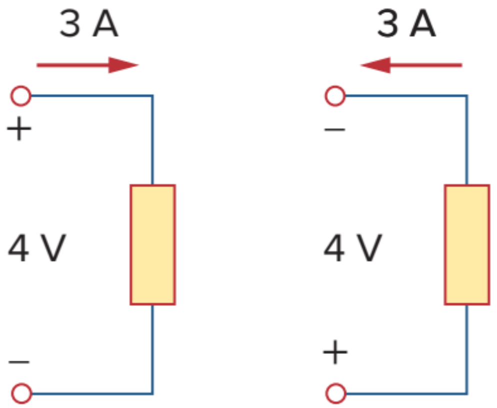
$$p = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = vi$$

Electric Power

Passive sign convention is satisfied when the current enters through the positive terminal of an element and $p = +vi$. If the current enters through the negative terminal, $p = -vi$.



$p = +vi$ $\qquad$ $p = -vi$



Passive sign convention

TABLE 1.4 Interpretation of Reference Directions in Fig. 1.5

	Positive Value	Negative Value
v	voltage drop from terminal 1 to terminal 2 *or* voltage rise from terminal 2 to terminal 1	voltage rise from terminal 1 to terminal 2 *or* voltage drop from terminal 2 to terminal 1
i	positive charge flowing from terminal 1 to terminal 2 *or* negative charge flowing from terminal 2 to terminal 1	positive charge flowing from terminal 2 to terminal 1 *or* negative charge flowing from terminal 1 to terminal 2

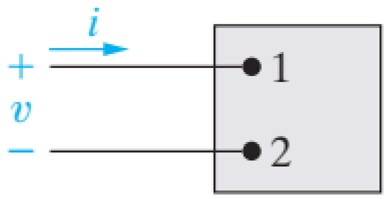


Figure 1.5 ▲ An ideal basic circuit element.

Whenever the reference direction for the current in an element is in the direction of the reference voltage drop across the element (as in Fig. 1.5), use a positive sign in any expression that relates the voltage to the current. Otherwise, use a negative sign.

◀ **Passive sign convention**

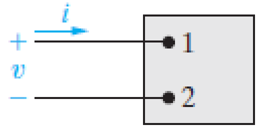


Figure 1.5 ▲ An ideal basic circuit element.

Power balance in an electrical circuit

$$+\text{Power absorbed} = -\text{Power supplied}$$

In fact, the *law of conservation of energy* must be obeyed in any electric circuit. For this reason, the algebraic sum of po wer in a circuit, at any instant of time, must be zero:

$$\boxed{\sum p = 0}$$

Energy

Energy is the capacity to do work, measured in joules (J).

$$w = \int_{t_0}^{t} p \, dt = \int_{t_0}^{t} vi \, dt$$

Electrical companies measure energy in Watt-Hour Wh

$$1 \text{ Wh} = 3{,}600 \text{ J}$$

Examples

How much energy does a 100-W electric bulb consume in two hours?

Solution:

$$w = pt = 100\ (\text{W}) \times 2\ (\text{h}) \times 60\ (\text{min/h}) \times 60\ (\text{s/min})$$

$$= 720{,}000\ \text{J} = 720\ \text{kJ}$$

This is the same as

$$w = pt = 100\ \text{W} \times 2\ \text{h} = 200\ \text{Wh}$$

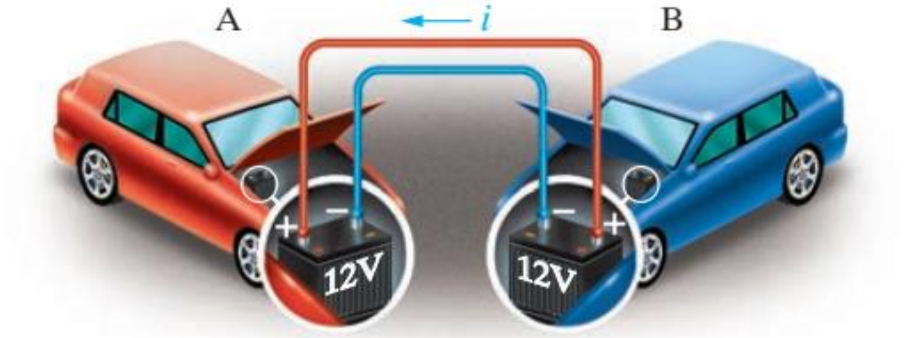
Exercise

When a car has a dead battery, it can often be started by connecting the battery from another car across its terminals. The positive terminals are connected together as are the negative terminals. The connection is illustrated in Fig. P1.15. Assume the current i in Fig. P1.15 is measured and found to be 30 A.

a) Which car has the dead battery?

b) If this connection is maintained for 1 min, how much energy is transferred to the dead battery?

Figure P1.15



Exercise and Answer

When a car has a dead battery, it can often be started by connecting the battery from another car across its terminals. The positive terminals are connected together as are the negative terminals. The connection is illustrated in Fig. P1.15. Assume the current i in Fig. P1.15 is measured and found to be 30 A.

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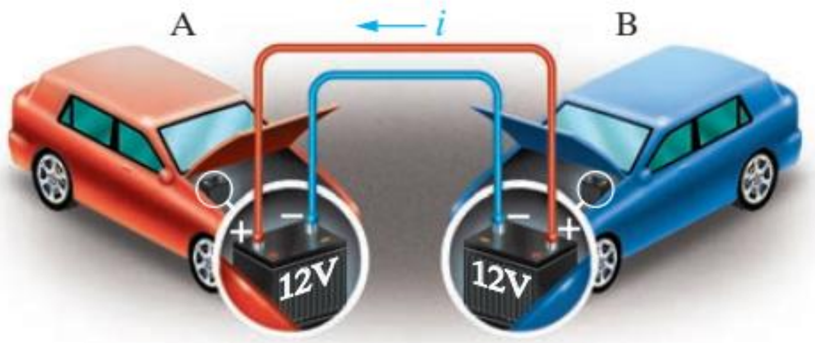
Figure P1.15



P 1.15 [a] In Car A, the current i is in the direction of the voltage drop across the 12 V battery(the current i flows into the + terminal of the battery of Car A). Therefore using the passive sign convention,

$p = vi = (30)(12) = 360$ W.

Since the power is positive, the battery in Car A is absorbing power, so Car A must have the "dead" battery.

[b] $w(t) = \int_0^t p\,dx; \qquad 1 \text{ min} = 60 \text{ s}$

$$w(60) = \int_0^{60} 360\,dx$$

$$w = 360(60 - 0) = 360(60) = 21{,}600 \text{ J} = 21.6 \text{ kJ}$$

Resistance

The ***resistance R*** of an element denotes its ability to resist the flow of electric current; it is measured in ohms (Ω).

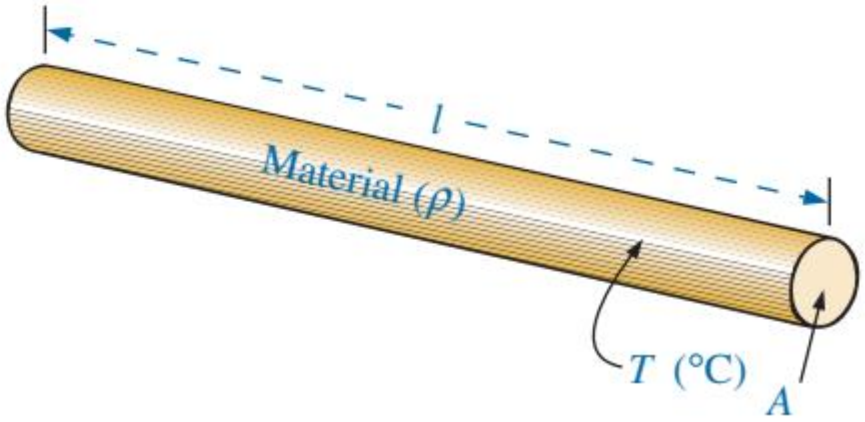
The resistance of any material is due primarily to four factors:

1. ***Material***
2. ***Length***
3. ***Cross-sectional area***
4. ***Temperature of the material***

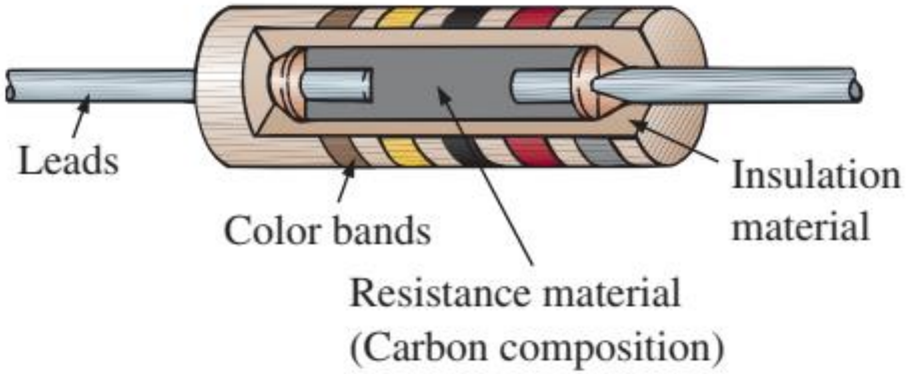
$$R = \rho \frac{\ell}{A}$$

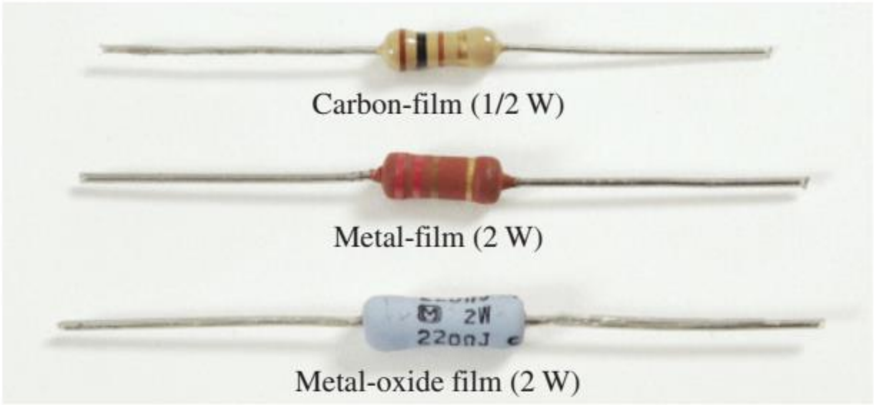
Resistivity (ρ) of various materials.

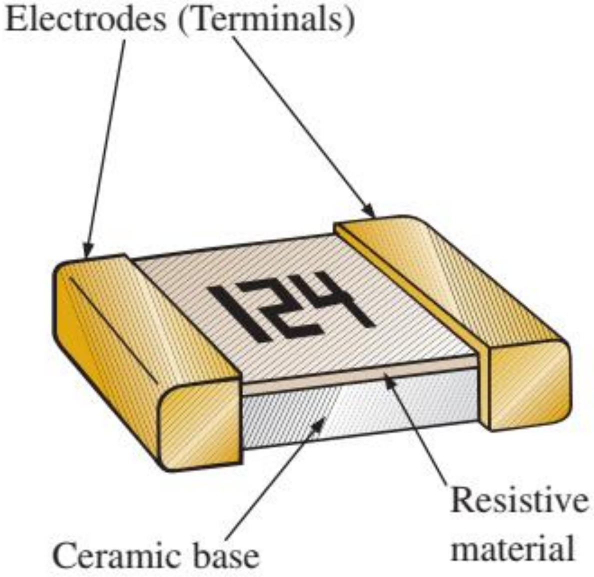
Material	ρ (CM-Ω/ft)@20°C
Silver	9.9
Copper	**10.37**
Gold	14.7
Aluminum	17.0
Tungsten	33.0
Nickel	47.0
Iron	74.0
Constantan	295.0
Nichrome	600.0
Calorite	720.0
Carbon	21,000.0



Resistors







22 kΩ, 1 W
Surface mount thick-film chip resistors with gold electrodes
(f)

Measuring resistance

- Color Code

FIG. 3.21
Color coding for fixed resistors.

Number		Color
0		Black
1		Brown
2		Red
3		Orange
4		Yellow
5		Green
6		Blue
7		Violet
8		Gray
9		White
±5% (0.1 multiplier if 3rd band)		Gold
±10% (0.01 multiplier if 3rd band)		Silver

FIG. 3.22
Color coding.

FIG. 3.23
Example 3.11.

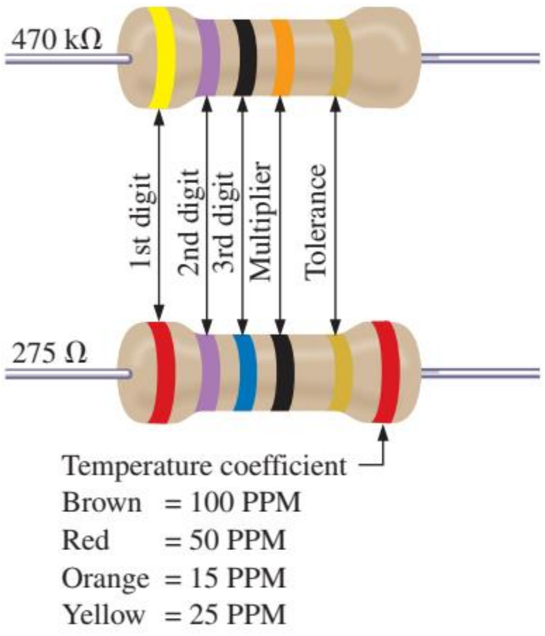


FIG. 3.25
Five-band color coding for fixed resistors.

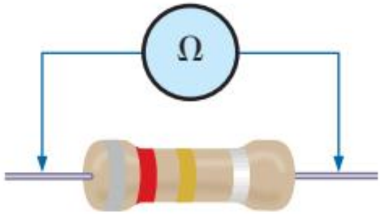


FIG. 3.28
Measuring the resistance of a single element.

Example

Calculate the power supplied or absorbed by each element in Fig. 1.15.

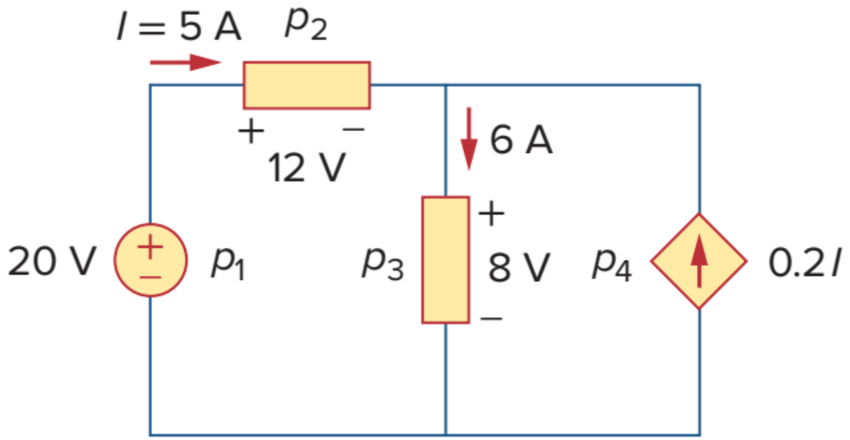


Figure 1.15
For Example 1.7.

Answers

$p_1 = 20(-5) = -100 \text{ W}$ Supplied power

$p_2 = 12(5) = 60 \text{ W}$ Absorbed power

$p_3 = 8(6) = 48 \text{ W}$ Absorbed power

$p_4 = 8(-0.2I) = 8(-0.2 \times 5) = -8 \text{ W}$ Supplied power

Check: $\boxed{\sum p = 0}$

$$p_1 + p_2 + p_3 + p_4 = -100 + 60 + 48 - 8 = 0$$

Exercise:

Example 1.3 Relating Voltage, Current, Power, and Energy

Assume that the voltage at the terminals of the element in Fig. 1.5, whose current was defined in Assessment Problem 1.3, is

$$v = 0 \qquad t < 0;$$
$$v = 10e^{-5000t}\ \text{kV}, \qquad t \geq 0.$$

a) Calculate the power supplied to the element at 1 ms.

b) Calculate the total energy (in joules) delivered to the circuit element.

Solution

a) Since the current is entering the + terminal of the voltage drop defined for the element in Fig. 1.5, we use a "+" sign in the power equation.

$$p = vi = (10{,}000e^{-5000t})(20e^{-5000t}) = 200{,}000e^{-10{,}000t}\ \text{W}.$$
$$p(0.001) = 200{,}000e^{-10{,}000t(0.001)} = 200{,}000e^{-10}$$
$$= 200{,}000(45.4 \times 10^{-6}) = 0.908\ \text{W}.$$

b) From the definition of power given in Eq. 1.3, the expression for energy is

$$w(t) = \int_0^t p(x)dx$$

To find the total energy delivered, integrate the expresssion for power from zero to infinity. Therefore,

$$w_{\text{total}} = \int_0^\infty 200{,}000e^{-10{,}000x}\,dx = \left.\frac{200{,}000e^{-10{,}000x}}{-10{,}000}\right|_0^\infty$$
$$= -20e^{-\infty} - (-20e^{-0}) = 0 + 20 = 20\ \text{J}.$$

Thus, the total energy supplied to the circuit element is 20 J.

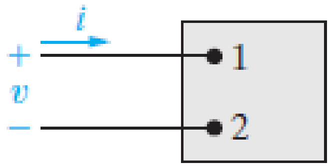


Figure 1.5 ▲ An ideal basic circuit element.

$$i = 0, \qquad t < 0;$$
$$i = 20e^{-5000t}\ \text{A}, \qquad t \geq 0.$$

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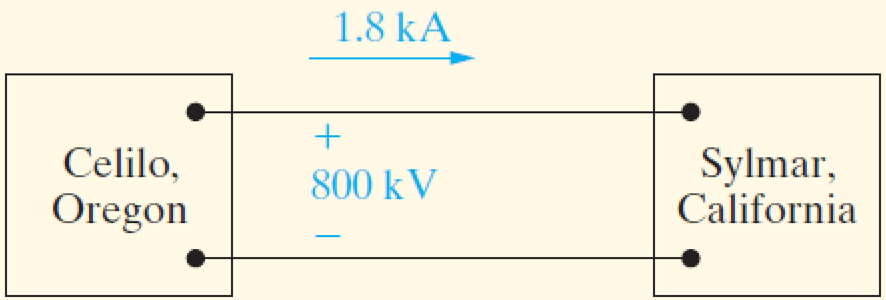
Exercise

1.7 A high-voltage direct-current (dc) transmission line between Celilo, Oregon and Sylmar, California is operating at 800 kV and carrying 1800 A, as shown. Calculate the power (in megawatts) at the Oregon end of the line and state the direction of power flow.



Answer: 1440 MW, Celilo to Sylmar

Exercise

1.6 The voltage and current at the terminals of the circuit element in Fig 1.5 are zero for $t < 0$. For $t \geq 0$, they are

$$v = 80{,}000te^{-500t}\ \text{V}, \qquad t \geq 0;$$

$$i = 15te^{-500t}\ \text{A}, \qquad t \geq 0.$$

a) Find the time when the power delivered to the circuit element is maximum.

b) Find the maximum value of power.

c) Find the total energy delivered to the circuit element.

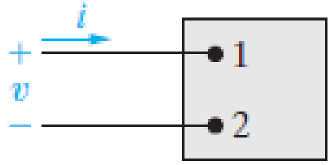
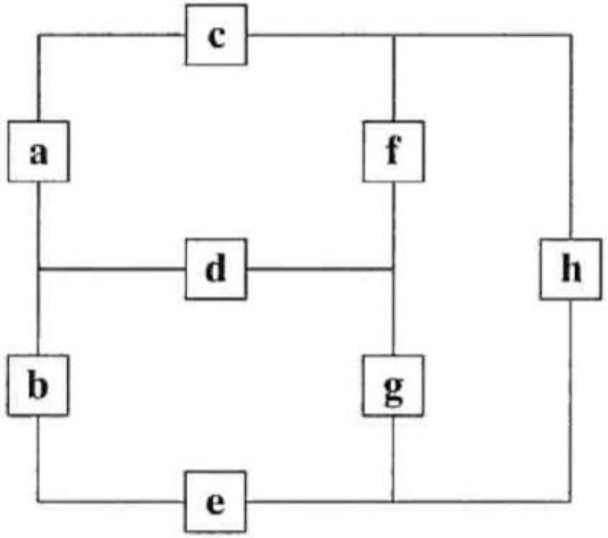


Figure 1.5 ▲ An ideal basic circuit element.

Balancing Power



- **a** and **b**: electrical source to the home;
- **c**, **d**, and **e**: the wires that carry the electrical current from the source to the devices in the home requiring electrical power;
- **f**, **g**, and **h**: lamps, televisions, hair dryers, refrigerators, and other devices that require power.

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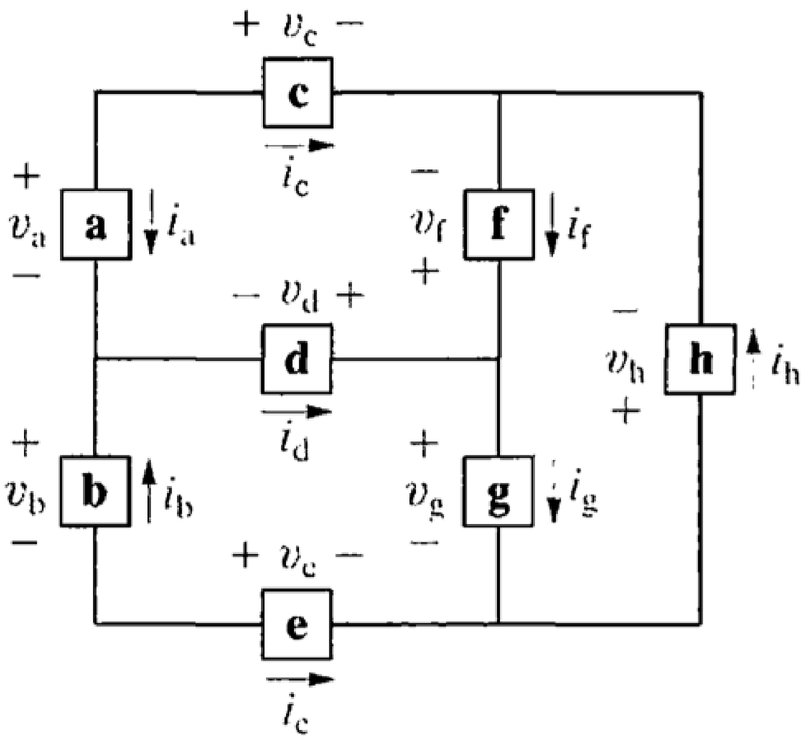
Example #4



Component	v(V)	i(A)
a	120	−10
b	120	9
c	10	10
d	10	1
e	−10	−9
f	−100	5
g	120	4
h	−220	−5

$$p_a = v_a i_a = (120)(-10) = -1200 \text{ W}$$

$$p_b = -v_b i_b = -(120)(9) = -1080 \text{ W}$$

$$p_c = v_c i_c = (10)(10) = 100 \text{ W}$$

$$p_d = -v_d i_d = -(10)(1) = -10 \text{ W}$$

$$p_e = v_e i_e = (-10)(-9) = 90 \text{ W}$$

$$p_f = -v_f i_f = -(-100)(5) = 500 \text{ W}$$

$$p_g = v_g i_g = (120)(4) = 480 \text{ W}$$

$$p_h = v_h i_h = (-220)(-5) = 1100 \text{ W}$$

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$$p_a = v_a i_a = (120)(-10) = -1200\ \text{W}$$

$$p_b = -v_b i_b = -(120)(9) = -1080\ \text{W}$$

$$p_c = v_c i_c = (10)(10) = 100\ \text{W}$$

$$p_d = -v_d i_d = -(10)(1) = -10\ \text{W}$$

$$p_e = v_e i_e = (-10)(-9) = 90\ \text{W}$$

$$p_f = -v_f i_f = -(-100)(5) = 500\ \text{W}$$

$$p_g = v_g i_g = (120)(4) = 480\ \text{W}$$

$$p_h = v_h i_h = (-220)(-5) = 1100\ \text{W}$$

The power calculations show that components a, b, and d are supplying power, since the power values are negative, while components c, e, f, g, and h are absorbing power. Now check to see if the power balances by finding the total power supplied and the total power absorbed.

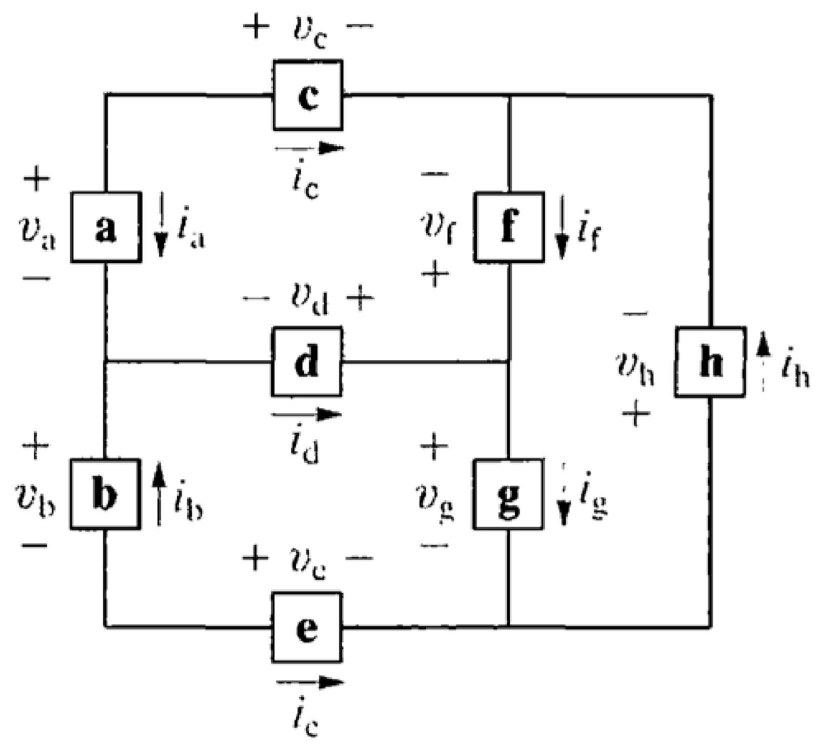
$$p_{\text{supplied}} = p_a + p_b + p_d = -1200 - 1080 - 10 = -2290 \text{ W}$$

$$p_{\text{absorbed}} = p_c + p_e + p_f + p_g + p_h$$

$$= 100 + 90 + 500 + 480 + 1100 = 2270 \text{ W}$$

$$p_{\text{supplied}} + p_{\text{absorbed}} = -2290 + 2270 = -20 \text{ W}$$

Something is wrong—if the values for voltage and current in this circuit are correct, the total power should be zero!



Component	v(V)	i(A)
a	120	−10
b	120	9
c	10	10
d	10	1
e	−10	−9
f	−100	5
g	120	4
h	−220	−5

Something is wrong—if the values for voltage and current in this circuit are correct, the total power should be zero! There is an error in the data and we can find it from the calculated powers if the error exists in the sign of a single component. Note that if we divide the total power by 2, we get −10 W, which is the power calculated for component d. If the power for component d was +10 W, the total power would be 0. Circuit analysis techniques from upcoming chapters can be used to show that the current through component d should be −1 A, not +1 A given in Table 1.4.

TABLE 1.4 Volatage and current values for the circuit in Fig. 1.7.

Component	v(V)	i(A)
a	120	−10
b	120	9
c	10	10
d	10	1
e	−10	−9
f	−100	5
g	120	4
h	−220	−5

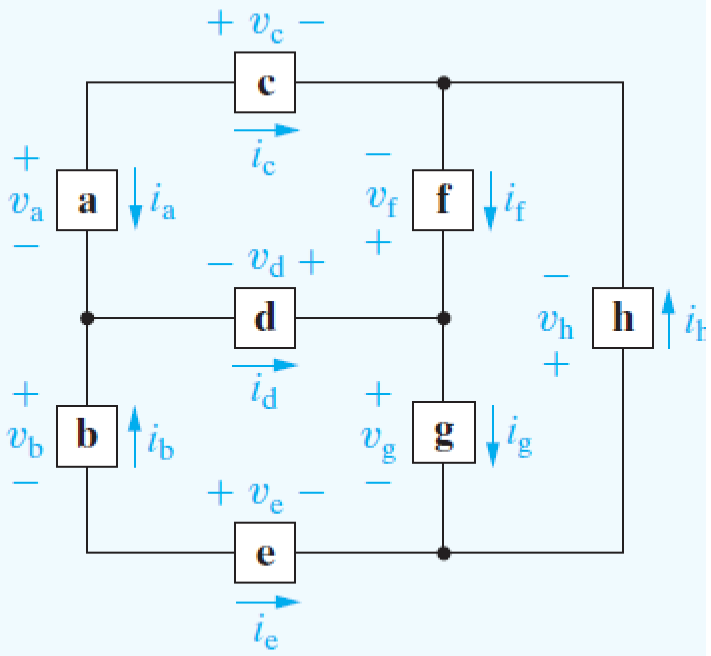


Figure 1.7 ▲ Circuit model for power distribution in a home, with voltages and currents defined.

1.22 The voltage and current at the terminals of the circuit element in Fig. 1.5 are zero for $t < 0$. For $t \geq 0$, they are

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$$v = (4000t + 4)e^{-1200t} \text{ V},$$
$$i = (138t + 0.26)e^{-1200t} \text{ A}.$$

a) At what instant of time is the maximum power delivered to the element?

b) Find the maximum power in watts.

c) Find the total energy delivered to the element in microjoules.

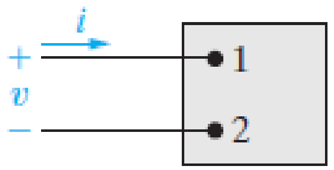

Figure 1.5 ▲ An ideal basic circuit element.

P 1.22 [a]

$$\begin{aligned} p &= vi \\ &= [(3200t + 3.2)e^{-1000t}][(160t + 0.16)e^{-1000t}] \\ &= e^{-2000t}[512{,}000t^2 + 1024t + 0.512] \\ \frac{dp}{dt} &= e^{-2000t}[1{,}024{,}000t + 1024] - 2000e^{-2000t}[512{,}000t^2 + 1024t + 0.512] \\ &= -e^{-2000t}[1024 \times 10^6 t^2 + 1{,}024{,}000t] \end{aligned}$$

Therefore, $\frac{dp}{dt} = 0$ when $t = 0$
so $p_{\max}$ occurs at $t = 0$.

[b]

$$\begin{aligned} p_{\max} &= e^{-0}[0 + 0 + 0.512] \\ &= 512 \text{ mW} \end{aligned}$$

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1.32 Suppose there is no power lost in the wires used to distribute power in a typical home.

a) Create a new model for the power distribution circuit by modifying the circuit shown in Fig 1.7. Use the same names, voltage polarities, and current directions for the components that remain in this modified model.

b) The following voltages and currents are calculated for the components:

$$v_a = 120\text{ V} \qquad i_a = -10\text{ A}$$
$$v_b = 120\text{ V} \qquad i_b = 10\text{ A}$$
$$v_f = -120\text{ V} \qquad i_f = 3\text{ A}$$
$$v_g = 120\text{ V}$$
$$v_h = -240\text{ V} \qquad i_h = -7\text{ A}$$

If the power in this modified model balances, what is the value of the current in component g?

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1.32 Suppose there is no power lost in the wires used to distribute power in a typical home.

a) Create a new model for the power distribution circuit by modifying the circuit shown in Fig 1.7. Use the same names, voltage polarities, and current directions for the components that remain in this modified model.

b) The following voltages and currents are calculated for the components:

$v_a = 120$ V $\quad i_a = -10$ A

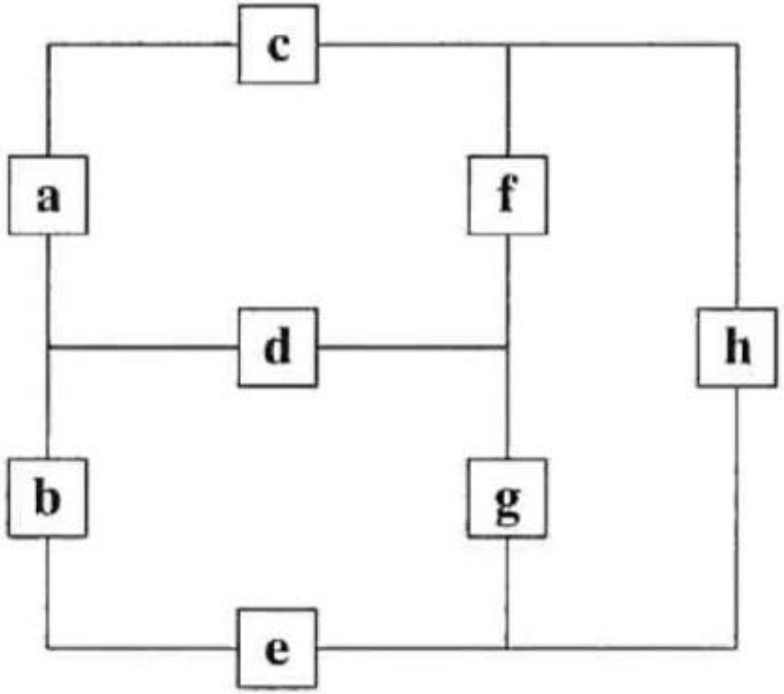
$v_b = 120$ V $\quad i_b = 10$ A

$v_f = -120$ V $\quad i_f = 3$ A

$v_g = 120$ V

$v_h = -240$ V $\quad i_h = -7$ A

If the power in this modified model balances, what is the value of the current in component g?



- **a** and **b**: electrical source to the home;
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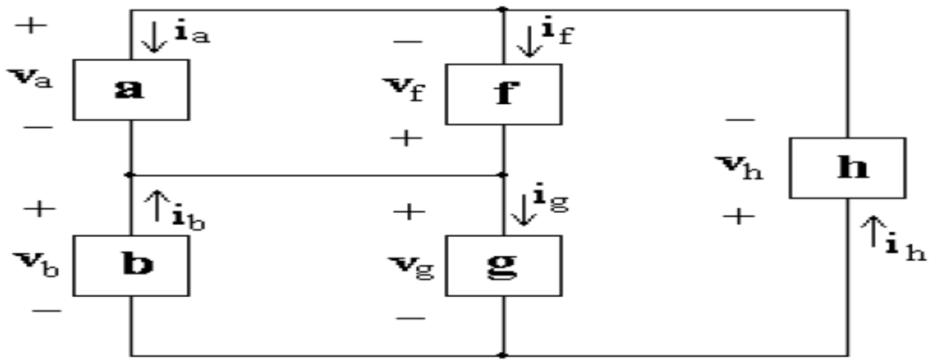
[a] The revised circuit model is shown below:



[b] The expression for the total power in this circuit is

$$v_a i_a - v_b i_b - v_f i_f + v_g i_g + v_h i_h$$

$$= (120)(-10) - (120)(10) - (-120)(3) + 120 i_g + (-240)(-7) = 0$$

Therefore,

$$120 i_g = 1200 + 1200 - 360 - 1680 = 360$$

so

$$i_g = \frac{360}{120} = 3 \text{ A}$$

Thus, if the power in the modified circuit is balanced the current in component g is 3 A.

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Thank You