EEE 201
Electrical Circuits-1

Assist. Prof. Dr. Şenol GÜLGÖNÜL

2023-2024 Summer Semester

Manager of Control&Electronic Systems
BMC Power · Full-time
2017 - 2022 · 5 yrs

-Managing Engine Control Unit (ECU) and (Transmission Control Unit) development of ALTAY Main Battle Tank and other military diesel ...see mor

Skills: OpenECU · MIL-STD-461 · MIL-STD-464 · MIL-STD-1275 · MIL-STD-810 · ISO 26262 · ECE R10 · IPC 620 · Simulink · Embedded Systems · Project

Parttime Instructor
Çankaya Üniversitesi · Part-time
2017 · Less than a year

ECE 439: Satellite and Mobile Communication Systems
ECE 246: Fundamentals of Electronics

Skills: Electronics · Satellite Communications (SATCOM)

Technical Manager
Turksat Uydu Haberleşme Kablo TV ve İşletme A.Ş. · Full-time
2004 - 2016 · 12 yrs
Ankara, Turkey

-VP of Satellite Operations: Involved in Turksat 4A&4B, Turksat 5A&5B and Turksat 6A satellite projects projects. Daily operation of teleport ...see mor

Skills: Satellite Systems Engineering · Satellite Ground Systems · Satellite TV Global Navigation Satellite System (GNSS) · Satellite Communications

Network Manager
KoçSistem · Full-time
Mar 2000 - Jul 2000 · 5 mos

Network Manager of Cisco routers

Skills: Cisco Routers

Senior Network Engineer
TurkNet · Full-time
1996 - 1999 · 3 yrs

Network manager of Turnet which was the first commercial internet backbone of SATCOM, Cisco routers

Skills: VSAT · Cisco Routers · Satellite Communications (SATCOM)

Chief Engineer
Turk Telekom · Full-time
1993 - 1995 · 2 yrs

Chief Ground Control Systems engineer of Turksat Satellite Control Center. The first communication sate of Turkey: Turksat-1A, Turksat-1B and Turksat-1C

Bilkent University
Bachelor of Science - BS
1986 - 1992

Gebze Technical University
Master's degree
1996 - 1998

Sakarya University
Doctor of Philosophy - PhD
2009 - 2014

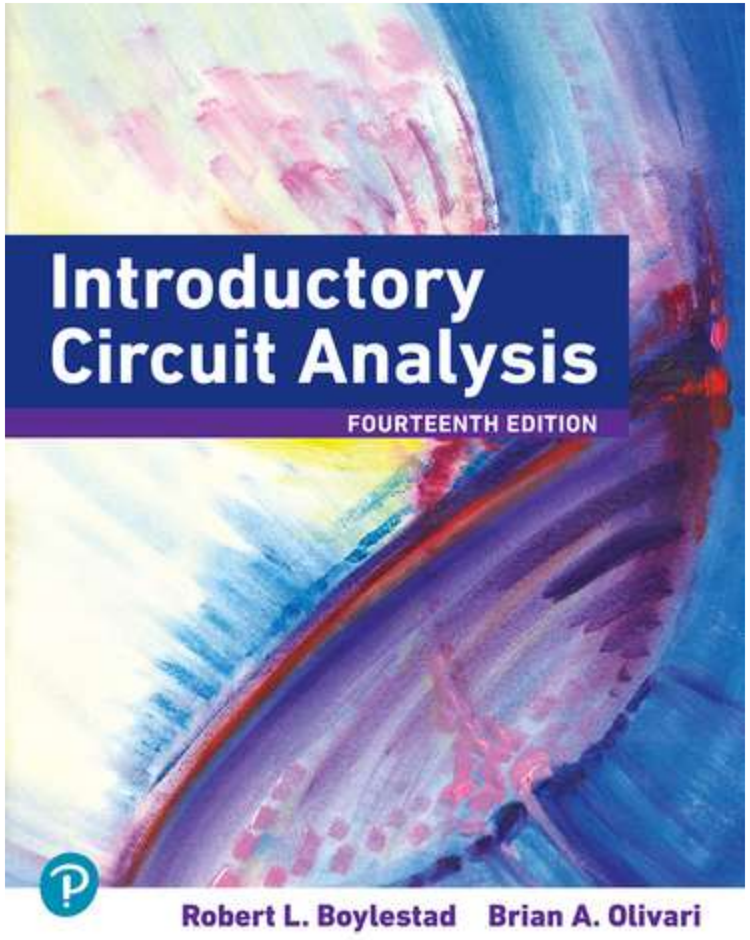
ABOUT

- Text Book: Introductory Circuit Analysis, Published by Pearson
  Robert L. Boylestad Brian A. Olivari

- Grades: 20% Midterm + 40% Project + 40% Final

- Course Objectives: Fundamentals of Electric Circuits

- Additional Resource:
  - Tinkercad



TIN
KER
CAD
AUTODESK
Tinkercad
Circuits

EXPERIMENT SET TO BUY

- Multimeter UNI-T UT33A+ or similar   x1
- Breadboard big one x1
- Resistors: 1Kohm, 100ohm, 10ohm 1W x5
- Potentiometer: 500 ohm or 1Kohm x2
- Jumper cable M-M   20cm x 20
- Battery 1.5V x4 and plastic housing or 9V with connector
- Temperature Resistor PT100
- LDR Resistor
- Load Cell 1Kg
- Electromagnet 5V
- DC motor 3-6V

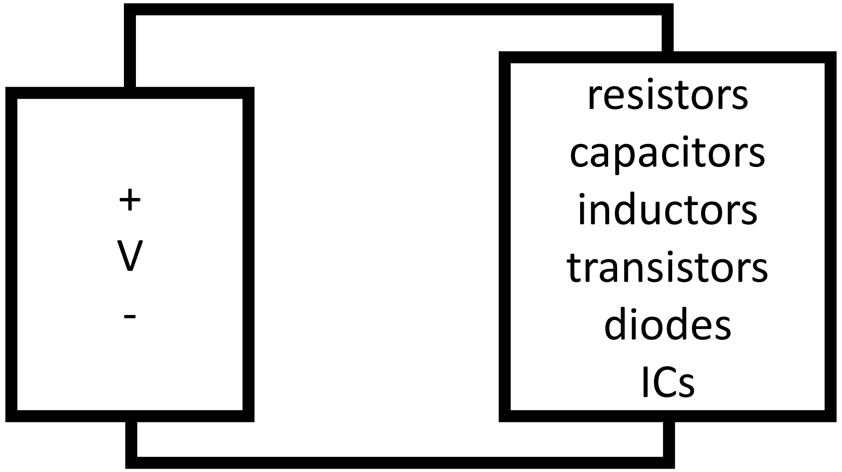
- www.direnc.net
- www.robotistan.com

WHY

- Although you are not electrical engineers, BUT our main profession (Mechanical Engineering, Aerospace Engineering etc.) will require to work together with electric circuits and we need to understand basics and fundamentals of electric circuits and circuit elements (Sensors, actuators, electrical machines, electronic control etc.)

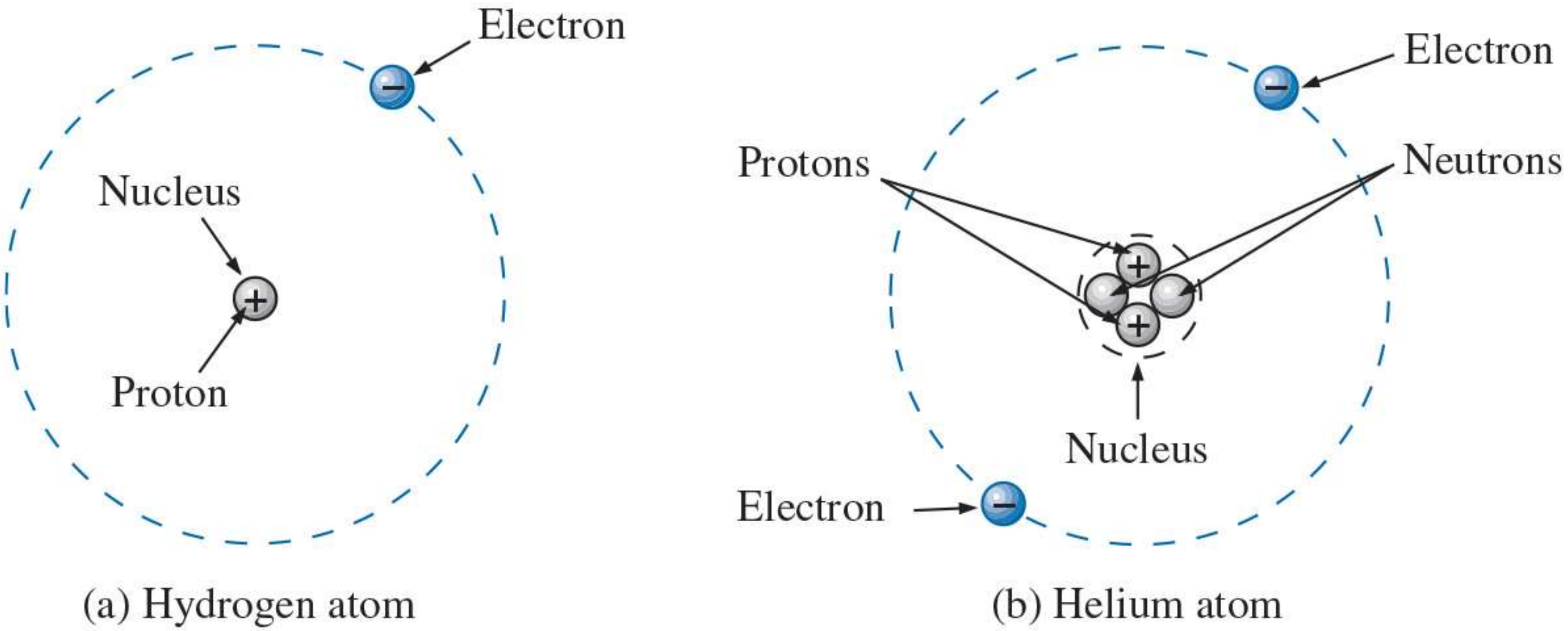
Electric Circuit

- Basic electric circuit is composed of power supply and circuit elements connected to each other
- Lets start with voltage sources and resistors



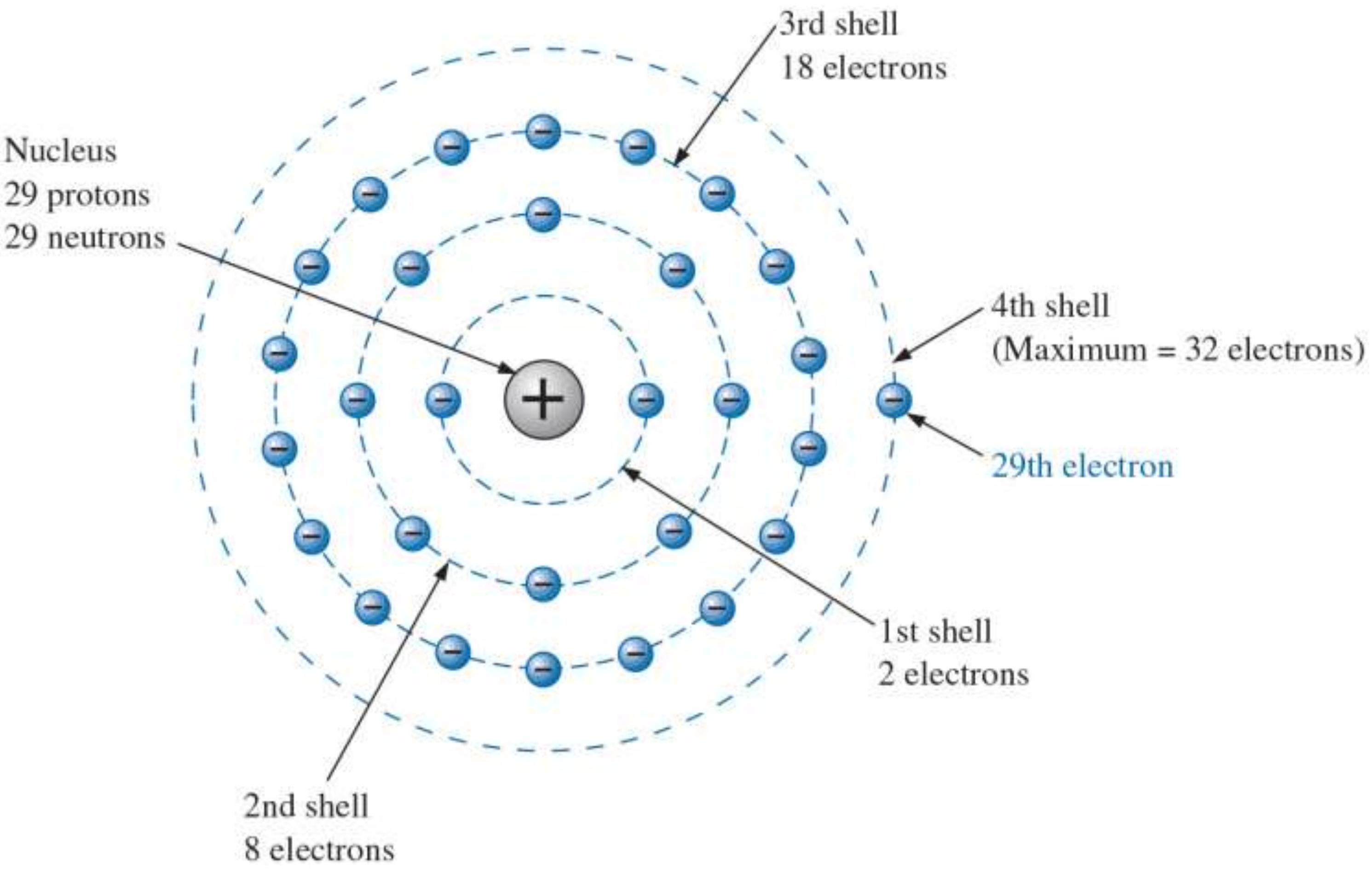
Atoms and Their Structure (2 of 5)

Fig. 2.1 *Hydrogen and helium atoms.*



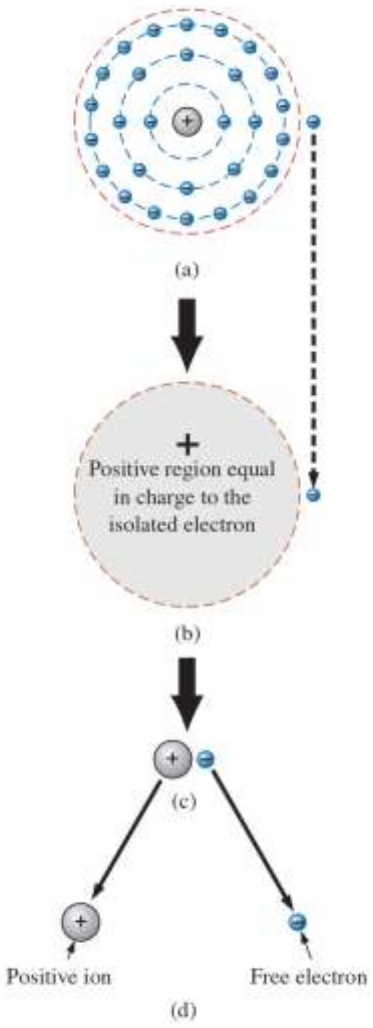
Atoms and Their Structure (4 of 5)

Fig. 2.2 *The atomic structure of copper.*



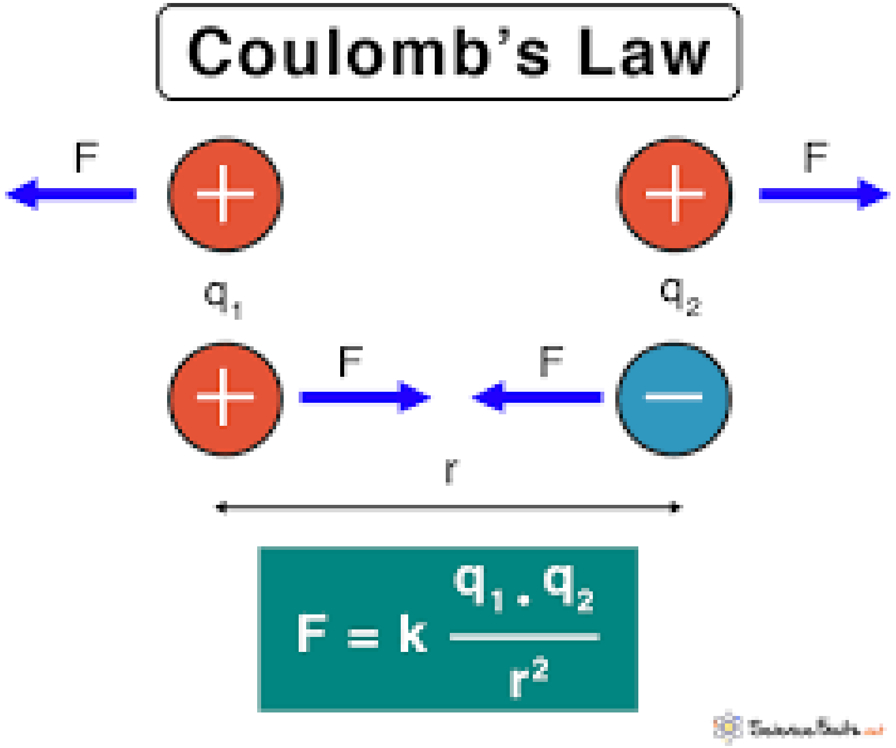
Voltage (2 of 5)

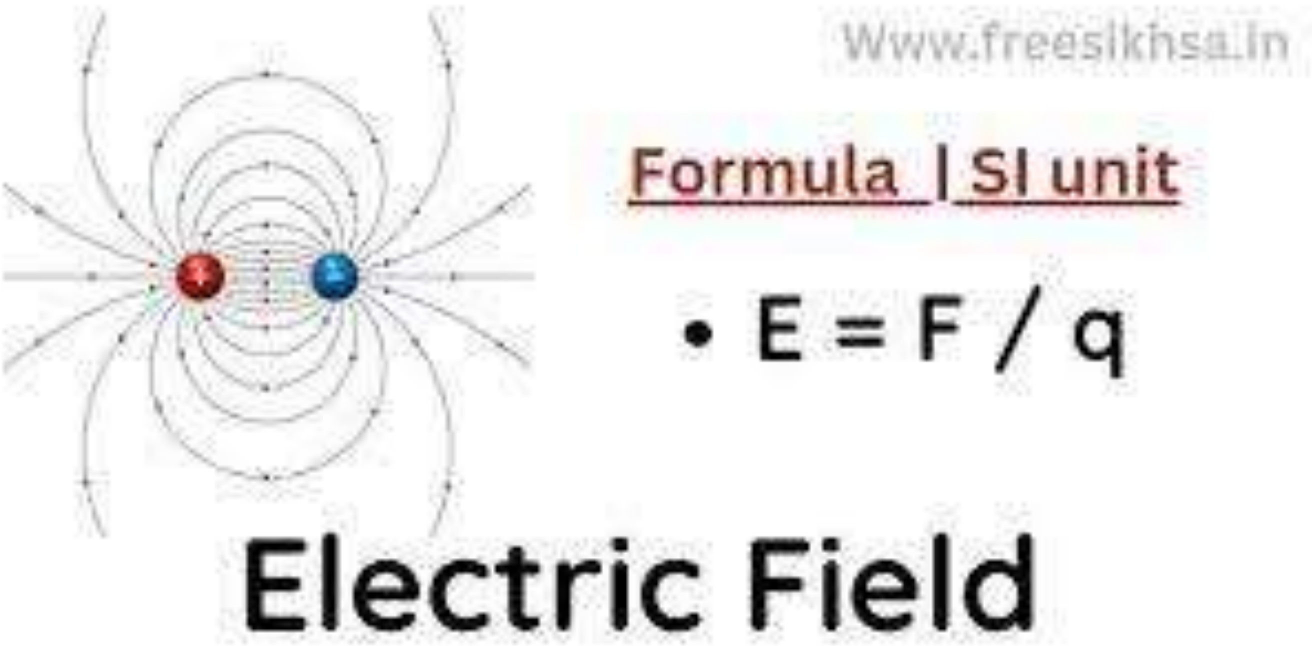
Fig. 2.5 *Defining the positive ion.*



Coulomb’s Law

- *Electric Field between charged particals*
- *Force between two charged particle*
- *F=q.E*





Gauss

- Gauss developed his law in the early 19th century, around 1835. The law was first published in his book "Theoria Electricitatis et Magnetismi" in 1867, but the work itself was a collection of Gauss' notes and manuscripts compiled and edited by his student, Wilhelm Weber, after Gauss' death in 1855.

- The electric flux through a closed surface, whether a sphere, a cylinder, or any other surface, is proportional to the amount of electric charge contained within that surface

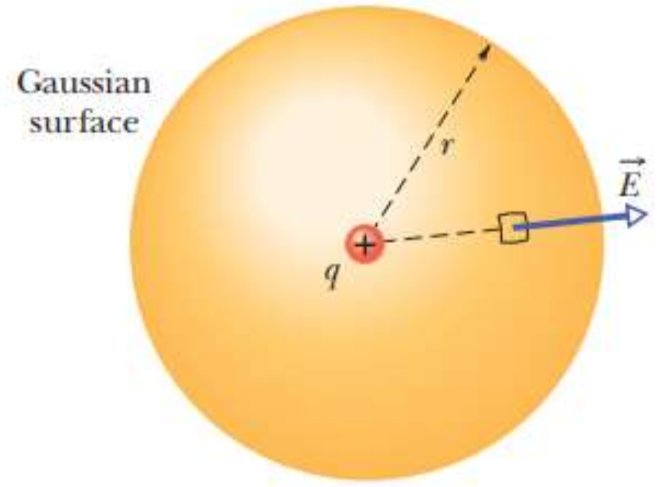


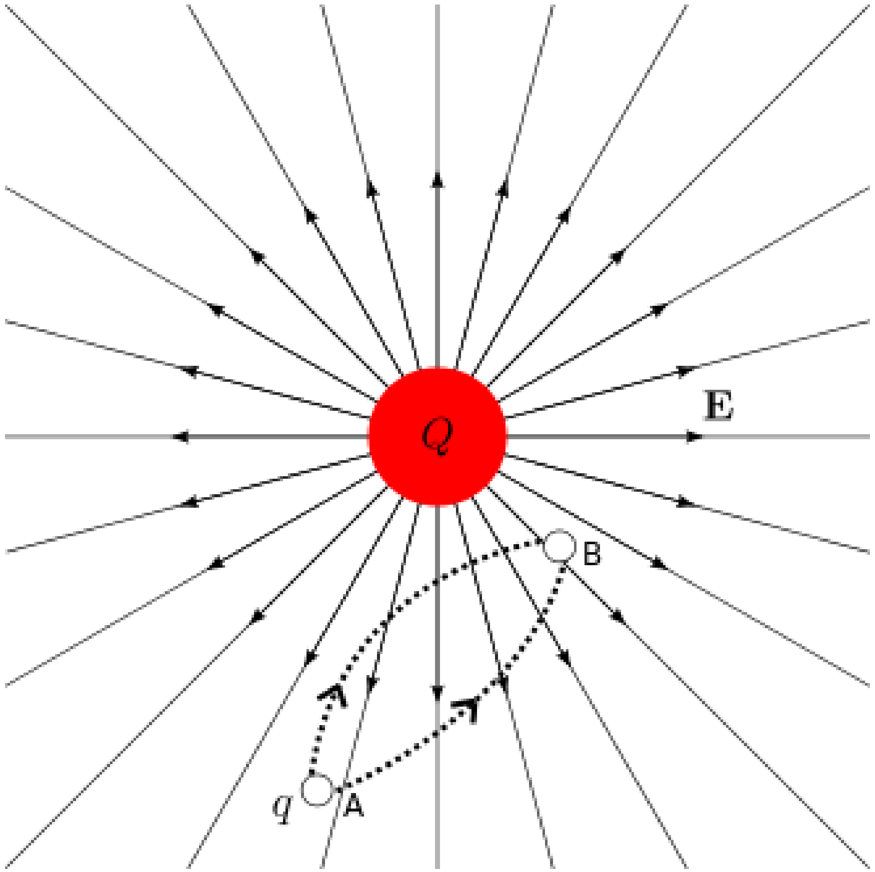
Figure 23-9 A spherical Gaussian surface centered on a particle with charge q.

$$\oint \vec{E}.\overrightarrow{dA} = \frac{q}{\varepsilon_0}$$

Electric Field and Voltage

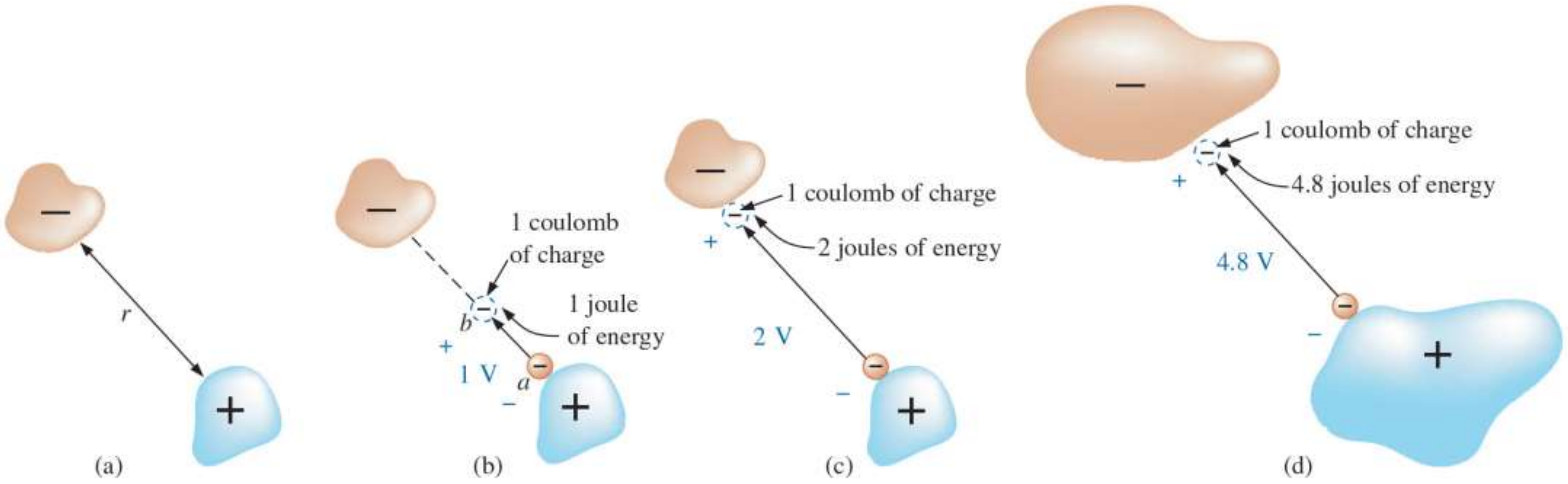
- *work=F.L*
- *work=q E.dl*
- *voltage = work / q*

$$\Delta V_{AB} = -\int_{\mathcal{P}} \mathbf{E} \cdot \mathrm{d}\boldsymbol{\ell}$$



Voltage (3 of 5)

Fig. 2.6 *Defining the voltage between two points.*



Voltage

A potential difference of 1 volt (V) exists between two points if 1 joule (J) of energy is exchanged in moving 1 coulomb (C) of charge between the two points.

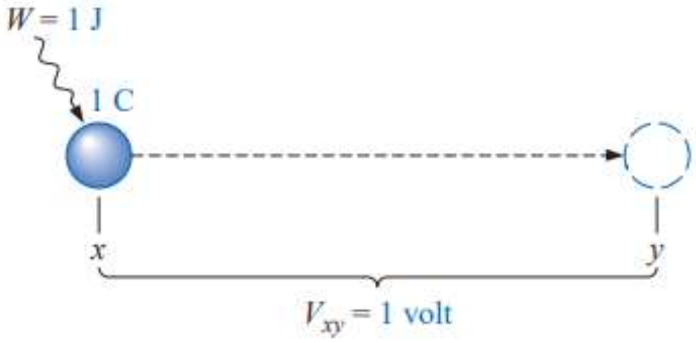
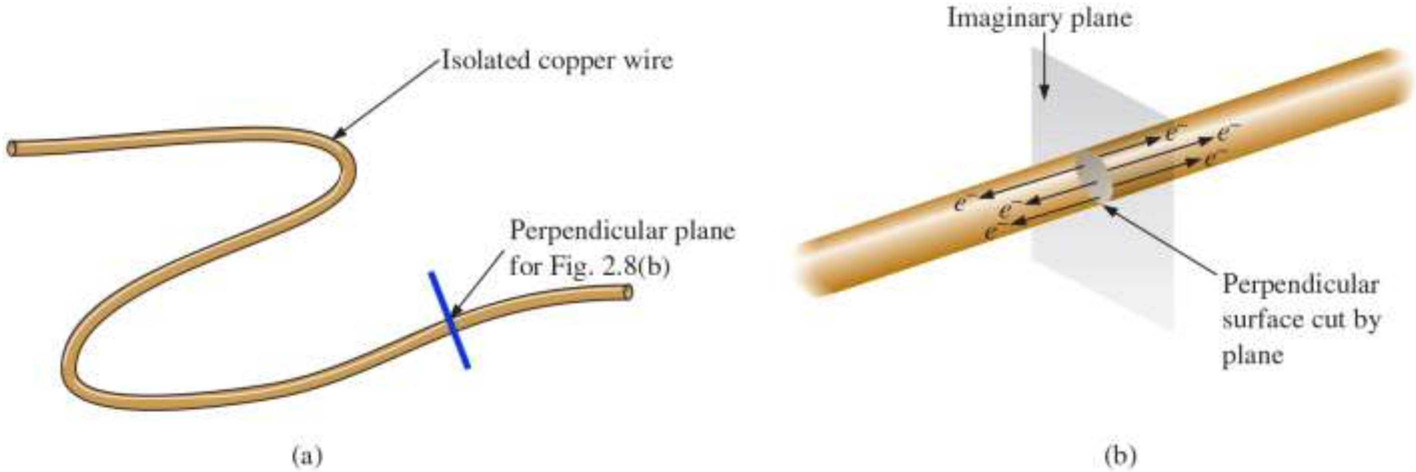


FIG. 2.10
Defining the unit of measurement for voltage.

Current (1 of 4)

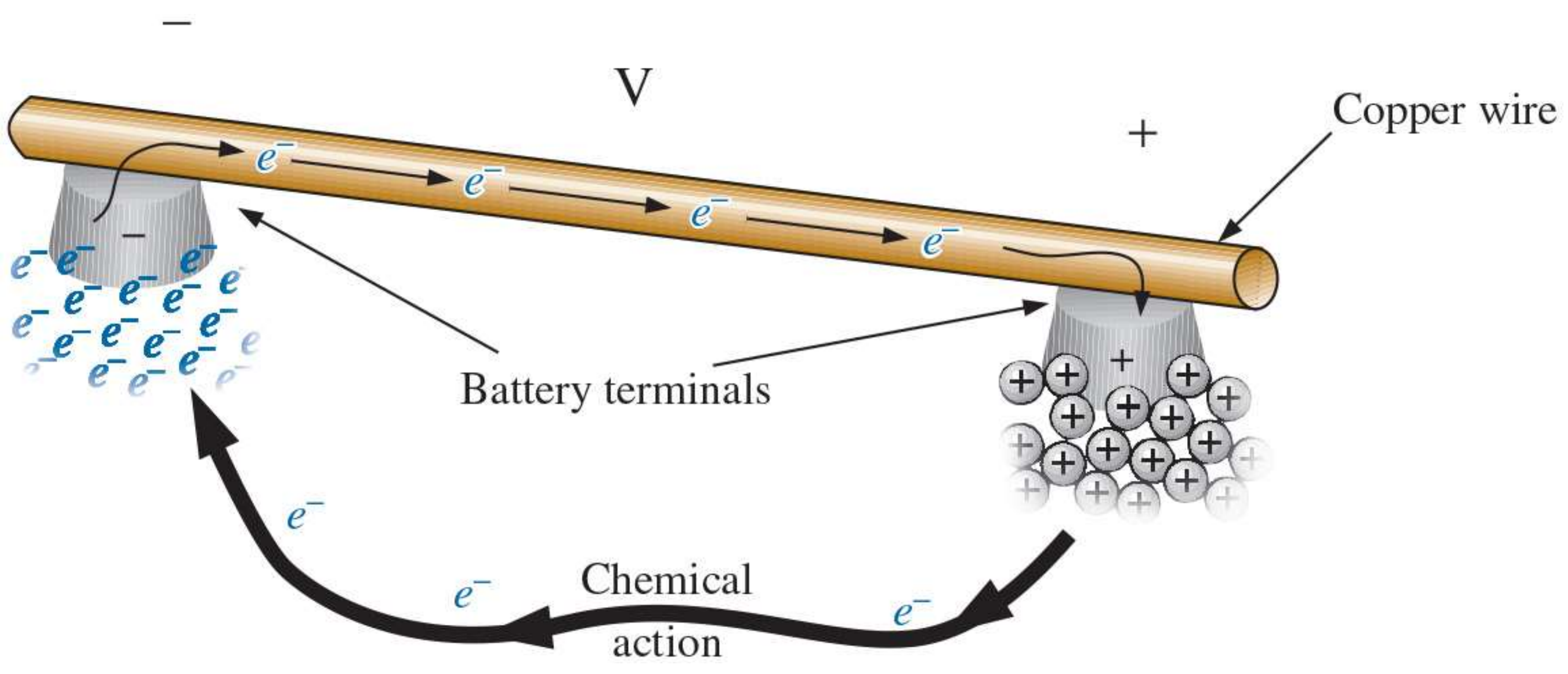
- The applied voltage is the starting mechanism—the current is a reaction to the applied voltage.

Fig. 2.8 *There is motion of free carriers in an isolated piece of copper wire, but the flow of charge fails to have a particular direction.*



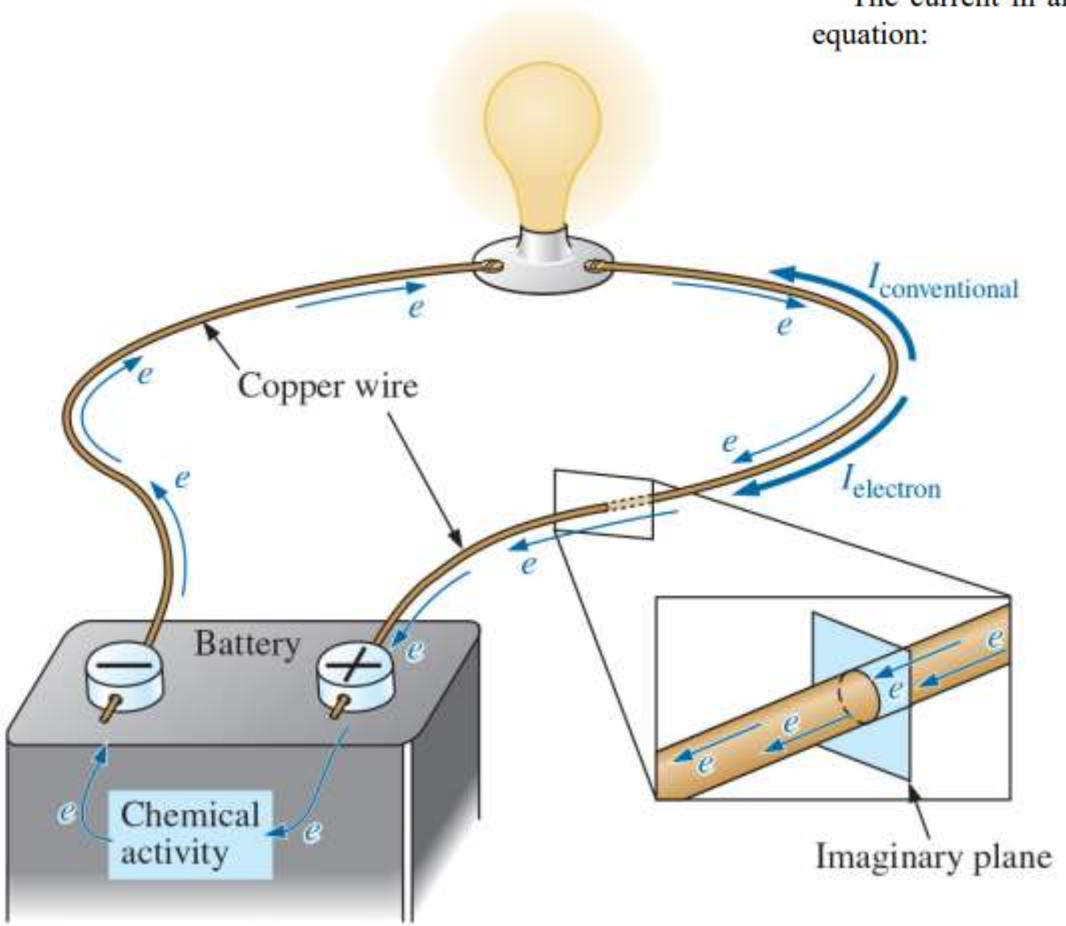
Current (2 of 4)

Fig. 2.9 *Motion of negatively charged electrons in a copper wire when placed across battery terminals with a difference in potential of volts (V).*



Current (3 of 4)

Fig. 2.10 *Basic electric circuit.*



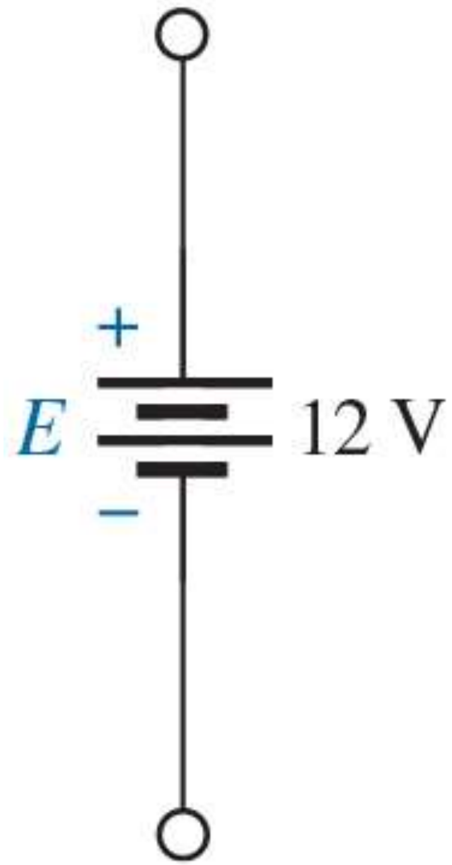
The current in amperes can now be calculated using the following equation:

$$\boxed{I = \frac{Q}{t}} \qquad \begin{aligned} I &= \text{amperes (A)} \\ Q &= \text{coulombs (C)} \\ t &= \text{seconds (s)} \end{aligned} \qquad \textbf{(2.2)}$$

Voltage Sources (1 of 2)

- The term dc, used throughout this text, is an abbreviation for direct current, which encompasses all Systems where there is a unidirectional (one direction) flow of charge.

Fig. 2.12 *Standard symbol for a dc voltage source.*



Voltage Sources (2 of 2)

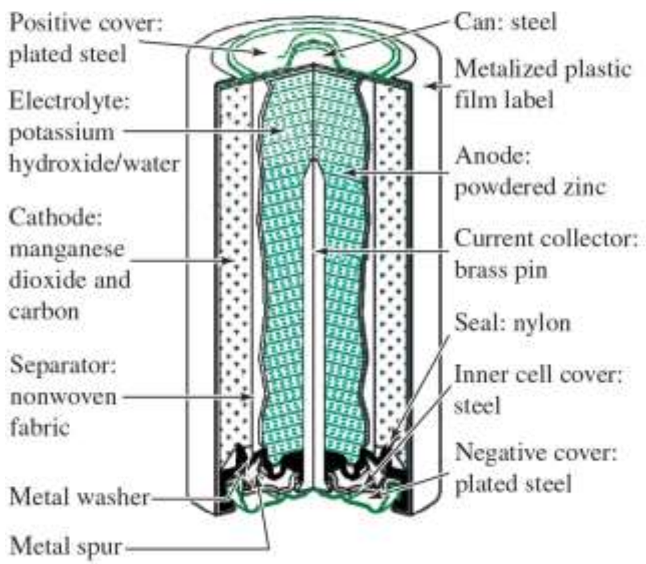
- In general, dc voltage sources can be divided into three basic types:
  - Batteries (chemical action or solar energy)
  - Generators (electromechanical), and
  - Power supplies (rectification—a conversion process to be described in your electronics courses).

Voltage Sources: Batteries (1 of 6)

- General Information
- Primary Cells (Non-rechargeable)
- Secondary Cells (Rechargeable)
  - Lead-Acid
  - Nickel–Metal Hydride (NiMH)
  - Lithium-ion (Li-ion)

Voltage Sources: Batteries (2 of 6)

Fig. 2.13 *Alkaline primary cells: (a) cutaway of cylindrical cell; (b)various types of primary cells.*



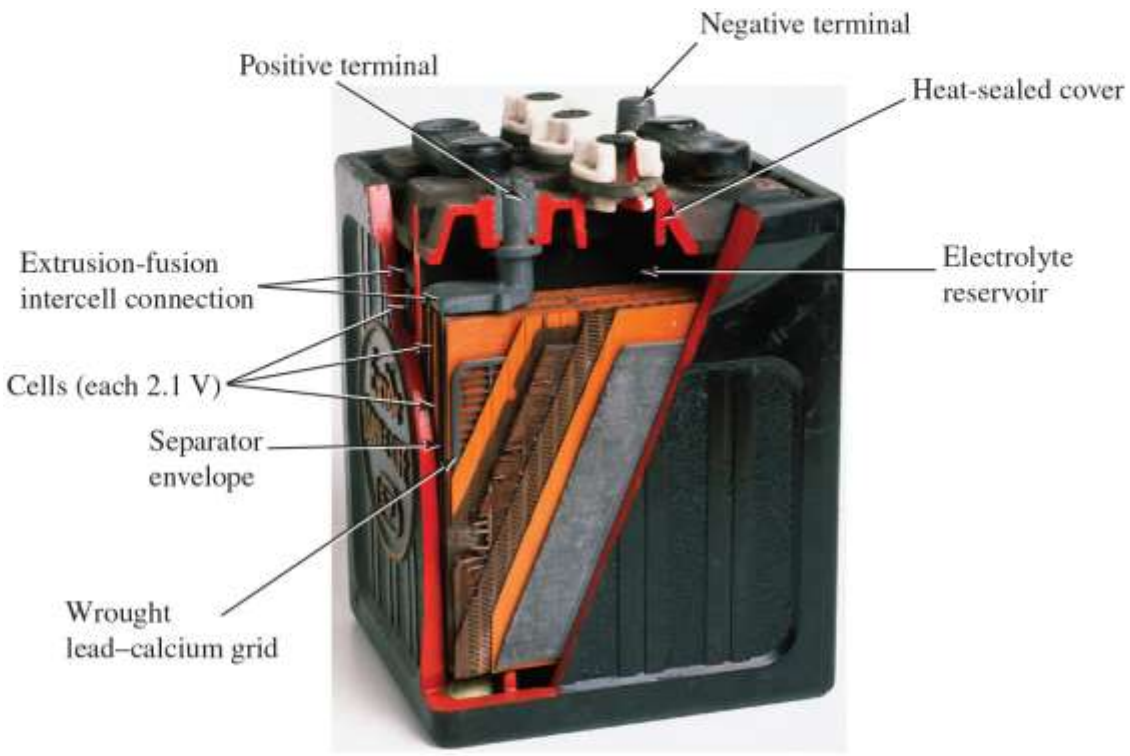
(a)

(b)

(b) photo by Robert Boylestad

Voltage Sources: Batteries (4 of 6)

Fig. 2.15 *Maintenance-free 12 V (actually 12.6 V) lead-acid battery.*



Clive Streeter of DK Images

Voltage Sources: Power Supplies (1 of 2)

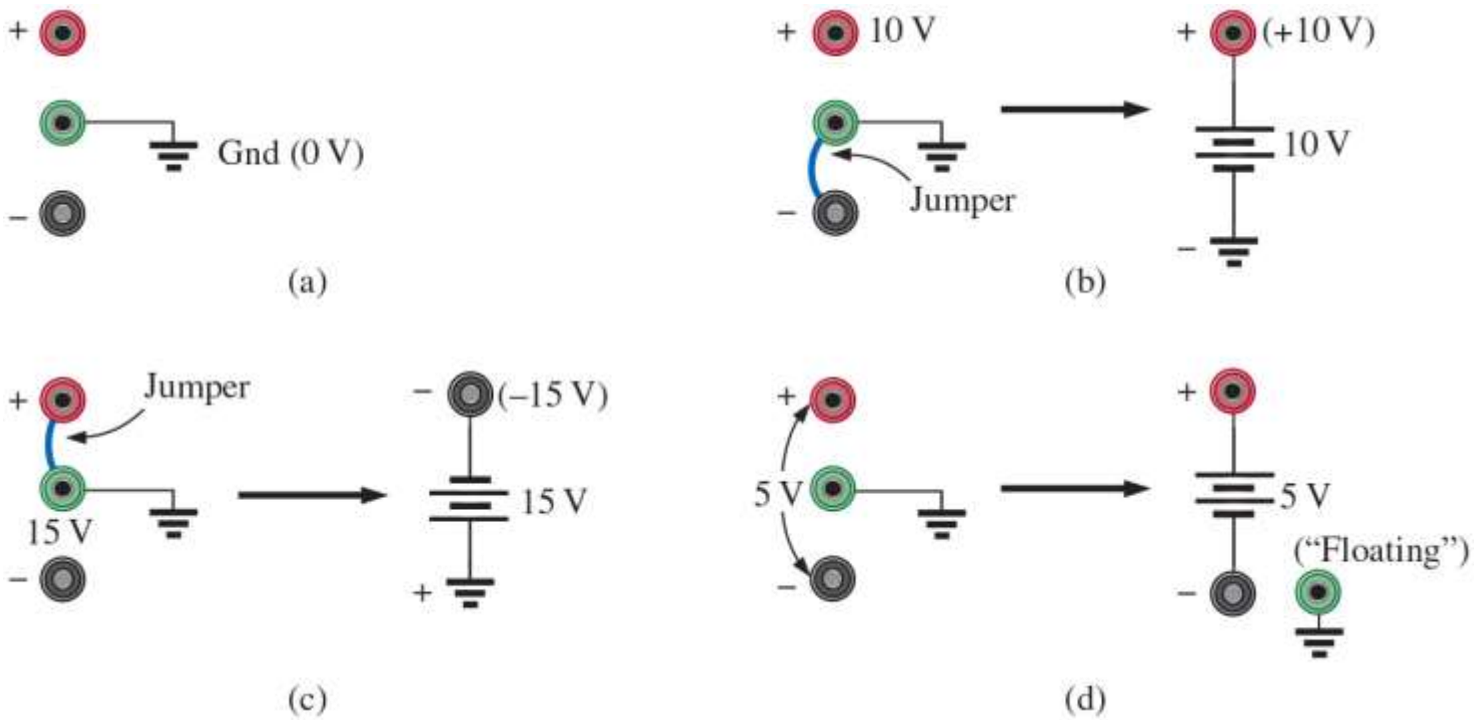
- The dc supply encountered most frequently in the laboratory uses the rectification and filtering processes as its means toward obtaining a steady dc voltage.

Fig. 2.21 *A 0 V to 60 V, 0 to 1.5 A digital display dc power supply.*

Courtesy of B+K Precision.

Voltage Sources: Power Supplies (2 of 2)

Fig. 2.22 *dc laboratory supply: (a) available terminals; (b) positive voltage with respect to (w.r.t.) ground; (c) negative voltage w.r.t. ground; (d) floating supply.*



Ampere-Hour Rating

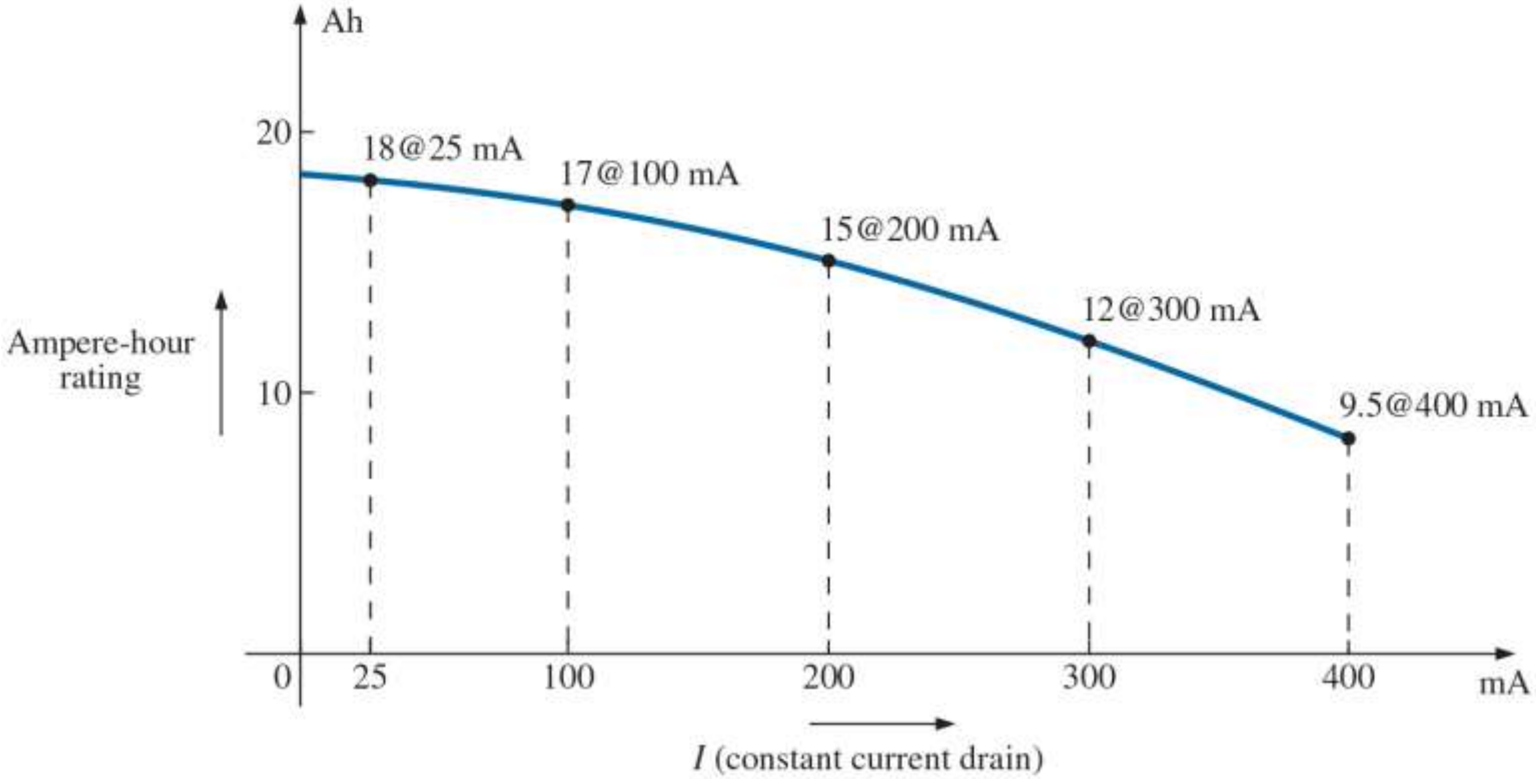
- The most important piece of data for any battery (other than its voltage rating) is its ampere-hour (Ah) rating.
- You have probably noted in the photographs of batteries in this chapter that both the voltage and the ampere-hour rating have been provided for each battery.
  - The ampere-hour (Ah) rating provides an indication of how long a battery of fixed voltage will be able to supply a particular current.

Battery Life Factors (1 of 4)

- The previous section made it clear that the life of a battery is directly related to the magnitude of the current drawn from the supply.
  - However, there are factors that affect the given ampere-hour rating of a battery, so we may find that a battery with an ampere-hour rating of 100 can supply a current of 10 A for 10 hours but can supply a current of 100 A for only 20 minutes rather than the full 1 hour calculated using Eq. (2.11).
  - In other words, the capacity of a battery (in ampere-hours) will change with change in current demand.

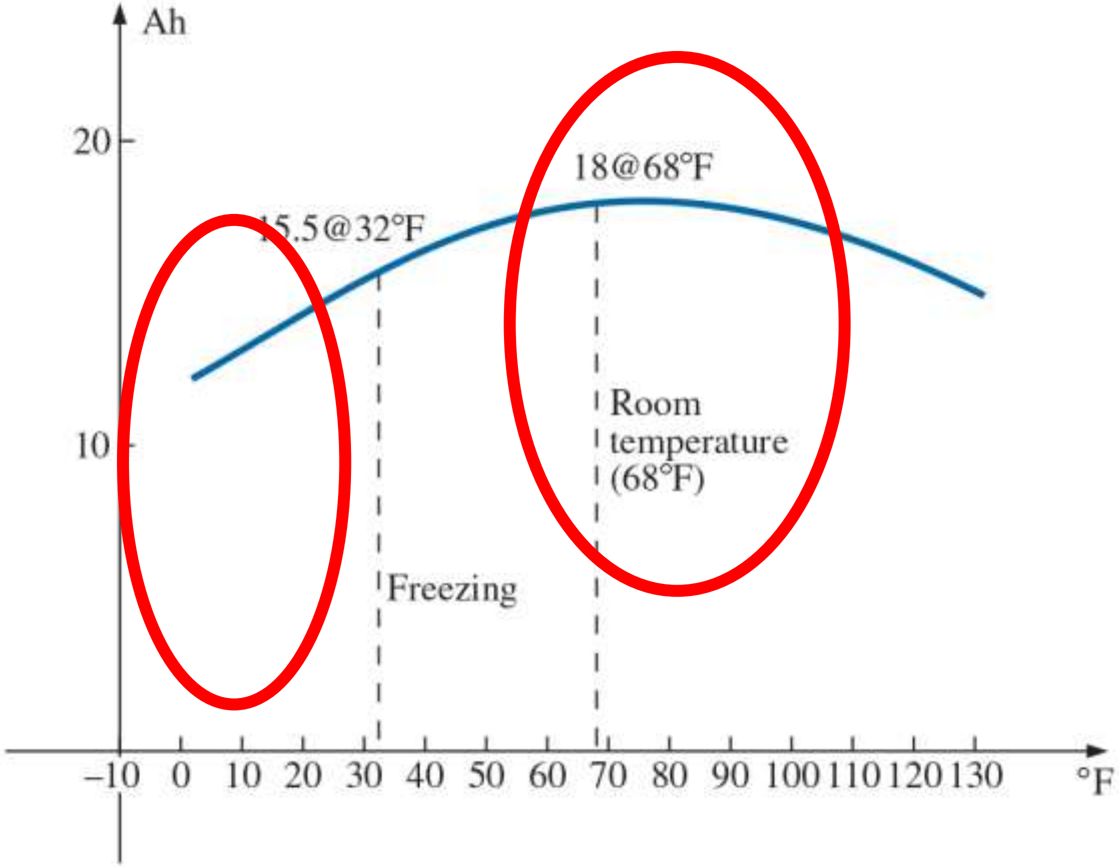
Battery Life Factors (2 of 4)

Fig. 2.25 *Ampere-hour rating (capacity) versus drain current for an Energizer® D cell.*



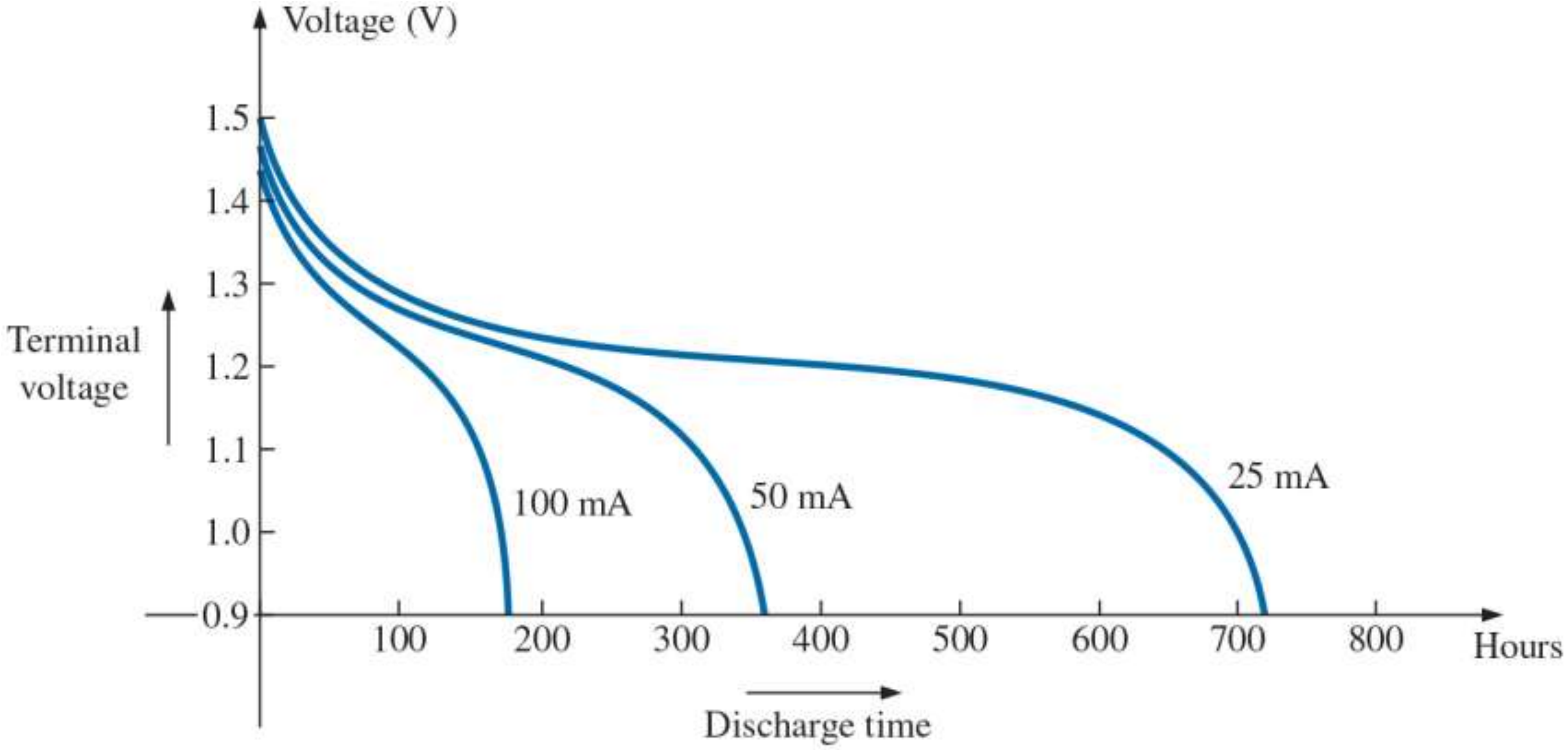
Battery Life Factors (3 of 4)

Fig. 2.26 *Ampere-hour rating (capacity) versus temperature for an Energizer® D cell.*



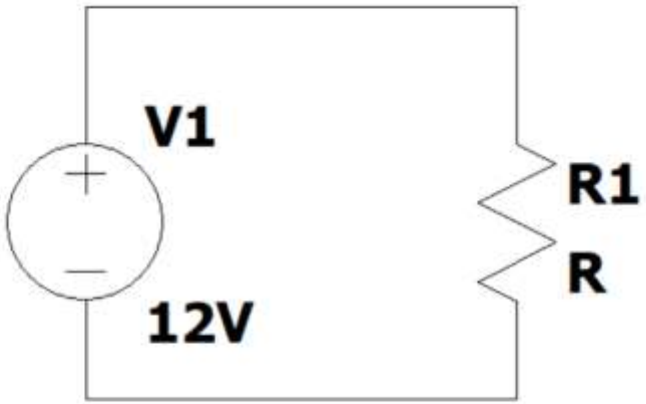
Battery Life Factors (4 of 4)

Fig. 2.27 *Terminal voltage versus discharge time for specific drain currents for an Energizer® D cell.*



Battery

- *voltage: 12V*
- *capacity: 60Ah (ampere x hour)*
- *CCA: 600A (Cold Cranking Current)*



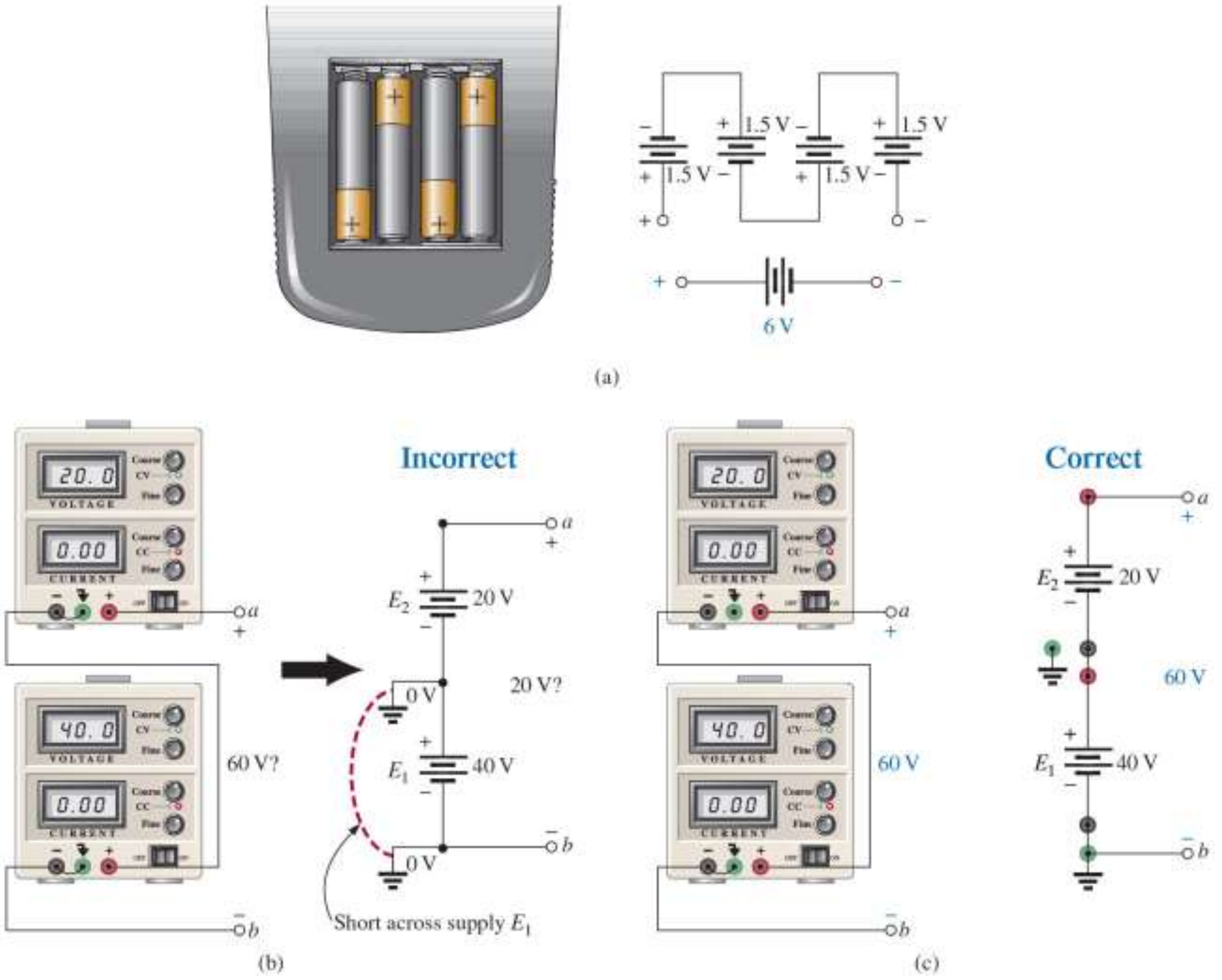
V = I*R, I = V/R

I = 12V / 1ohm = 12A
I = 12V / 1 mOhm != 1200A
in fact max current 600A

max resistor power
P=V*I = 12 * 600 = 7200W

Voltage Sources in Series Instrumentation

Fig. 5.26 *Series connection of dc supplies: (a) four 1.5 V batteries in series to establish a terminal voltage of 6 V; (b) incorrect connections for two series dc supplies; (c) correct connection of two series supplies to establish 60 V at the output terminals.*



Voltage Sources in Series

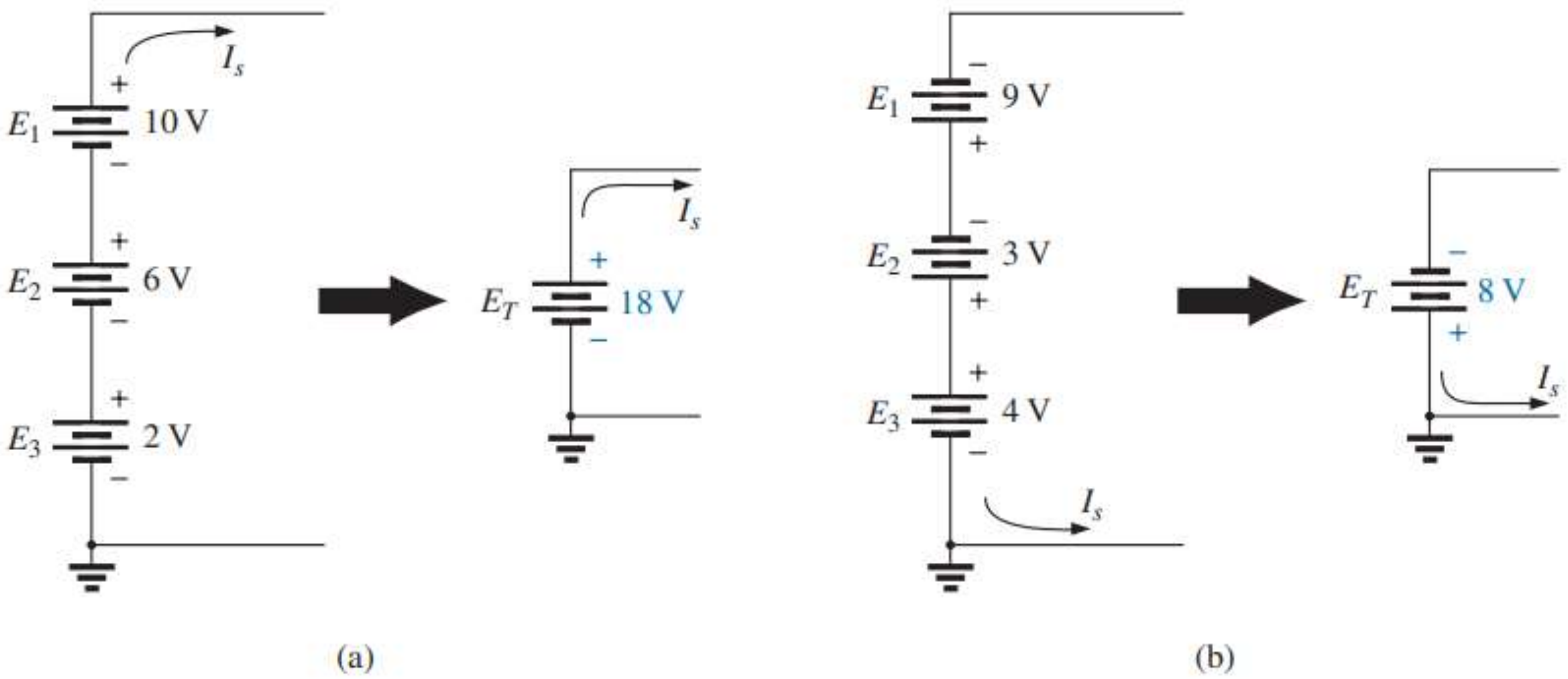
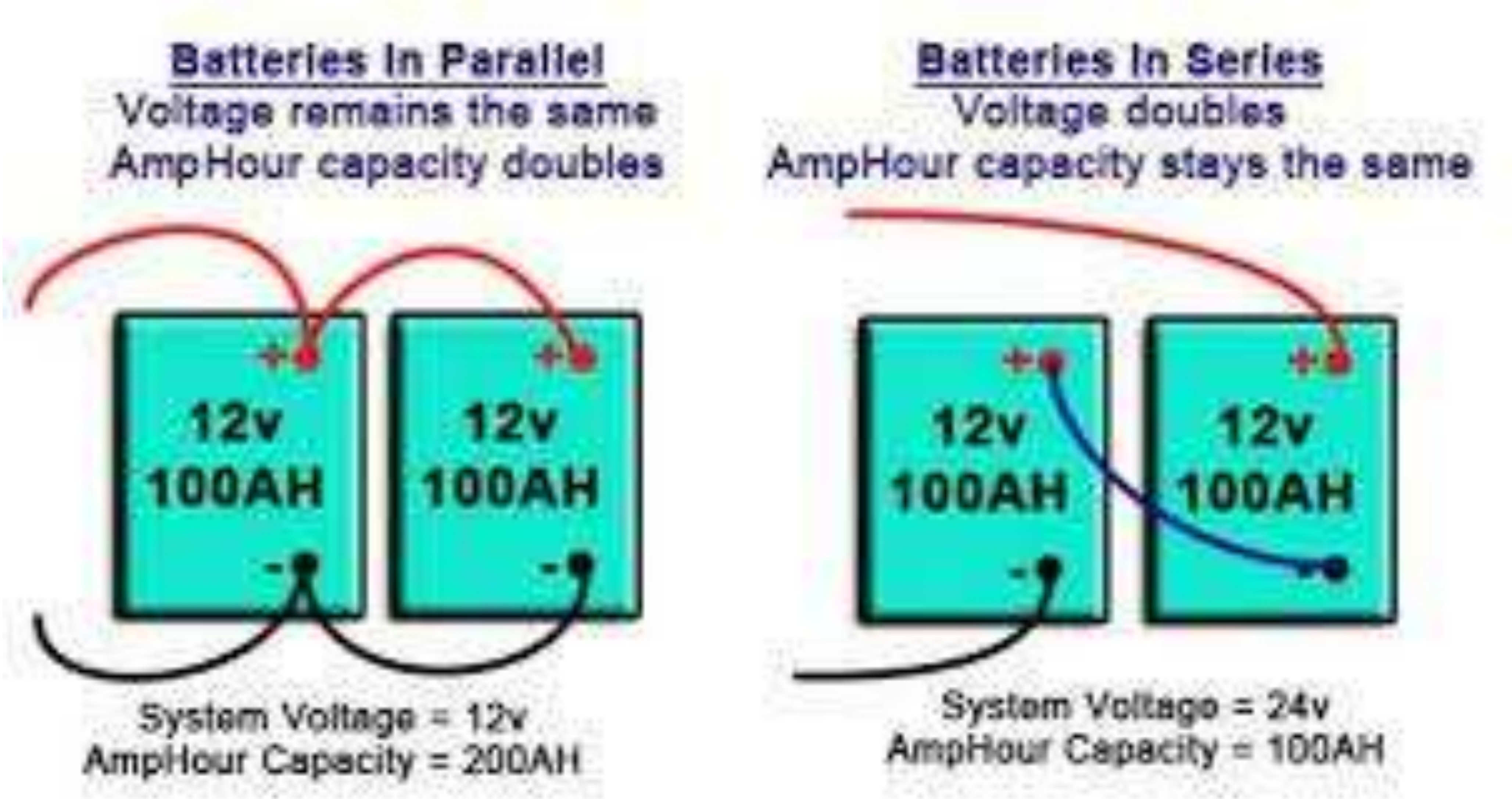
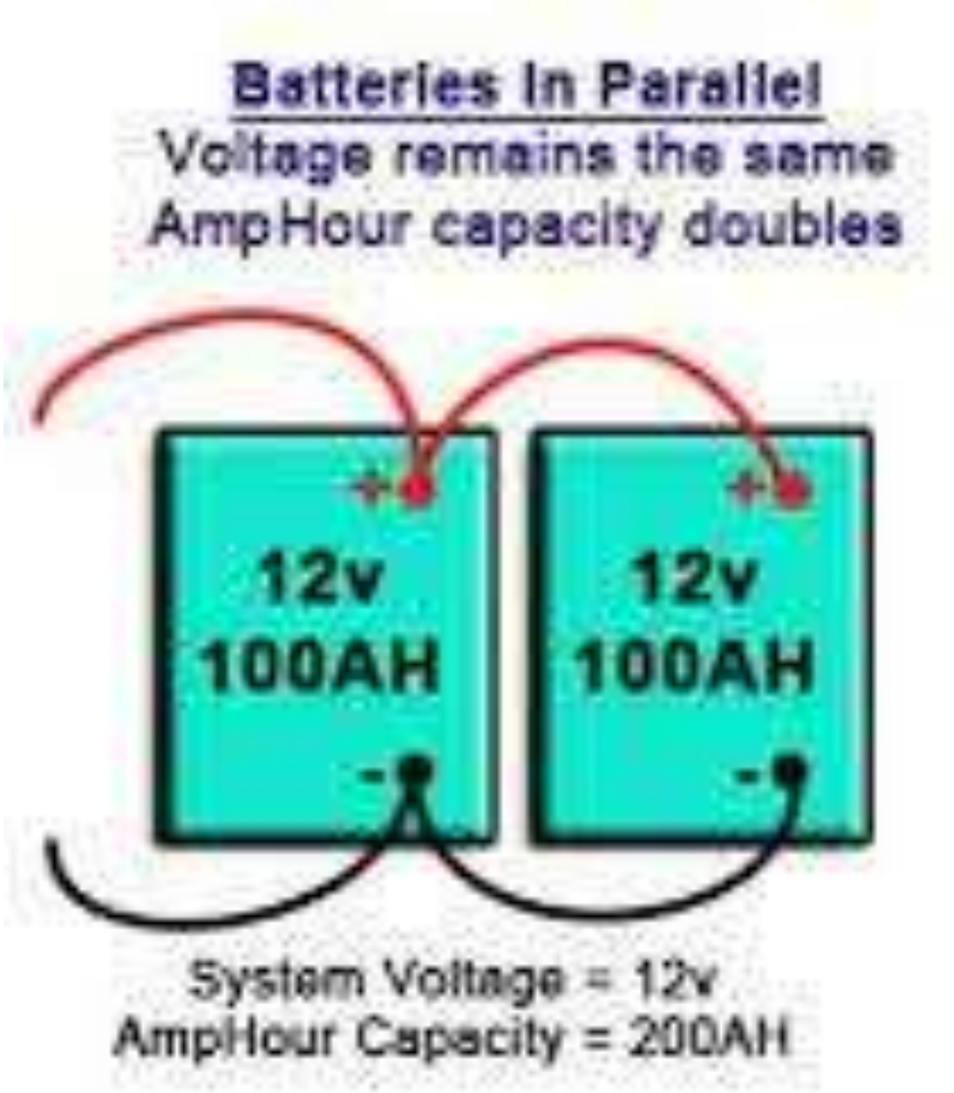


FIG. 5.25
Reducing series dc voltage sources to a single source.

Voltage Sources in Parallel



Voltage Sources in Parallel



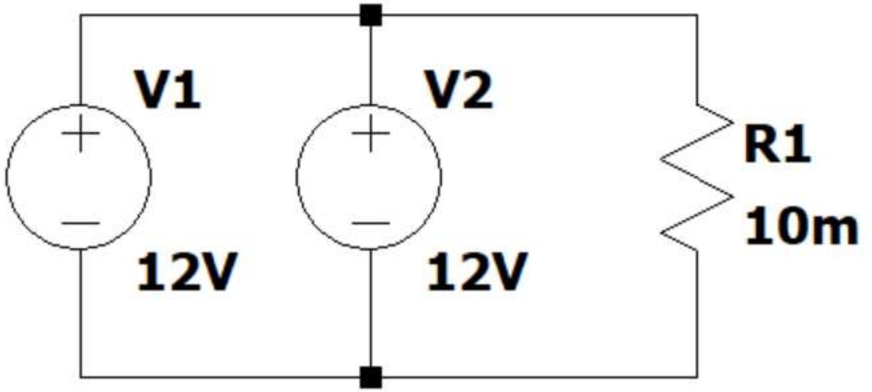
12V, 60Ah, 600A

2 batteries in parallel

12V , 120 Ah, 1200A

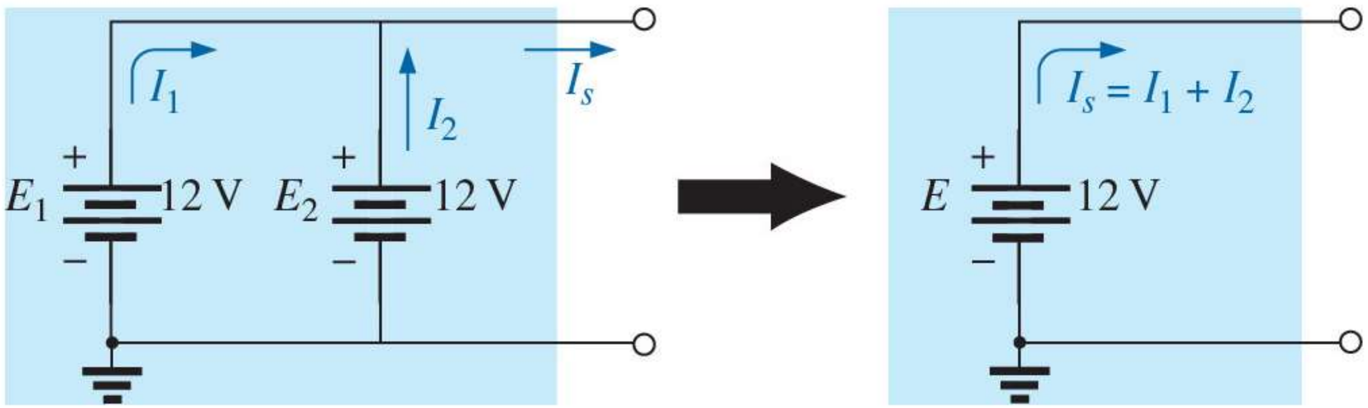
Voltage Sources in Parallel

current with single battery
V=IR, I=V/R
I=12/10m=1200A BUT battery can supply maximum of 600A Thus we need to use 2 battery in parallel



Voltage Sources in Parallel

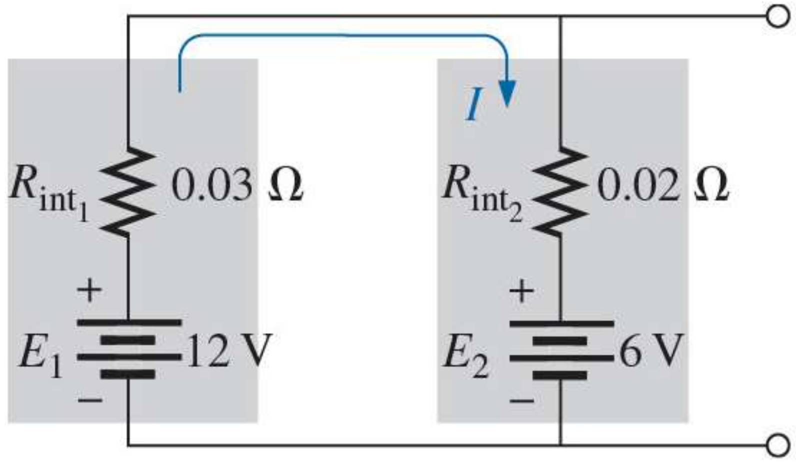
Fig. 6.46 *Demonstrating the effect of placing two ideal supplies of the same voltage in parallel.*



Voltage Sources in Parallel

- If for some reason two batteries of different voltages are placed in parallel, both will become ineffective or damaged because the battery with the larger voltage will rapidly discharge through the battery with the smaller terminal voltage.

Fig. 6.47 *Examining the impact of placing two lead-acid batteries of different terminal voltages in parallel.*



KVL:

-12 + i*0.03 + i*0.02 + 6 = 0

i * 0.05 = 6, i= 120A

Boosting a Car Battery

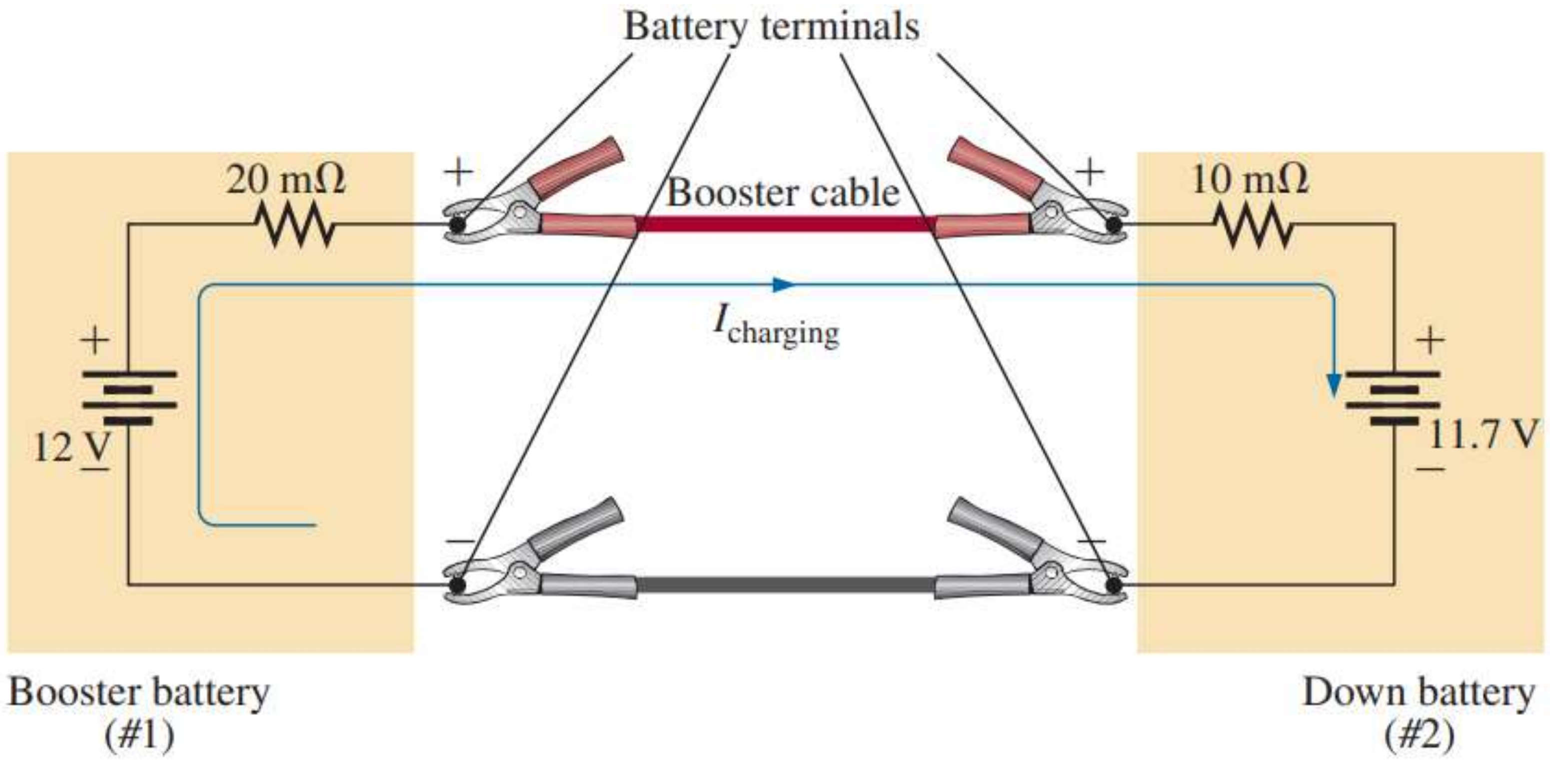


FIG. 7.63
Boosting a car battery.

The initial charging current will be
I = (12 - 11.7)/(20m+10m) =10 A

Boosting a Car Battery

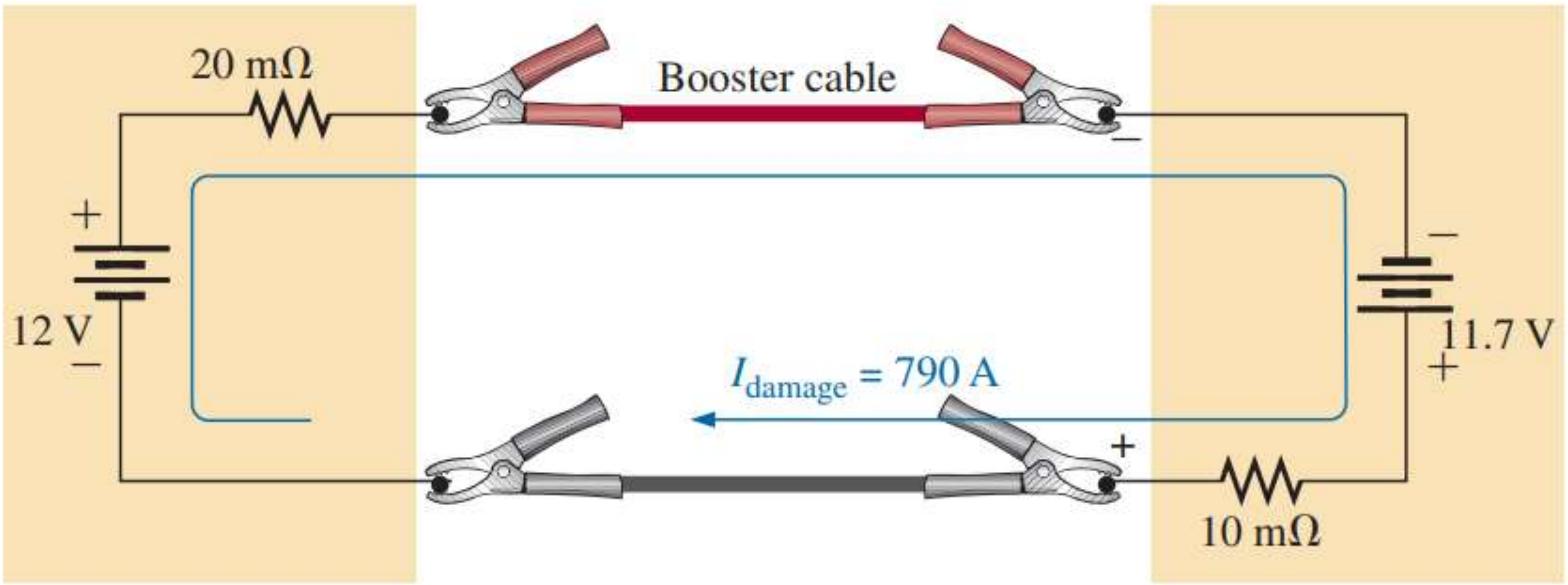


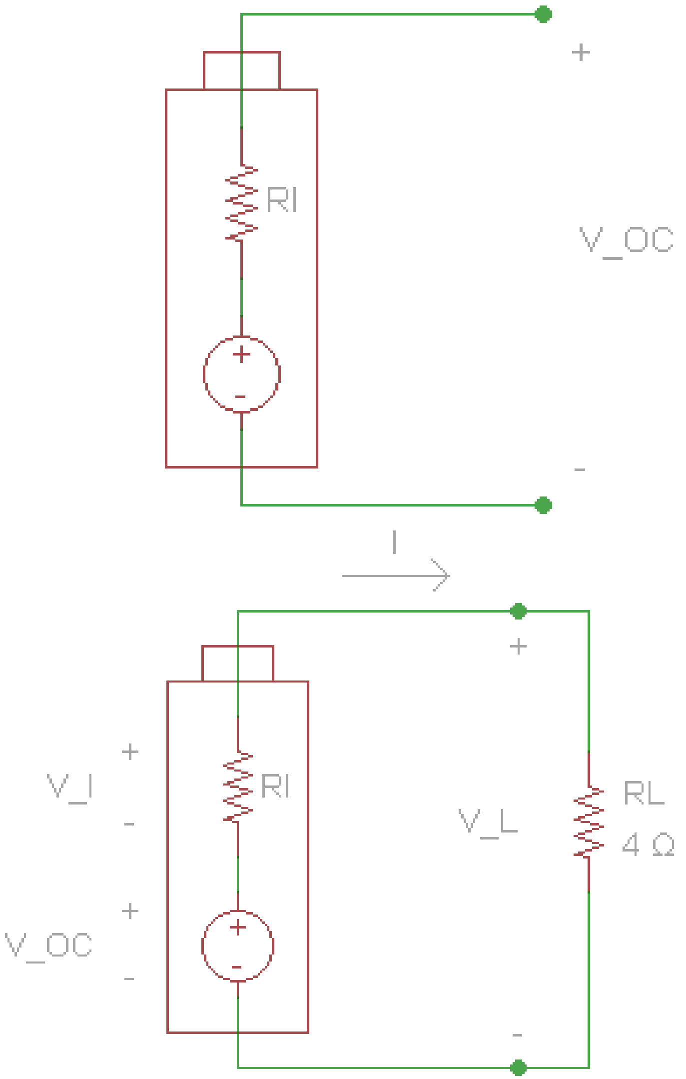
FIG. 7.65

Current levels if the booster battery is improperly connected.

-12 + 0.020*i -11.7 + i*0.010 = 0
i * 0.03 = 23.7 , i = 790A

$$[I = (12\text{ V} + 11.7\text{ V})/30\text{ m}\Omega = 23.7\text{ V}/30\text{ m}\Omega = 790\text{ A}],$$

Battery Internal Resistance



Vs=1.5V open circuit
V2=1.4V with R2=4 ohm

VL = Voc*RL/(RL+Ri)
1.4=1.5*4(4+Ri)
4*1.4 +1.4Ri = 1.5*4
5.6 +1.4Ri = 5
Ri=0.4/1.4=0.3 ohm

[Measuring Internal Resistance of Batteries - SparkFun Learn]

Conductors and Insulators (1 of 4)

- Different wires placed across the same two battery terminals allow different amounts of charge to flow between the terminals.
- Many factors, such as the density, mobility, and stability characteristics of a material, account for these variations in charge flow.
  - In general, however, conductors are those materials that permit a generous flow of electrons with very little external force (voltage) applied.
  - In addition, good conductors typically have only one electron in the valence (most distant from the nucleus) ring.

Conductors and Insulators (2 of 4)

Table 2.1 *Relative conductivity of various materials*

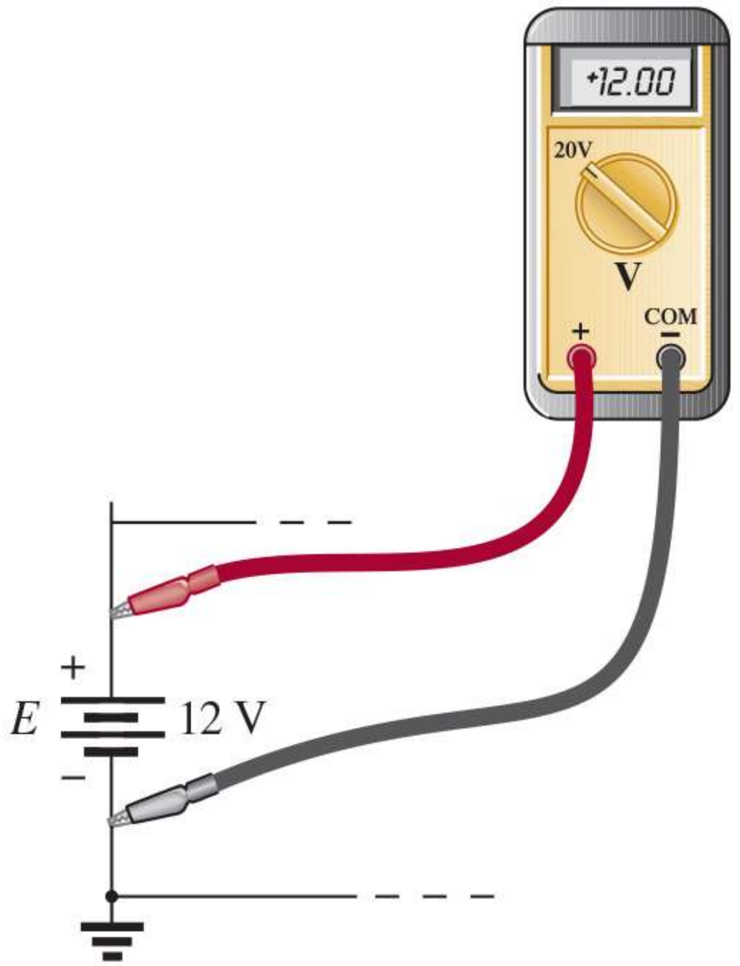
Metal	Relative Conductivity (%)
Silver	105
Copper	**100**
Gold	70.5
Aluminum	61
Tungsten	31.2
Nickel	22.1
Iron	14
Constantan	3.52
Nichrome	1.73
Calorite	1.44

Conductors and Insulators (3 of 4)

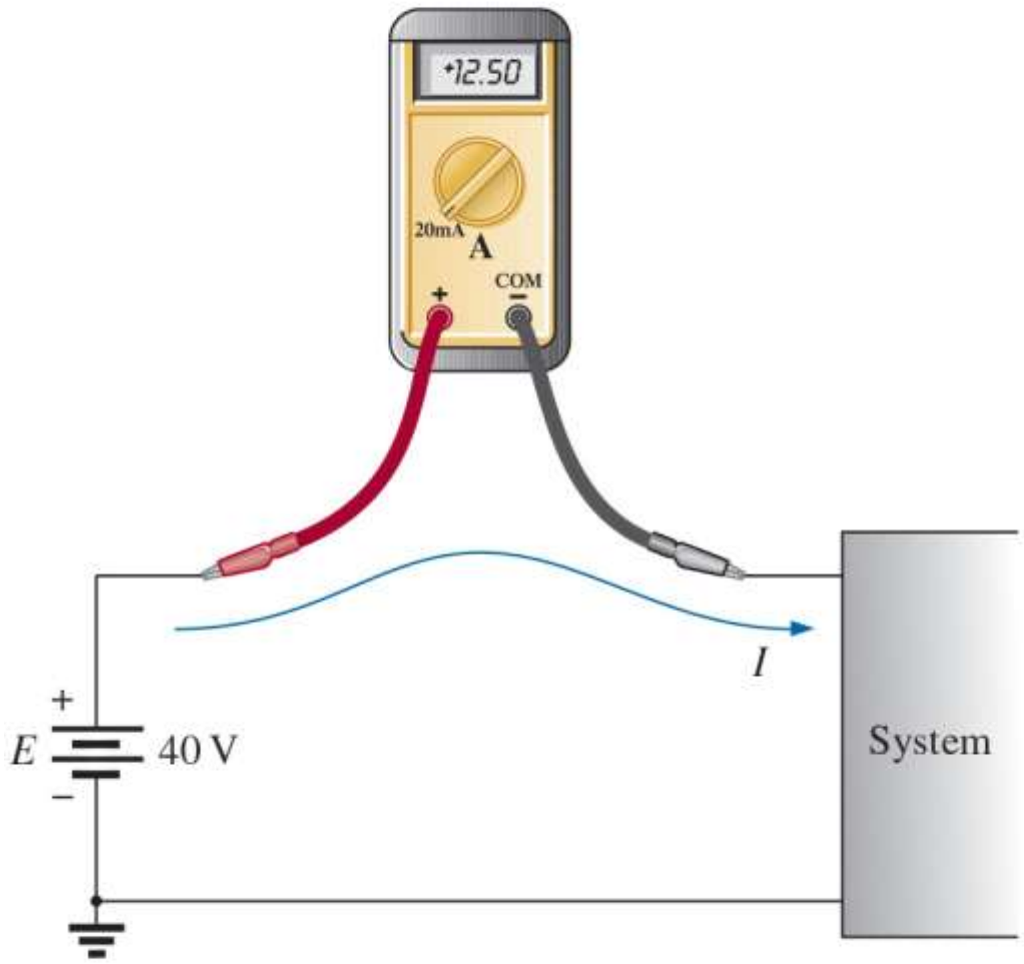
Table 2.2 *Breakdown strength of some common insulators*

Material	Average Breakdown Strength (kV/cm)
Air	30
Porcelain	70
Oils	140
Bakelite®	150
Rubber	270
Paper (paraffin-coated)	500
Teflon®	600
Glass	900
Mica	2000

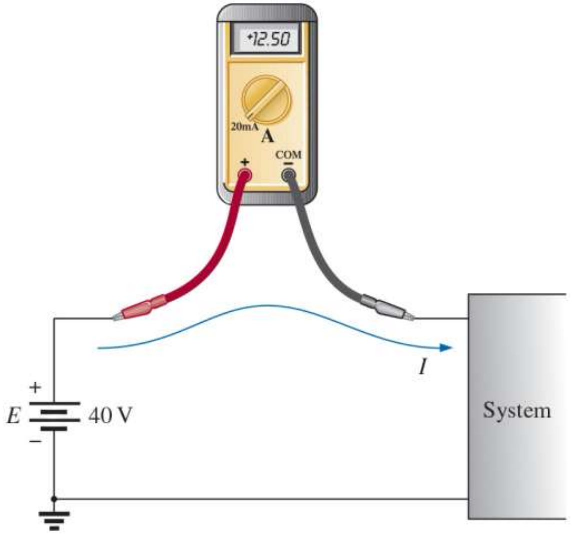
Multimeter Voltage Measurement



Multimeter Current Measurement

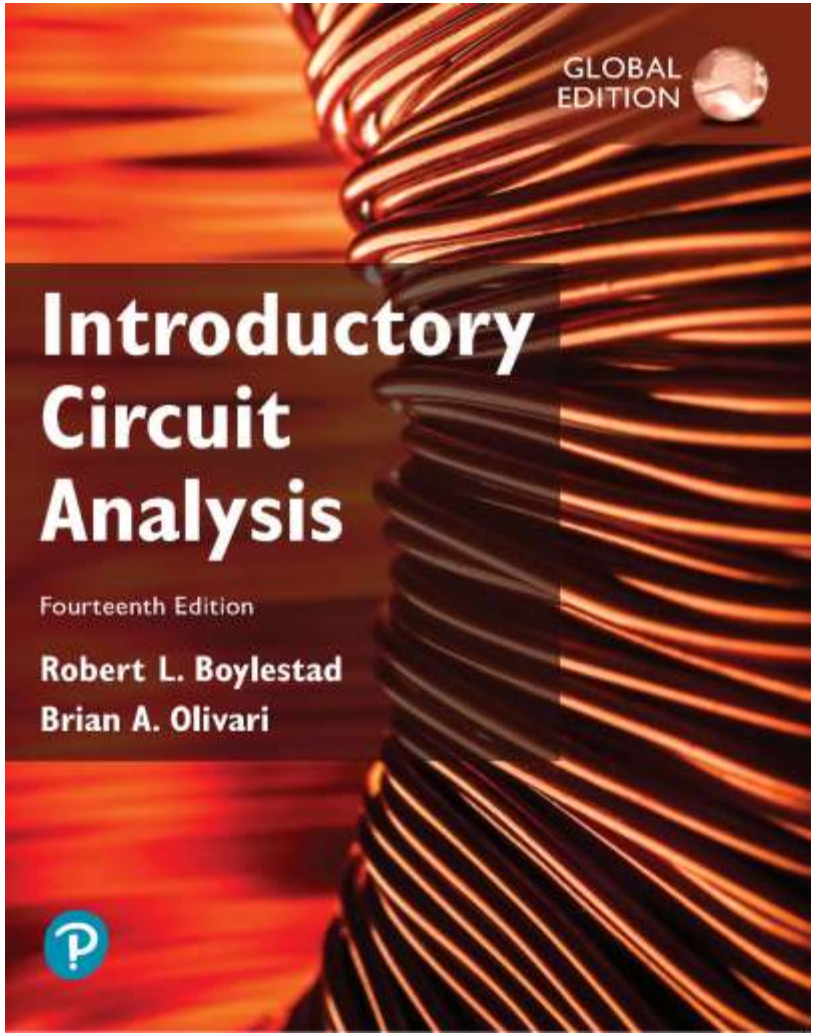


Current Clamp Measurement



Introductory Circuit Analysis

Fourteenth Edition, Global Edition



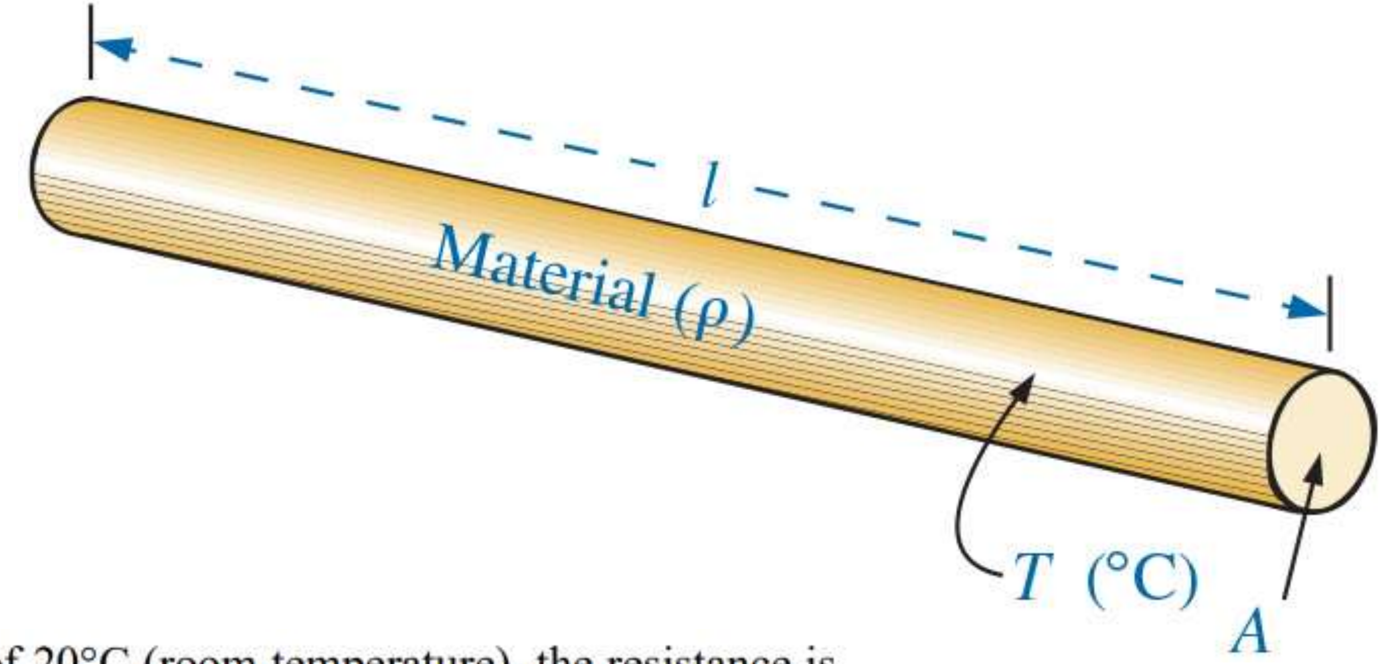
Chapter 3

Resistance

FIG. 3.1
Resistance symbol and notation.

Resistance: Circular Wires (4 of 6)

Fig. 3.2 *Factors affecting the resistance of a conductor.*



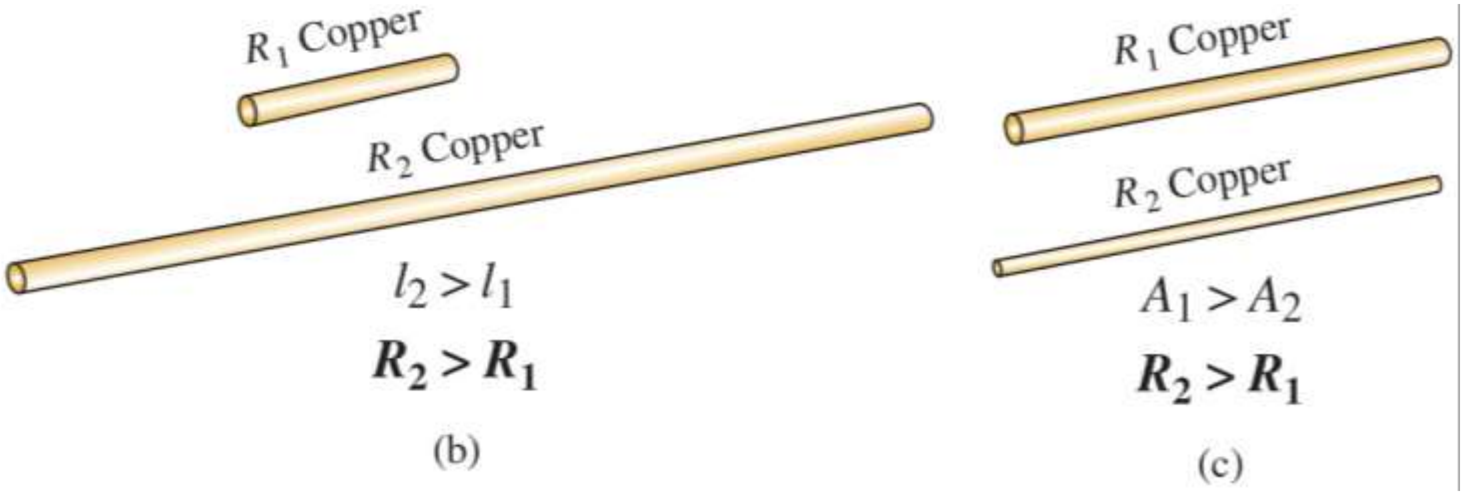
At a fixed temperature of 20°C (room temperature), the resistance is related to the other three factors by

$$\boxed{R = \rho \frac{l}{A}} \quad \text{(ohms, } \Omega) \qquad \textbf{(3.1)}$$

It is important to realize at this point that since the resistivity is provided at room temperature, Eq. (3.1) is applicable only at that temperature.

Resistance: Circular Wires (6 of 6)

Fig. 3.3 *Cases in which* $R2 > R1.$ *For each case, all remaining parameters that control the resistance level are the same.*

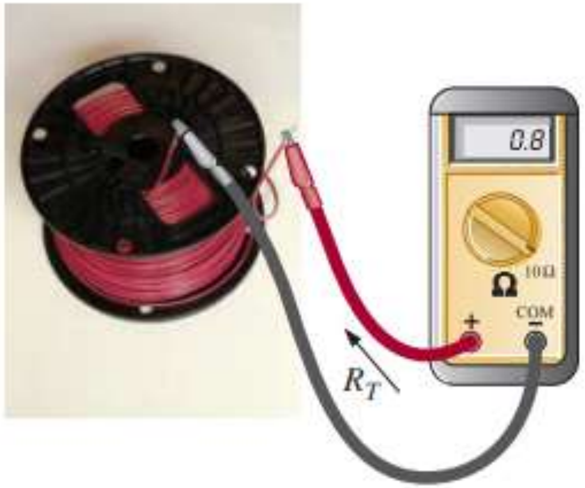


Resistance: Circular Wires (5 of 6)

Table 3.1 *Resistivity (ρ) of various materials.*

Material	Resistivity, ρ, at 20 °C (Ω·m)
Silver[d]	1.59×10^{-8}
Copper[e]	1.68×10^{-8}
Annealed copper[f]	1.72×10^{-8}
Gold[g]	2.44×10^{-8}
Aluminium[h]	2.65×10^{-8}

Example



(Don Johnson Photo)

FIG. 3.6
Example 3.2.

100 m copper wire with 0.1mm diameter. What is the resistance ?

R=p*L/A, A=pi*r^2=pi* (D/2)^2
A=pi*D^2/4
R=p*L / A

R = p*L*4*10^6 / (pi*D^2)   **L is in meter, D is in mm**

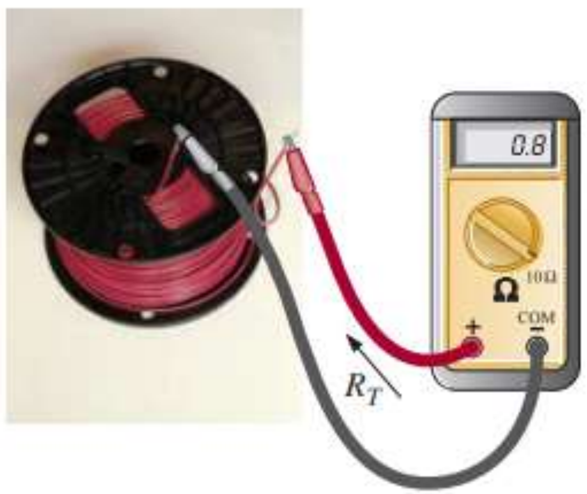
1mm=10^-3 meter

R=1.68e-8 x 100 x 4 x 1e6 / (pi x 0.1^2)
R= 214 ohm

At a fixed temperature of 20°C (room temperature), the resistance is related to the other three factors by

$$\boxed{R = \rho\frac{l}{A}} \qquad \text{(ohms, } \Omega) \qquad \textbf{(3.1)}$$

Example



(Don Johnson Photo)

FIG. 3.6
Example 3.2.

1 m copper wire AWG 8 (3.26mm diameter). What is the resistance ?

R=p*L/A, A=pi*r^2=pi* (D/2)^2
A=pi*D^2/4
R=p*L / A

R = p*L*4*10^-6 / (pi*D^2) **L is in meter, D is in mm**

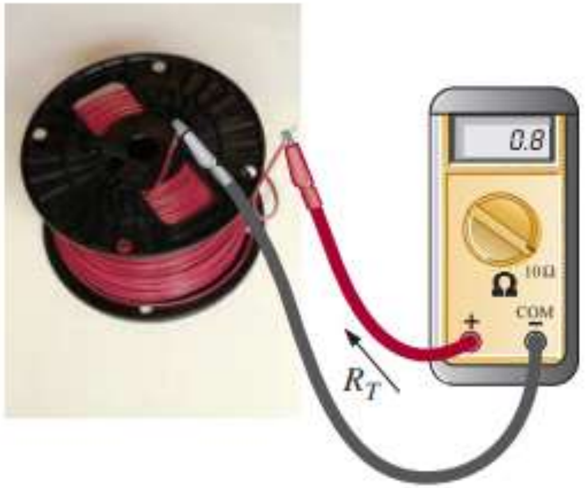
1mm=10^-3 meter

R=1.68e-8 x 1 x 4 x 1e6 / (pi x 3.26^2)
R= 0.002 ohm = 2 mOhm

At a fixed temperature of 20°C (room temperature), the resistance is related to the other three factors by

$$\boxed{R = \rho\frac{l}{A}} \qquad \text{(ohms, } \Omega) \qquad \textbf{(3.1)}$$

Example



(Don Johnson Photo)

FIG. 3.6
Example 3.2.

1 m copper wire AWG 8 resistance is 2 mOhm. What is the resistance of 20m cable?

R=p*L/A, A=pi*r^2=pi* (D/2)^2

A=pi*D^2/4

R=p*L / A

R = p*L*4*10^-6 / (pi*D^2)   **L is in meter, D is in mm**

1mm=10^-3 meter

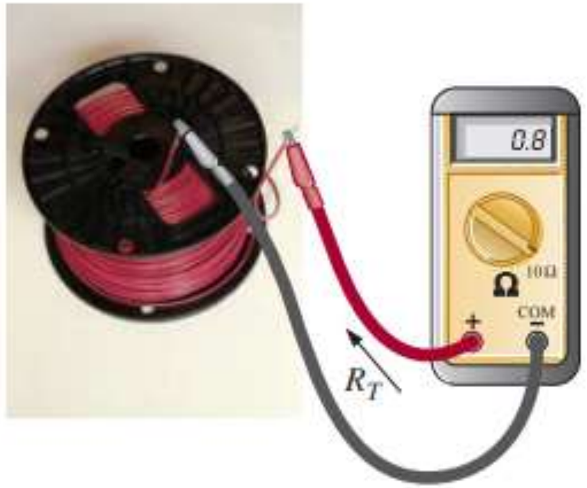
R=1.68e-8 x 1 x 4 x 1e6 / (pi x 3.26^2)

if 1m is 2 mOhm then 20m is 20*2mOhm=40mOhm

At a fixed temperature of 20°C (room temperature), the resistance is related to the other three factors by

$$\boxed{R = \rho \frac{l}{A}} \qquad \text{(ohms, } \Omega) \qquad \textbf{(3.1)}$$

Example



(Don Johnson Photo)

FIG. 3.6
Example 3.2.

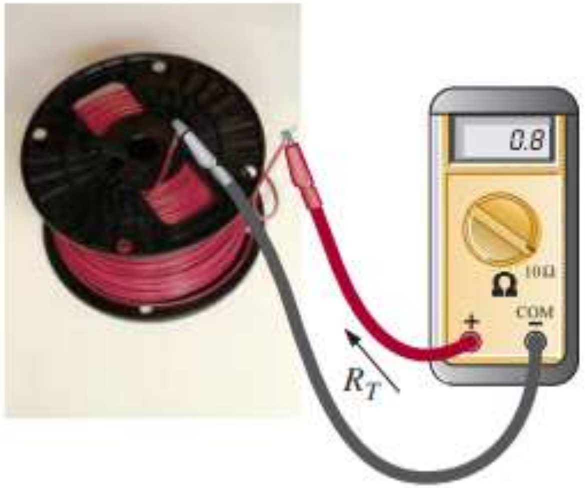
Example 1: Copper Wire

Suppose you have a copper wire with a resistivity of 1.68×10^{-8} Ω·m, a length of 5 meters, and a diameter of 0.002 meters. Calculate its resistance.

$$R = \frac{1.68\times10^{-8}\ \Omega\text{\textbackslash cdotp}\mathrm{m}\cdot 5\ \mathrm{m}}{\frac{\pi}{4}\cdot(0.002\ \mathrm{m})^2} = \frac{8.4\times10^{-8}\ \Omega\text{\textbackslash cdotp}\mathrm{m}^2}{\frac{\pi}{4}\cdot 4\times10^{-6}\ \mathrm{m}^2} \approx 1.065 \times 10^{-2}\ \Omega$$

So, the resistance of the copper wire is approximately 0.01065 ohms.

Example



(Don Johnson Photo)

FIG. 3.6

Example 3.2.

Example 2 (Revised): Aluminum Wire with Resistivity 2.65×10^{-8} Ω·m

Suppose you have an aluminum wire with a resistivity of 2.65×10^{-8} Ω·m, a length of 10 meters, and a diameter of 0.003 meters. Calculate its resistance.

$$R = \frac{2.65\times10^{-8}\ \Omega\backslash\text{cdotpm}\cdot10\ \text{m}}{\frac{\pi}{4}\cdot(0.003\ \text{m})^2} = \frac{2.65\times10^{-7}\ \Omega\backslash\text{cdotpm}^2}{\frac{\pi}{4}\cdot9\times10^{-6}\ \text{m}^2} \approx 2.817 \times 10^{-2}\ \Omega$$

So, with a resistivity of 2.65×10^{-8} Ω·m for aluminum, the resistance of the aluminum wire is approximately 0.02817 ohms.

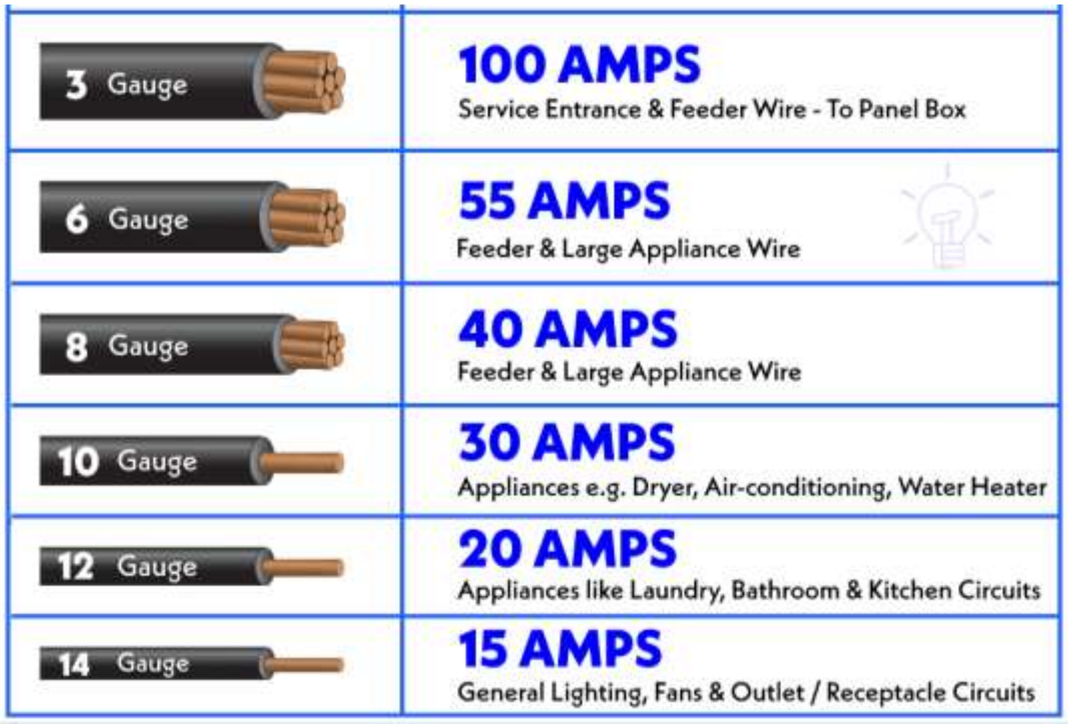
Wire Tables (3 of 5)

The American Wire Gage (AWG) sizes are given in Table round copper wire.
A column indicating the maximum allowable current in amperes, as determined by the National Fire Protection Association, has also been included

AWG Size	Diameter (mm)	Max Current Capacity (A)*
0	8.25 mm	125 A
1	7.35 mm	110 A
2	6.54 mm	95 A
3	5.83 mm	80 A
4	5.19 mm	70 A
5	4.62 mm	55 A
6	4.12 mm	45 A
7	3.67 mm	40 A
8	3.26 mm	35 A
9	2.91 mm	30 A
10	2.59 mm	25 A
11	2.30 mm	20 A
12	2.05 mm	20 A
13	1.83 mm	15 A
14	1.63 mm	15 A
15	1.45 mm	10 A
16	1.29 mm	10 A
17	1.15 mm	7 A
18	1.02 mm	7 A
19	0.91 mm	5 A
20	0.81 mm	5 A
21	0.72 mm	3 A
22	0.64 mm	3 A
23	0.57 mm	2 A
24	0.51 mm	2 A

AWG

Ampper 8 AWG Battery Cable Set, 20 Inch



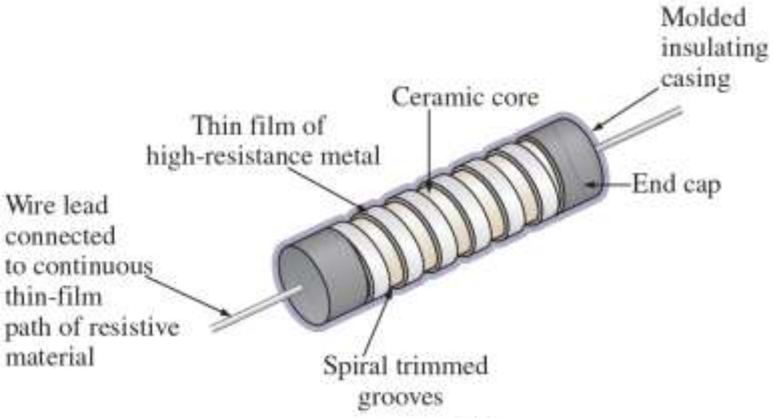
AWG

Tek Damarlı Montaj Kablosu Teknik Özellikler

Ürün Kategorisi	Montaj Kablosu - Zil Teli
Dış Çap	1.2mm
İç Çap	0.50mm
AWG Değeri	24
Kaldıracağı Akım	Max: 3A (yaklaşık olarak)

Types of Resistors Fixed Resistors (2 of 5)

Fig. 3.12 *Film resistors: (a) construction; (b) types.*

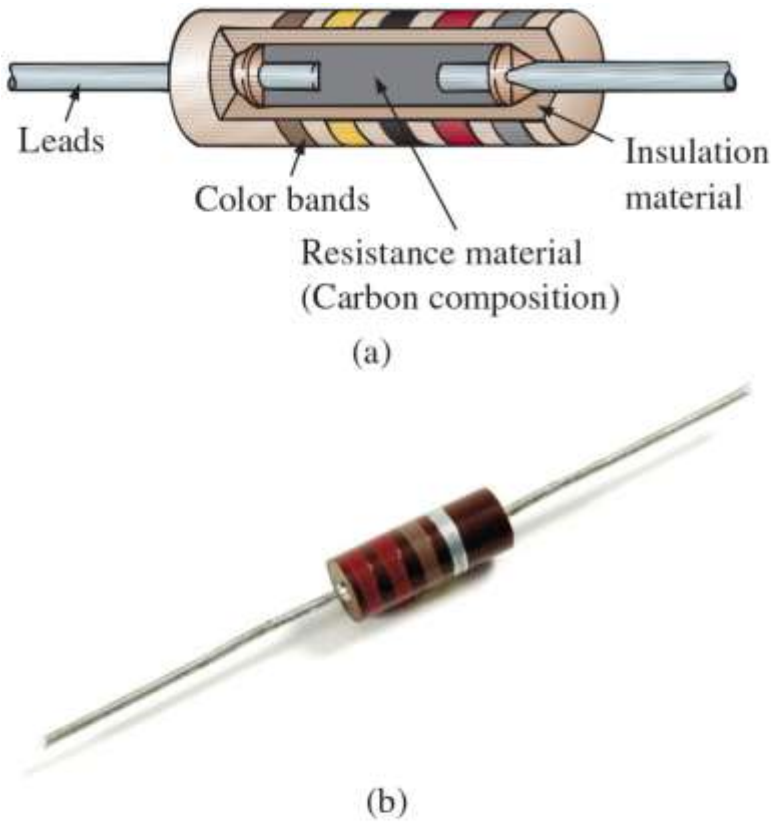


(a)

(b)

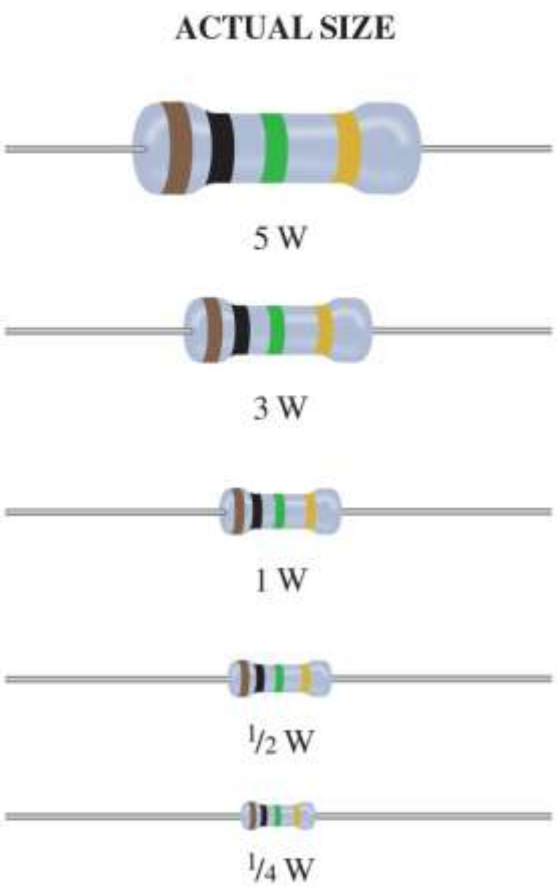
Types of Resistors Fixed Resistors (3 of 5)

Fig. 3.13 *Fixed-composition resistors: (a) construction; (b) appearance.*



Types of Resistors Fixed Resistors (4 of 5)

Fig. 3.14 *Fixed metal-oxide resistors of different wattage ratings.*



Power = Voltage x Current
P = V x I

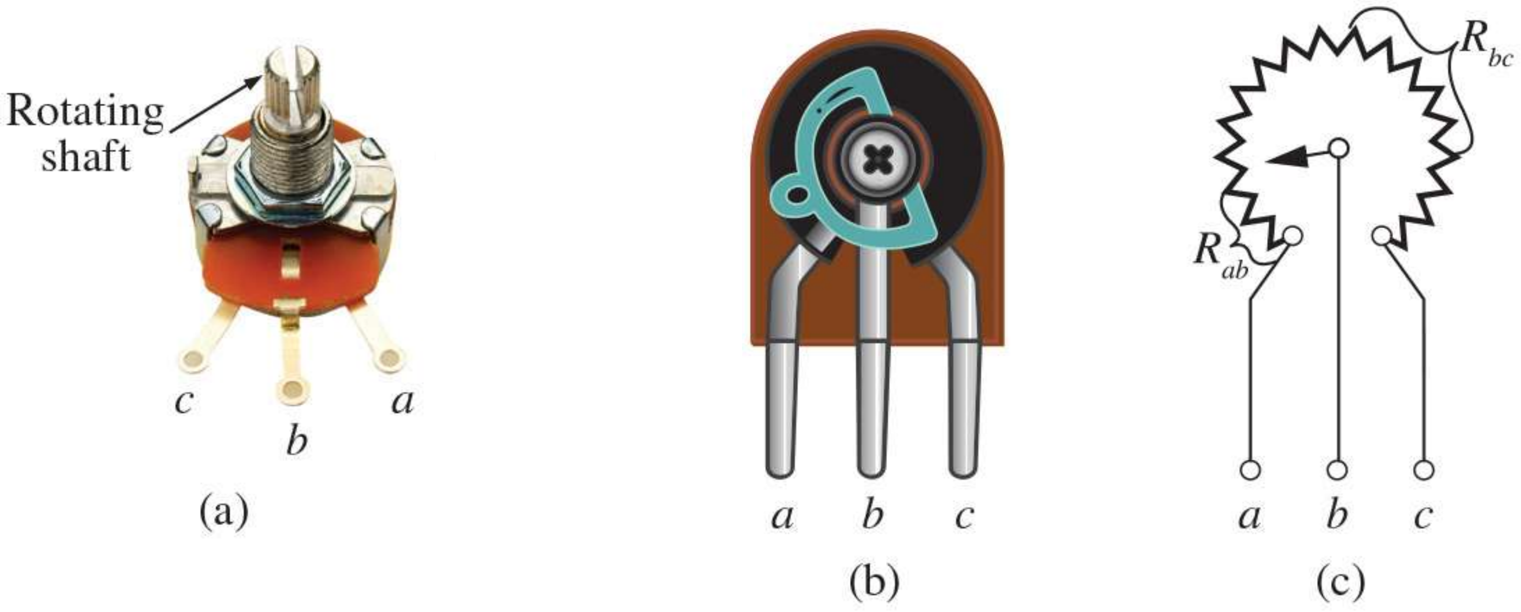
What is the current a 1W , 1ohm resistor can carry with 5V ?

1W= 5V x I
I=1/5=0.2A=200mA

depending on your current requirements you need to select relevant power range

Types of Resistors Variable Resistors (4 of 7)

Fig. 3.17 *Potentiometer: (a) external, (b) internal, (c) circuit equivalent.*



Don Johnson Photo

Types of Resistors Variable Resistors (6 of 7)

Fig. 3.19 *Variable resistors: (a) 4 mm* $(\approx 5/32\ in.)$ *trimmer ;*

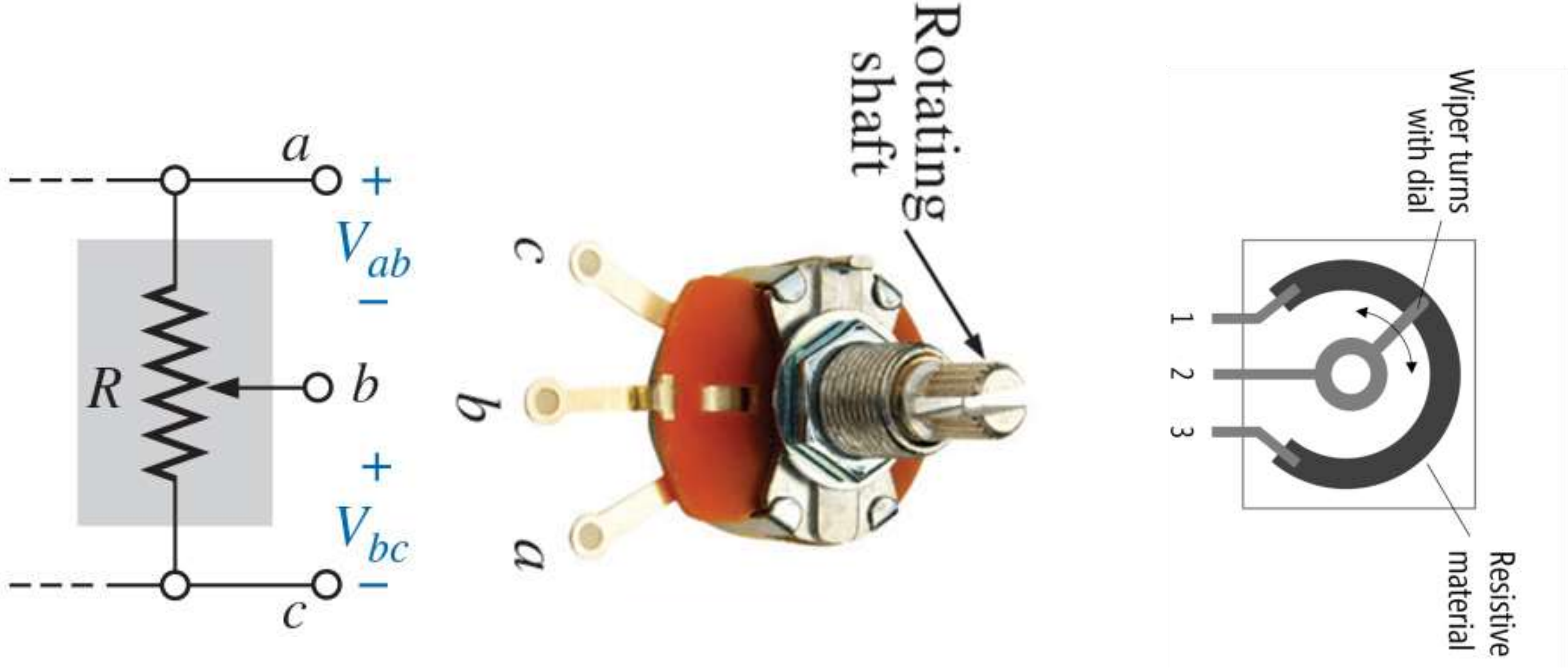
(b) conductive plastic and cermet elements; (c) three-point wire-wound resistor.

(a) (b) (c)

(a) viabo/Shutterstock

Types of Resistors Variable Resistors (7 of 7)

Fig. 3.20 *Potentiometer control of voltage levels.*



Types of Resistors Variable Resistors

The resistance between the wiper arm and either outside terminal can be varied from a minimum of $0\ \Omega$ to a maximum value equal to the full rated value of the potentiometer.

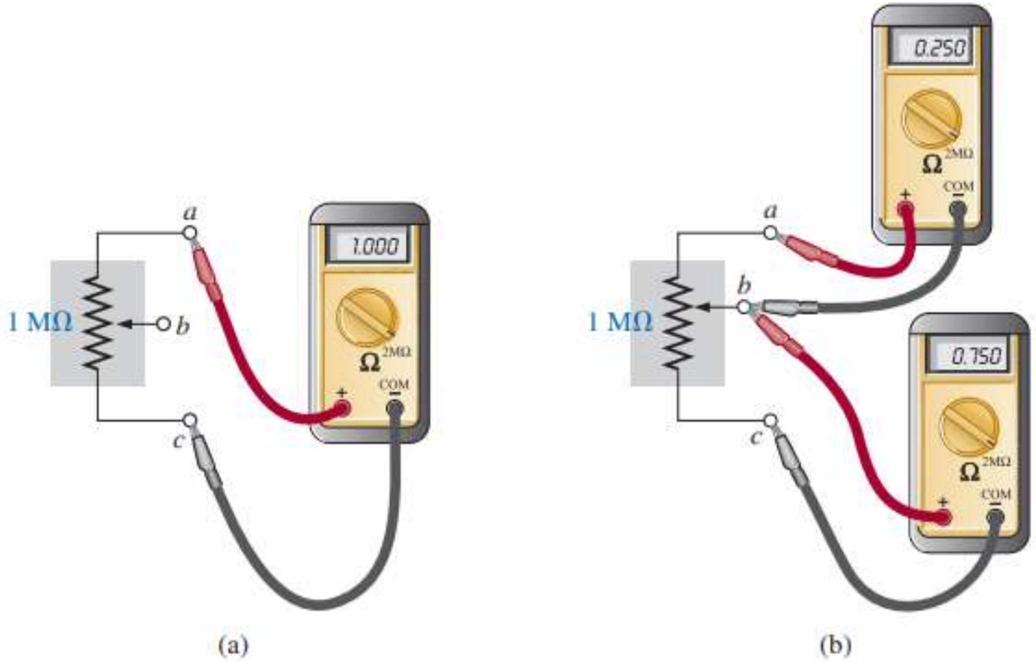


FIG. 3.18
Resistance components of a potentiometer: (a) between outside terminals; (b) between wiper arm and each outside terminal.

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

Color Coding and Standard Resistor Values

The first two bands represent the first and second digits, respectively.

They are the actual first two numbers that define the numerical value of the resistor.

The third band determines the power-of-ten multiplier for the first two digits (actually the number of zeros that follow the second digit for resistors greater than 10 Ω).

The fourth band is the manufacturer's tolerance, which is an indication of the precision by which the resistor was made.

color code ABCD
R = AB*10^C , D is tolerance
example: RED, BLUE, BROWN, GOLD
R= 2 6 0 ohm 5% tolerance

[Resistor Color Code Calculator - 4 band, 5 band, 6 band | DigiKey Electronics]

FIG. 3.21
Color coding for fixed resistors.

Color Coding and Standard Resistor Values

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

The first two bands represent the first and second digits, respectively.

They are the actual first two numbers that define the numerical value of the resistor.

The third band determines the power-of-ten multiplier for the first two digits (actually the number of zeros that follow the second digit for resistors greater than 10 Ω).

The fourth band is the manufacturer's tolerance, which is an indication of the precision by which the resistor was made.

color code ABCD
R = AB*10^C , D is tolerance
example: RED, RED, BROWN, GOLD
R= 2 2 0 ohm 5% tolerance

[Resistor Color Code Calculator - 4 band, 5 band, 6 band | DigiKey Electronics]

Color Coding and Standard Resistor Values

EXAMPLE 3.11 Find the value of the resistor in Fig. 3.23.

Solution: Reading from the band closest to the left edge, we find that the first two colors of brown and red represent the numbers 1 and 2, respectively. The third band is orange, representing the number 3 for the power of the multiplier as follows:

$$12 \times 10^3 \ \Omega$$

resulting in a value of 12 kΩ. As indicated above, if 12 kΩ is written as 12,000 Ω, the third band reveals the number of zeros that follow the first two digits.

Now for the fourth band of gold, representing a tolerance of ±5%: To find the range into which the manufacturer has guaranteed the resistor will fall, first convert the 5% to a decimal number by moving the decimal point two places to the left:

$$5\% \Rightarrow 0.05$$

Then multiply the resistor value by this decimal number:

$$0.05(12 \text{ k}\Omega) = 600 \ \Omega$$

Finally, add the resulting number to the resistor value to determine the maximum value, and subtract the number to find the minimum value. That is,

$$\text{Maximum} = 12{,}000 \ \Omega + 600 \ \Omega = 12.6 \text{ k}\Omega$$

$$\text{Minimum} = 12{,}000 \ \Omega - 600 \ \Omega = 11.4 \text{ k}\Omega$$

$$\text{Range} = \mathbf{11.4 \text{ k}\Omega \text{ to } 12.6 \text{ k}\Omega}$$

FIG. 3.23
Example 3.11.

Color Coding and Standard Resistor Values

FIG. 3.24
Example 3.12.

EXAMPLE 3.12 Find the value of the resistor in Fig. 3.24.

Solution: The first two colors are gray and red, representing the numbers 8 and 2, respectively. The third color is gold, representing a multiplier of 0.1. Using the multiplier, we obtain a resistance of

$$(0.1)(82\,\Omega) = 8.2\,\Omega$$

The fourth band is silver, representing a tolerance of $\pm 10\%$. Converting to a decimal number and multiplying through yields

$$10\% = 0.10 \quad \text{and} \quad (0.1)(8.2\,\Omega) = 0.82\,\Omega$$

$$\text{Maximum} = 8.2\,\Omega + 0.82\,\Omega = 9.02\,\Omega$$

$$\text{Minimum} = 8.2\,\Omega - 0.82\,\Omega = 7.38\,\Omega$$

so that $\text{Range} = \mathbf{7.38\,\Omega \text{ to } 9.02\,\Omega}$

Color Coding and Standard Resistor Values

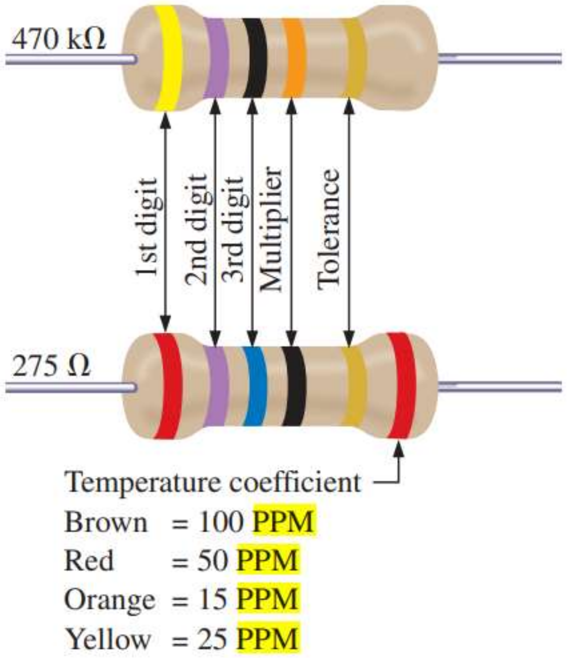


FIG. 3.25
Five-band color coding for fixed resistors.

Some manufacturers prefer to use a **five-band color code**. In such cases, as shown in the top portion of Fig. 3.25, three digits are provided before the multiplier. The fifth band remains the tolerance indicator. If the manufacturer decides to include the temperature coefficient, a sixth band will appear as shown in the lower portion of Fig. 3.25, with the color indicating the PPM level.

Ohm meter

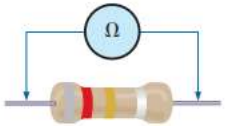


FIG. 3.28
Measuring the resistance of a single element.

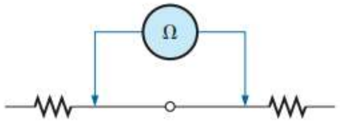


FIG. 3.29
Checking the continuity of a connection.

FIG. 3.30
Identifying the leads of a multilead ribbon cable.

3.12 OHMMETERS

The **ohmmeter** is an instrument used to perform the following tasks and several other useful functions:

1. ***Measure the resistance of individual or combined elements.***
2. ***Detect open-circuit (high-resistance) and short-circuit (low-resistance) situations.***
3. ***Check the continuity of network connections and identify wires of a multilead cable.***
4. ***Test some semiconductor (electronic) devices.***

Temperature Effects

for good conductors, an increase in temperature will result in an increase in the resistance level. Consequently, conductors have a positive temperature coefficient.

The plot of Fig. 3.13(a) has a positive temperature coefficient.

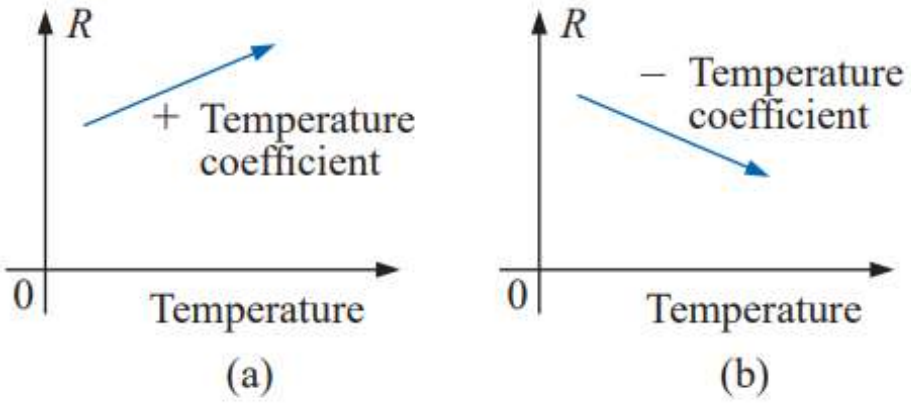
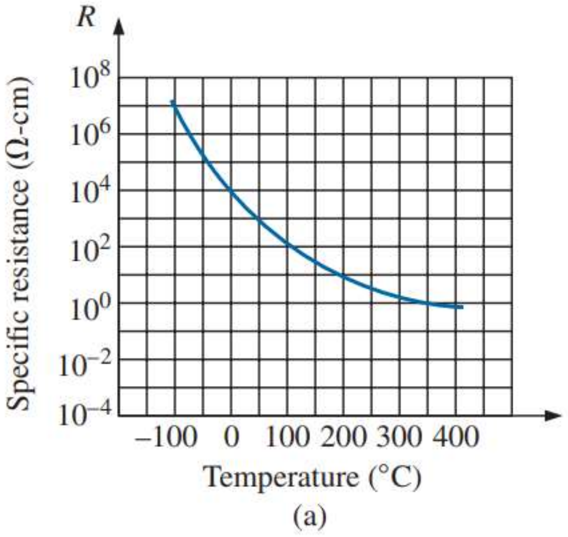


FIG. 3.13

(a) Positive temperature coefficient—conductors; (b) negative temperature coefficient—semiconductors.

THERMISTORS



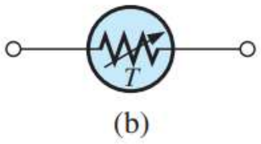
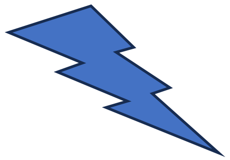


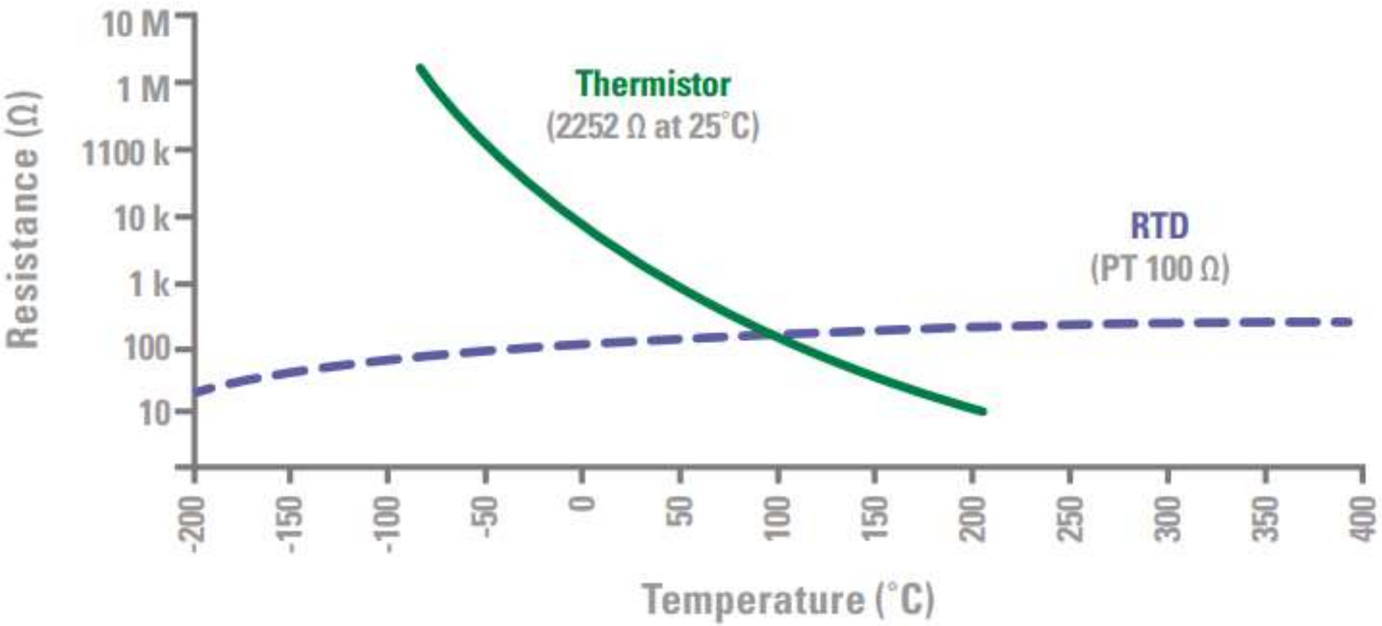
FIG. 3.36
Thermistor: (a) characteristics; (b) symbol.

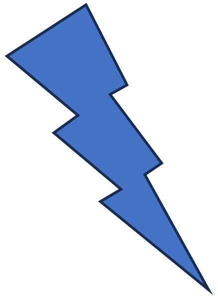


The **thermistor** is a two-terminal semiconductor device whose resistance, as the name suggests, is temperature sensitive. A representative characteristic appears in Fig. 3.36 with the graphic symbol for the device. Note the nonlinearity of the curve and the drop in resistance from about 5000 Ω-cm to 100 Ω-cm for an increase in temperature from 20°C to 100°C. The decrease in resistance with an increase in temperature indicates a negative temperature coefficient.

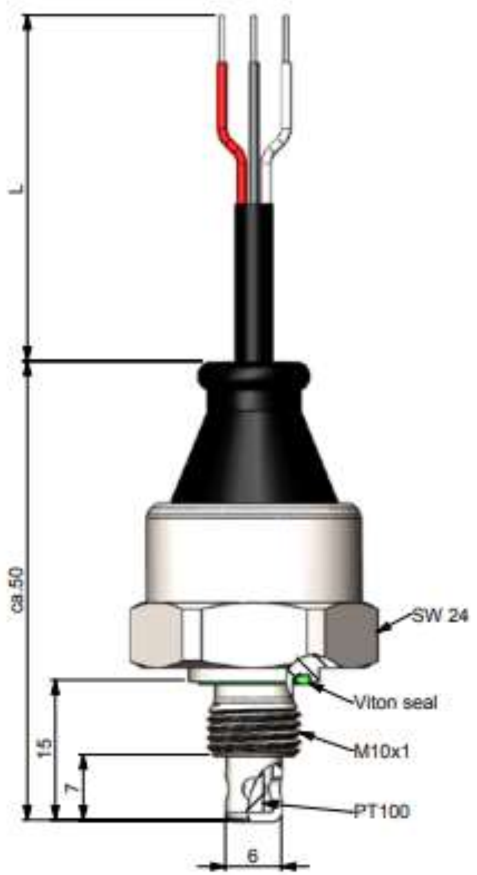
NTC vs RTD

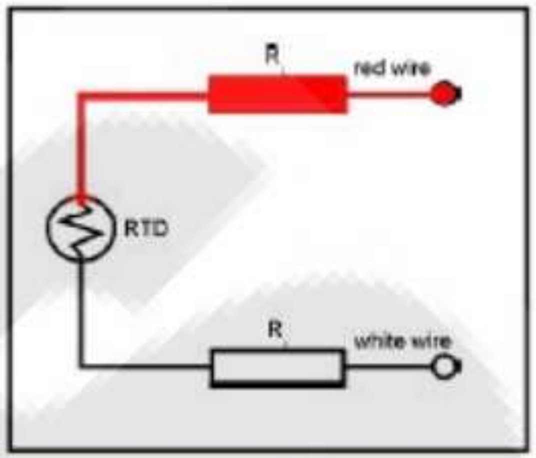
NTC Thermistors	RTDs (Pt Thin Film)
Both are electrical resistors in which resistance changes with temperature Both require excitation current	
Metal oxide on ceramic substrate	Precious metal (typically Pt) on ceramic substrate

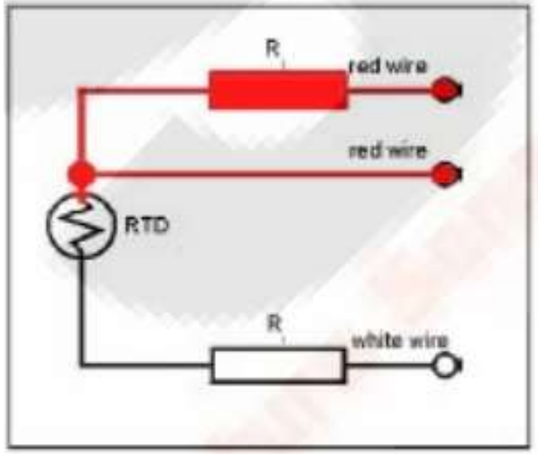




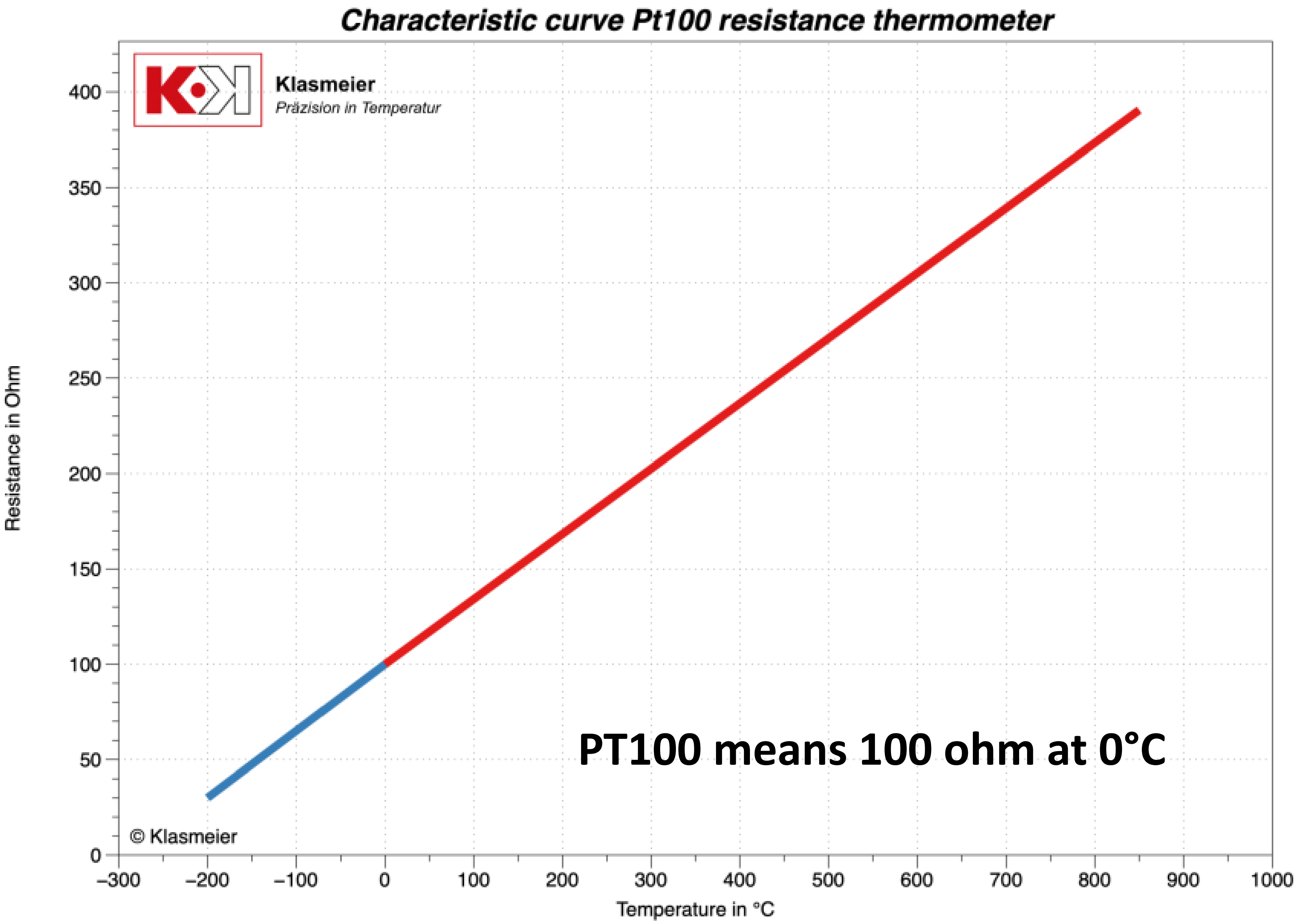
PT100 PT1000 Temperature Sensors





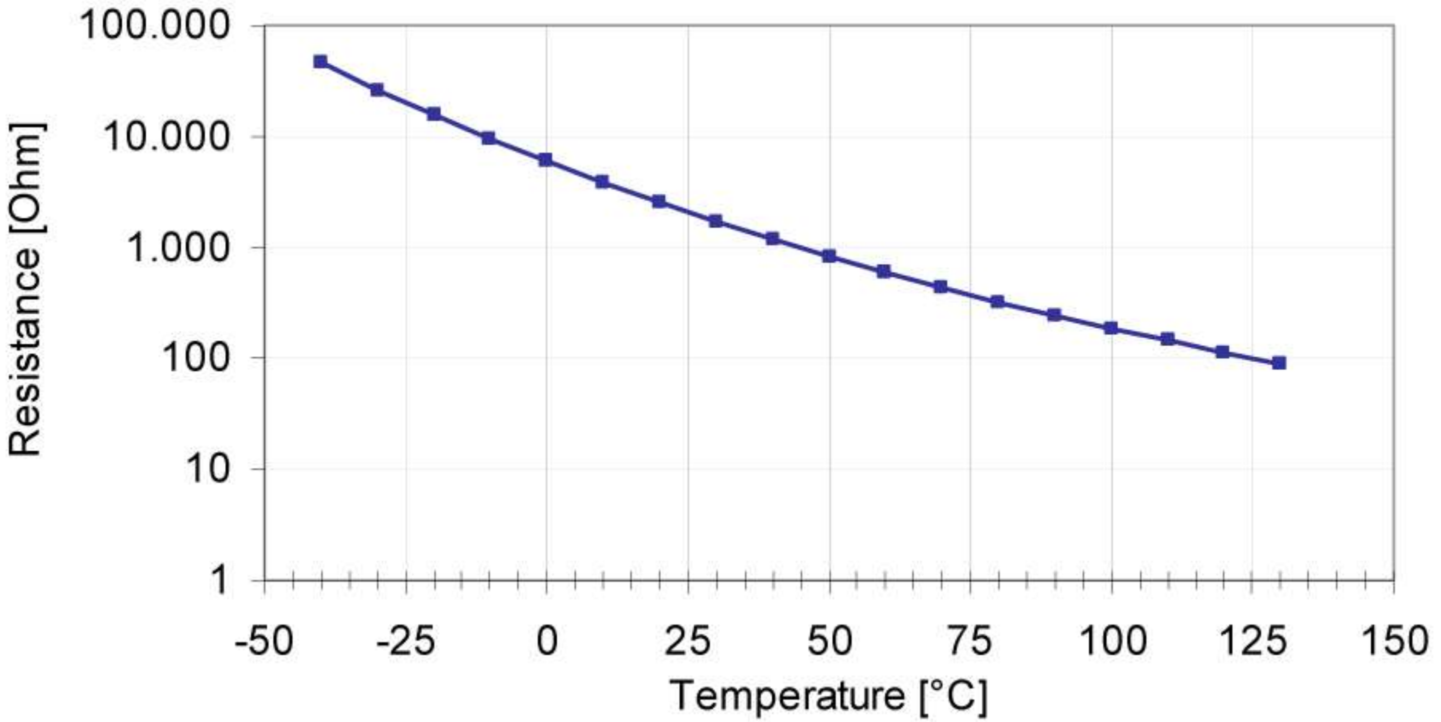


PT100 Temperature Sensors



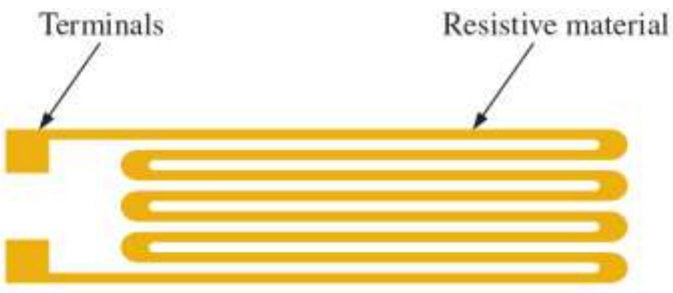
PT100 means 100 ohm at 0°C

NTC Temperature Sensors

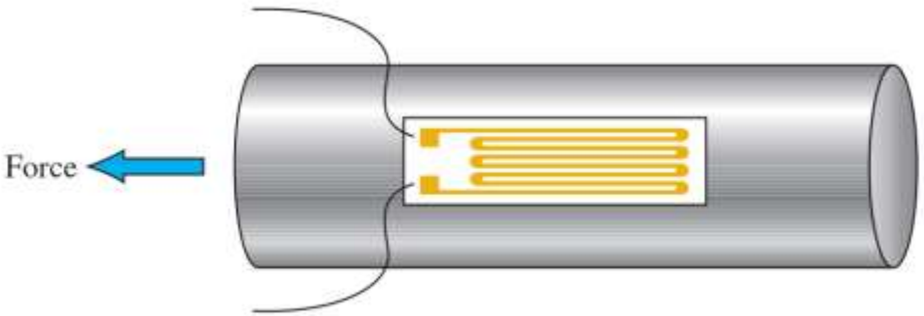


Applications Strain Gauges (2 of 2)

Fig. 3.42 *Resistive strain gauge.*

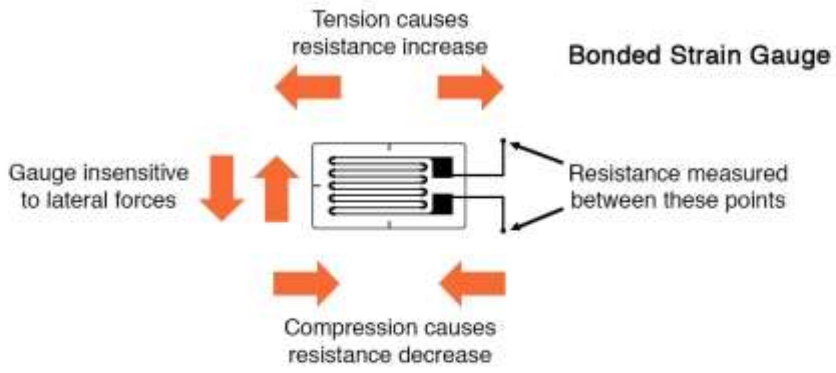


(a) Typical strain gauge configuration.

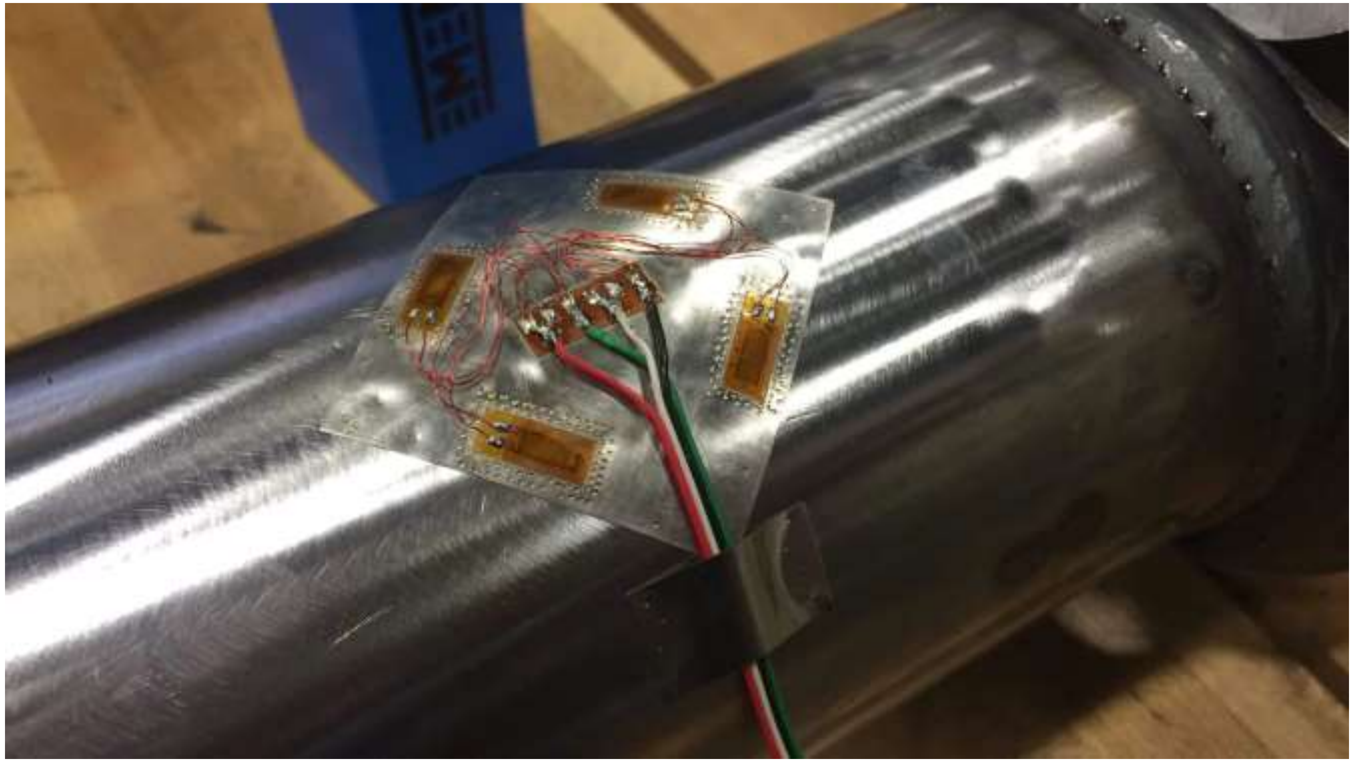


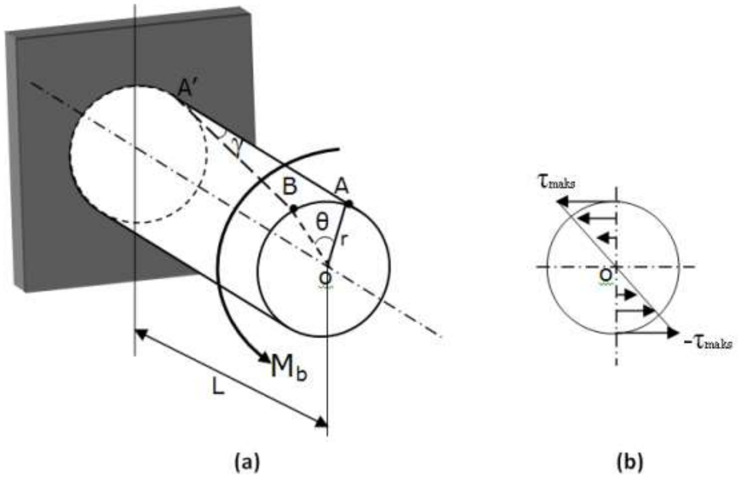
(b) The strain gauge is bonded to the surface to be measured along the line of force. When the surface lengthens, the strain gauge stretches.

length of strain gauge metal changes with bending thus resistance changes

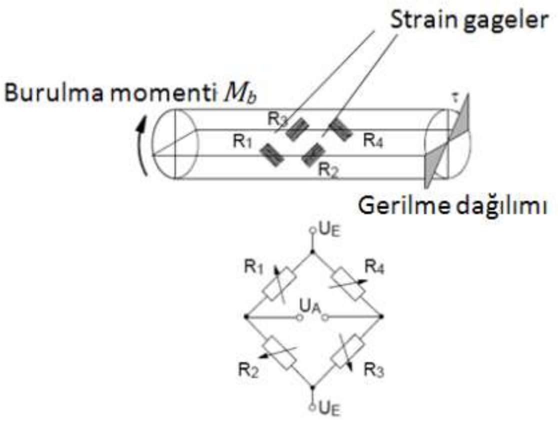


Applications Strain Gauges

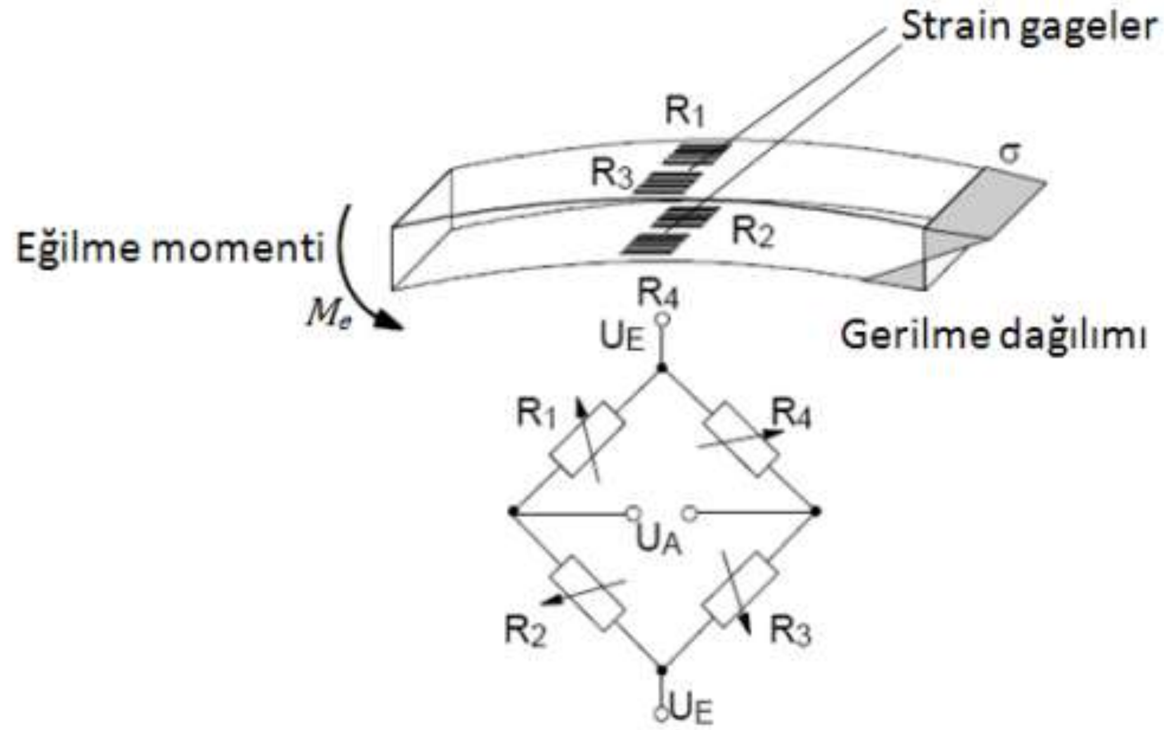




Şekil 14. Burulma momentine maruz bir çubuk

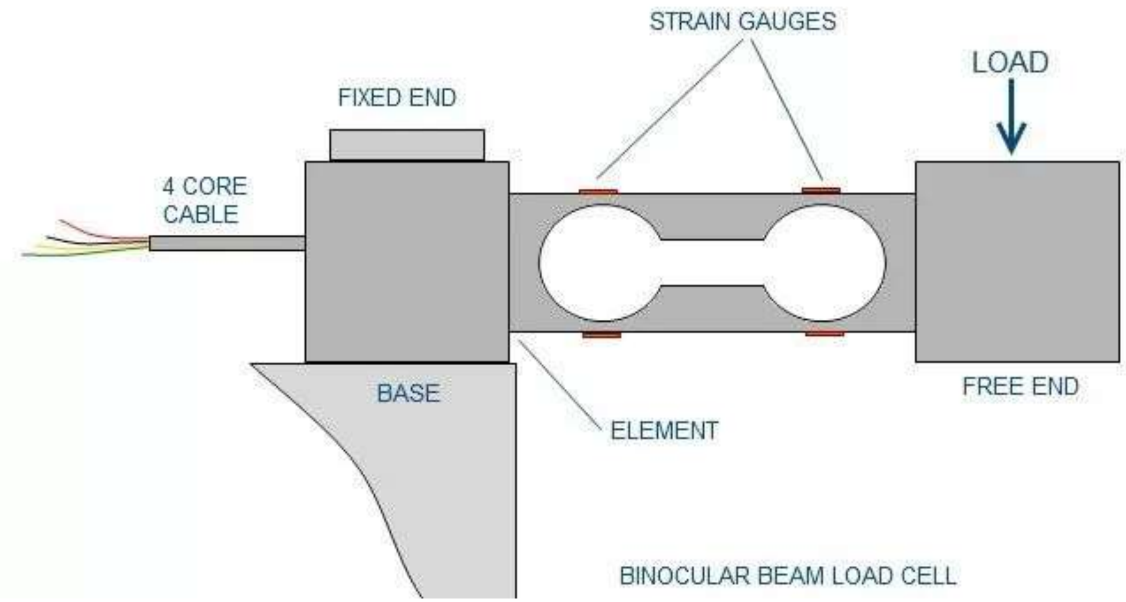


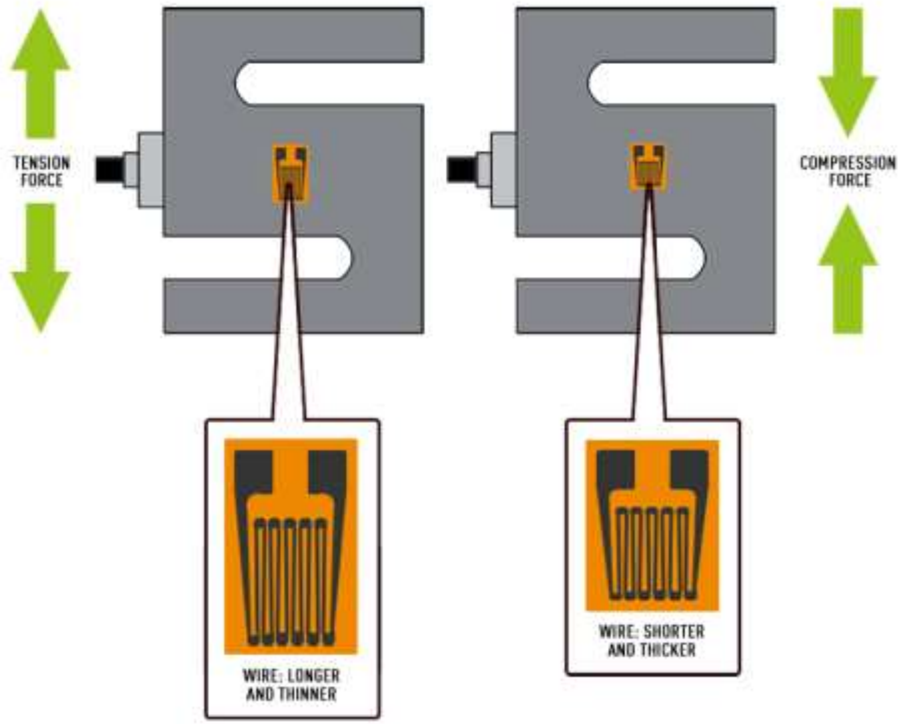
Applications Strain Gauges

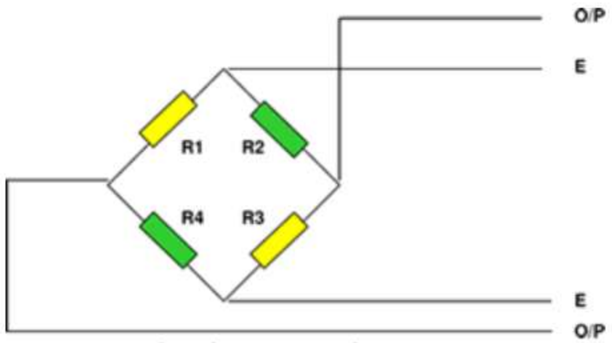


Şekil 9. Eğme yüküne maruz çubuk üzerindeki strain gagelerin konumları

Applications Strain Gauges

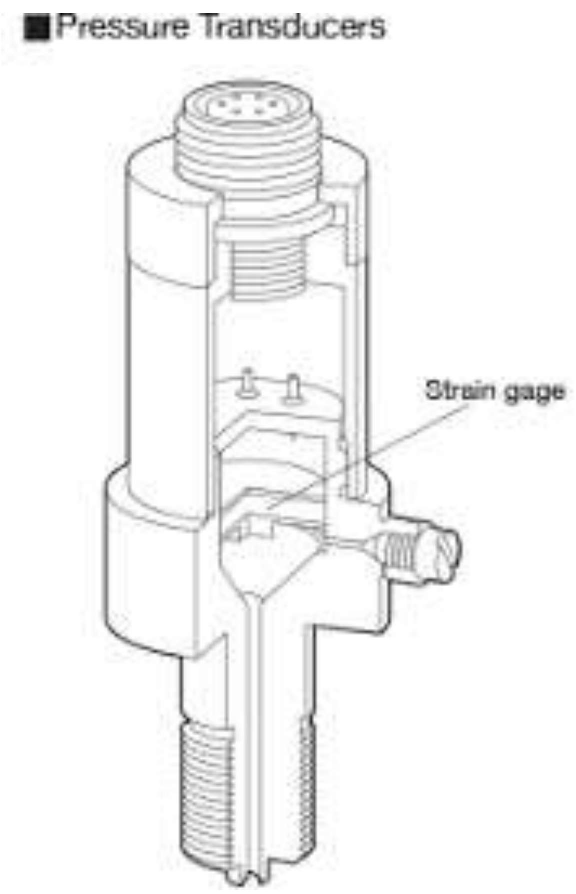






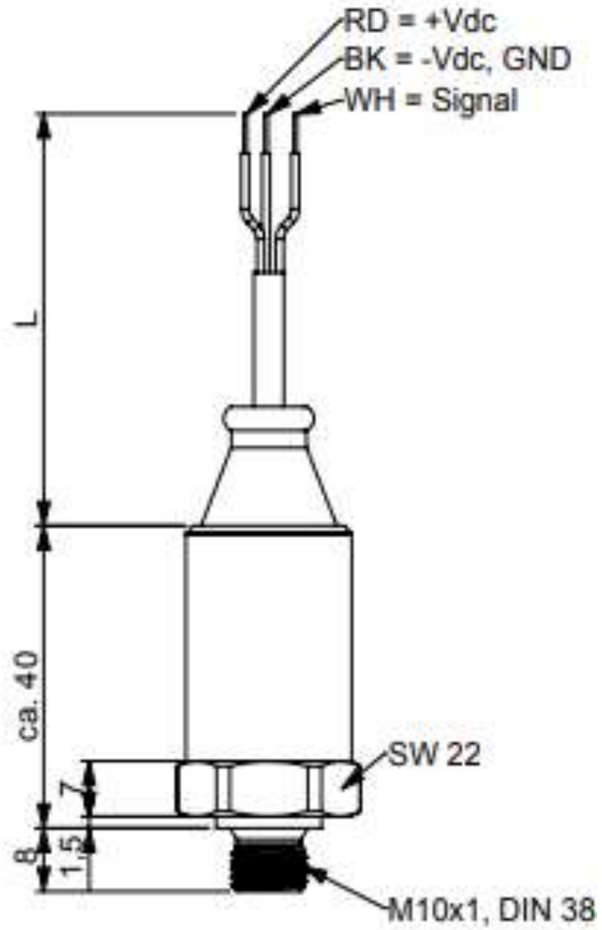
The Wheatstone Bridge Circuit

Applications Strain Gauges



Applications Strain Gauges

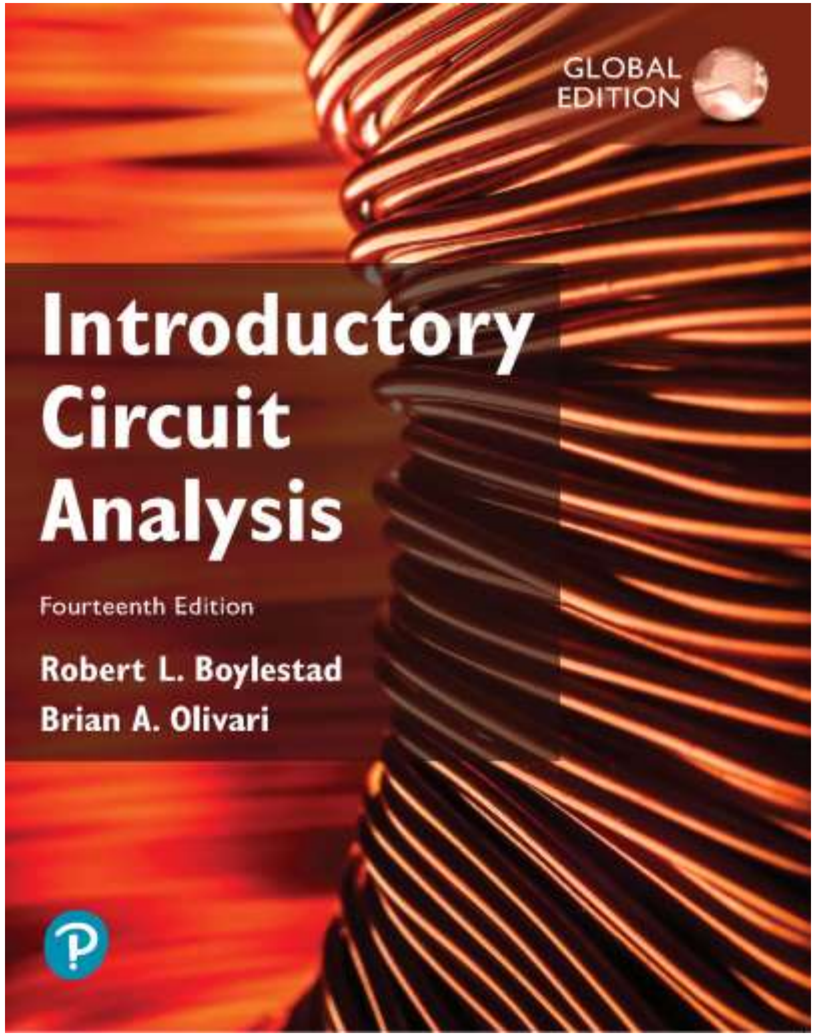
Cable assembly



5 = 0.5..4.5 V - ratiometric (with 5V supply voltage)

Introductory Circuit Analysis

Fourteenth Edition, Global Edition

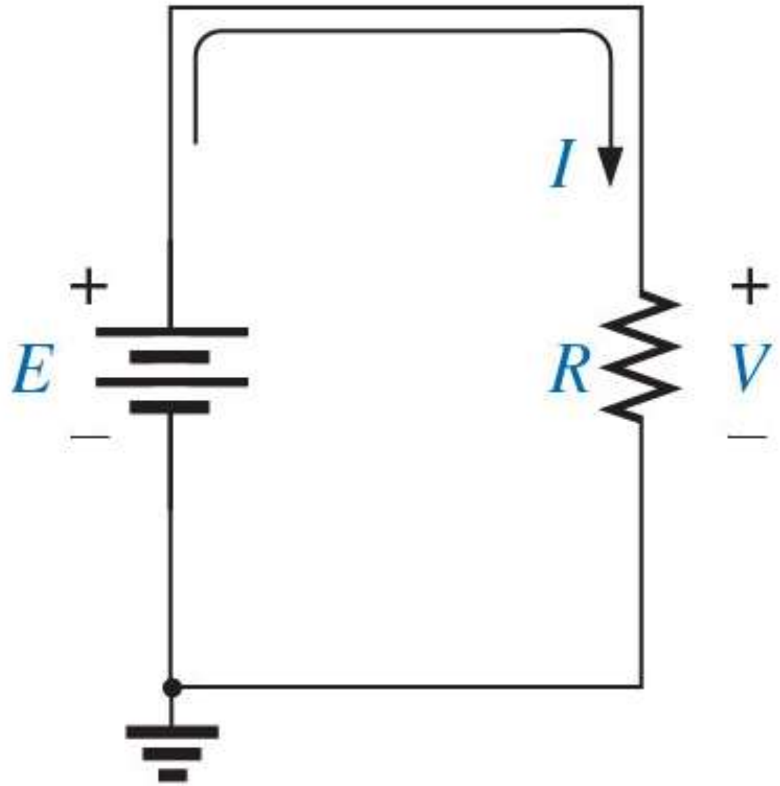


Chapter 4

Ohm’s Law, Power, and Energy

Ohm's Law

Fig. 4.2 *Basic circuit.*



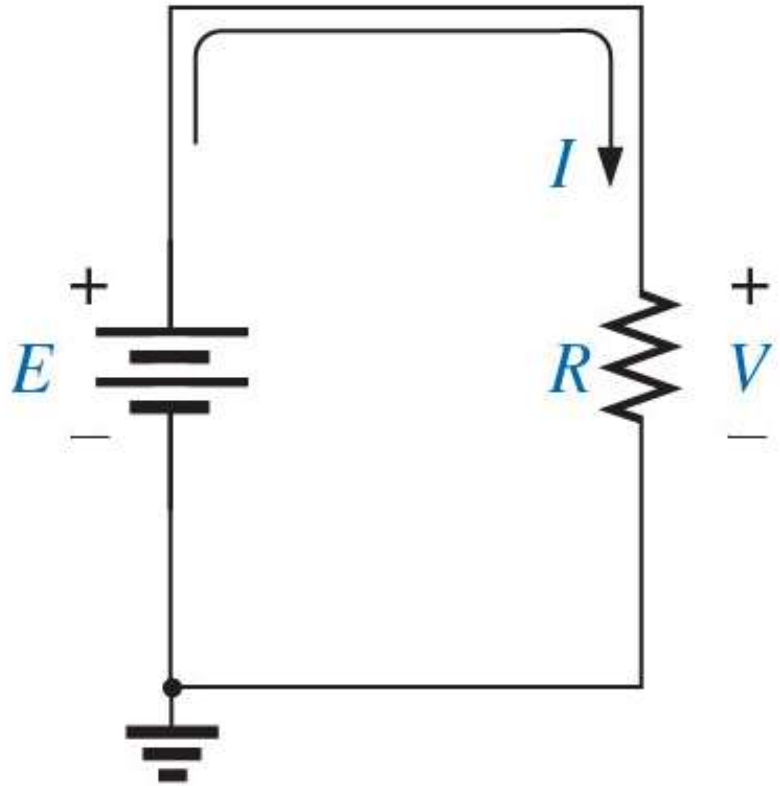
V = I * R

9V = I * 10 ohm
I= 9V/10 ohm = 0.9 A

direction of current is important

Ohm's Law

Fig. 4.2 *Basic circuit.*



V = I * R

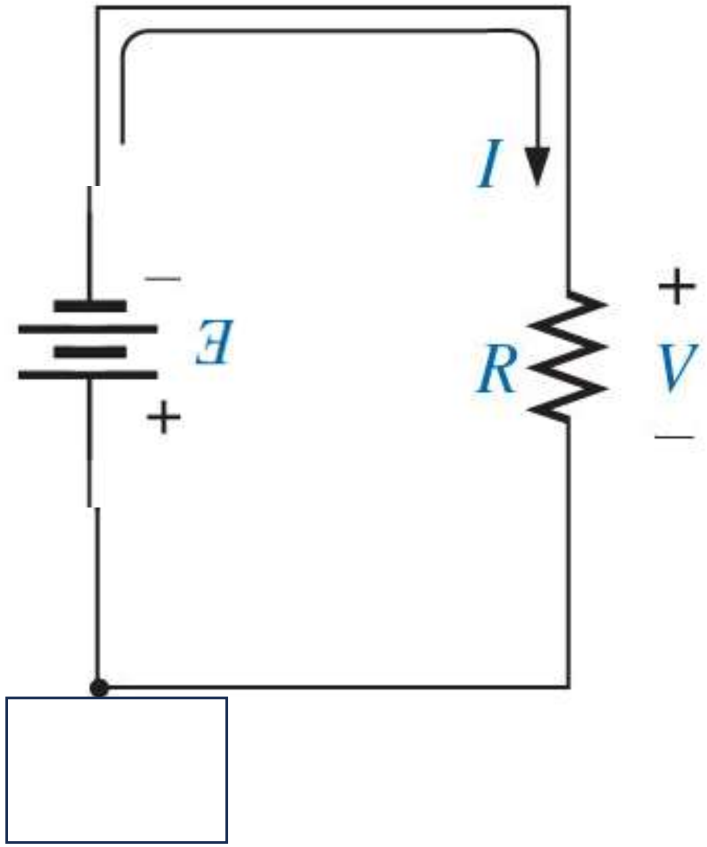
9V=I * 1Kohm

I= 9V/1Kohm = 0.009 A = 9mA

direction of current is important

Ohm's Law

Fig. 4.2 *Basic circuit.*



V = I * R
negative battery case
-9V = I * 1Kohm ohm
I= 9V/1Kohm ohm = -0.009 A=-9mA

direction of current is important

Power

the term power is applied to provide an indication of how much work (energy conversion) can be accomplished in a specified amount of time; that is, power is a rate of doing work.

$$\boxed{1 \text{ watt } (\text{W}) = 1 \text{ joule/second } (\text{J/s})}$$

In equation form, power is determined by

$$\boxed{P = \frac{W}{t}} \quad \text{(watts, W, or joule/second, J/s)}$$

$$\boxed{1 \text{ horsepower} \cong 746 \text{ watts}}$$

Power

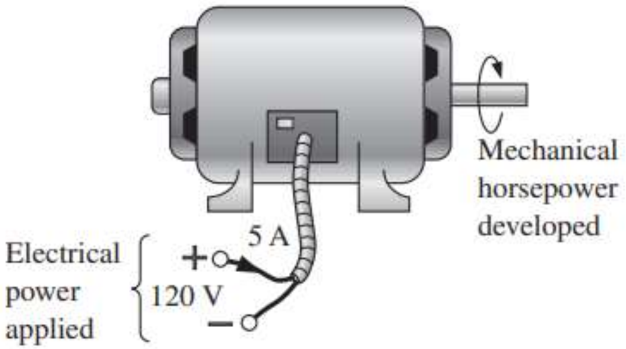


FIG. 4.13
Example 4.4.

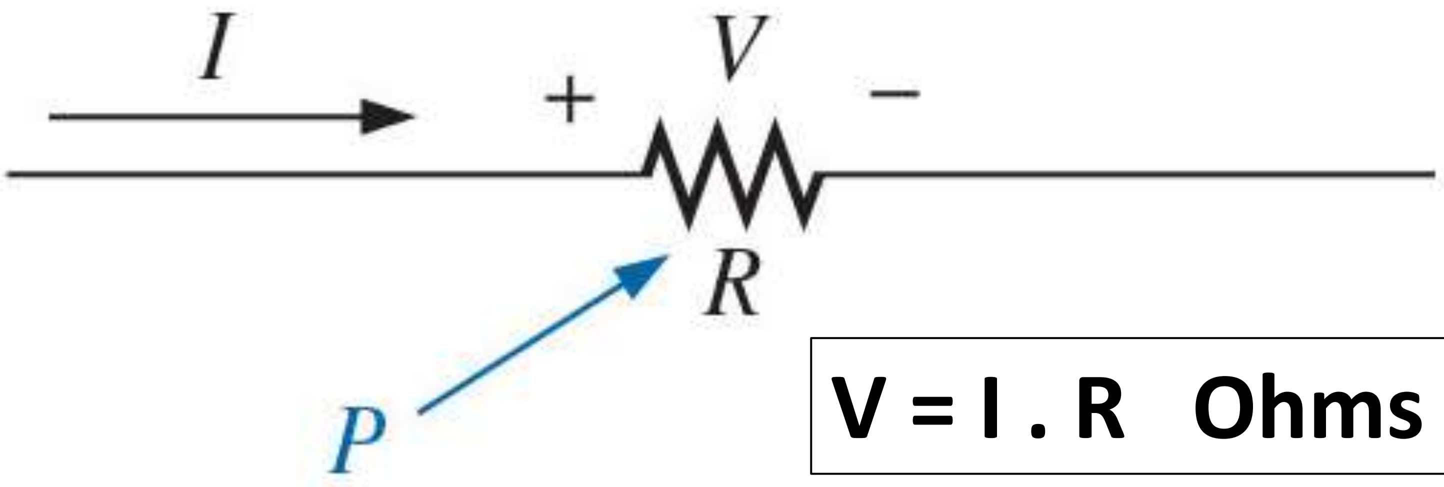
EXAMPLE 4.4 Find the power delivered to the dc motor of Fig. 4.13.

Solution:

$$P = EI = (120\ \text{V})(5\ \text{A}) = 600\ \text{W} = \mathbf{0.6\ kW}$$

Power (2 of 5)

Fig. 4.12 *Defining the power to a resistive element.*



V = I . R   Ohms Law

$$\boxed{P = VI} \quad \text{(watts)} \qquad \textbf{(4.10)}$$

$$\boxed{P = \frac{V^2}{R}} \quad \text{(watts)} \qquad \textbf{(4.11)}$$

$$\boxed{P = I^2R} \quad \text{(watts)} \qquad \textbf{(4.12)}$$

Power

max **current** is 100mA, Resistor: 1Kohm
what is the power level?

Watt, Amper, Volt, Ohm

dont use mA, mV etc

$P = I^2 . R$

$P = (0.100)^2 * 1000 \text{ ohm} = 0.01*1000=10W$

Power

What is the max **current** can pass through this resistor?

P=1W, R=1Kohm

given I=?

P=I^2 . R
I^2 = P/R = 1W/1000 ohm
I= 0.031A = 31 mA

Power

My iphone adapter is 9V, 2.2A. What is the power Level ?

$P = V * I = 9V * 2.2A = 19.8W = 20W$

Efiiciency = Pout/Pin

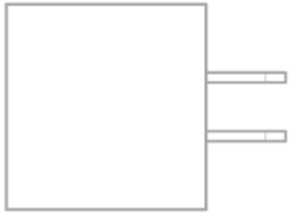
verimlilik = Pout / Pin

Always < 1 , due to heat dissipation

example aplle adapter
Pin=20W
Pout=19.8 W

eff = 19.8/20 = 99%, 0.99 < 1

Apple 20 W USB-C güç adaptörü



- *Çıkış Voltajı/Akımı:* 9 VDC/2,2 A
- *Minimum Güç Çıkışı:* 20 W

Power

100R 1W Direnç

What is the max current can pass through this resistor?

P=1W, R=100 ohm

$P=I^2 . R$

$I^2=P/R=1/100$

I=0.1A = 100mA

Power

12V, 21W
What is the current passing through this automotive lamp?

$V=12V$
$P=21W$
$P=V.I$
$I=P/V=21/12=1.75A$

Energy

$$\text{Energy (Wh)} = \text{power (W)} \times \text{time (h)}$$

$$\text{Energy (kWh)} = \frac{\text{power (W)} \times \text{time (h)}}{1000}$$

Since power is measured in watts (or joules per second) and time in
seconds, the unit of energy is the wattsecond or joule

The wattsecond, however, is too small a quantity for most practical purpposes, so the watthour (Wh) and the kilowatthour (kWh) are defined

(b)

Energy

$$\boxed{\text{Energy (Wh)} = \text{power(W)} \times \text{time (h)}}$$

$$\boxed{\text{Energy (kWh)} = \frac{\text{power (W)} \times \text{time (h)}}{1000}}$$

EXAMPLE 4.9 How much energy (in kilowatthours) is required to light a 60 W bulb continuously for 1 year (365 days)?

Solution:

$$W = \frac{Pt}{1000} = \frac{(60\text{ W})(24\text{ h/day})(365\text{ days})}{1000} = \frac{525{,}600\text{ Wh}}{1000}$$

$$= \mathbf{525.60\ kWh}$$

Efficiency

Conservation of energy requires that

Energy input = energy output + energy used, lost, or stored by the system

Dividing both sides of the relationship by t gives

$$\frac{W_{\text{in}}}{t} = \frac{W_{\text{out}}}{t} + \frac{W_{\text{used, lost, or stored by the system}}}{t}$$

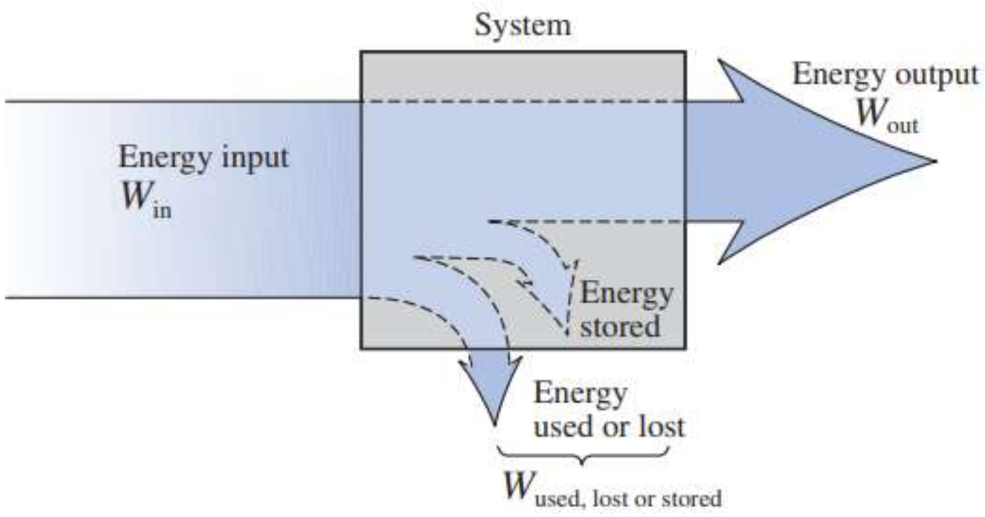


FIG. 4.19
Energy flow through a system.

Since $P = W/t$, we have the following:

$$\boxed{P_i = P_o + P_{\text{used, lost or stored}}} \quad \text{(W)}$$

as depicted in Fig. 4.20.

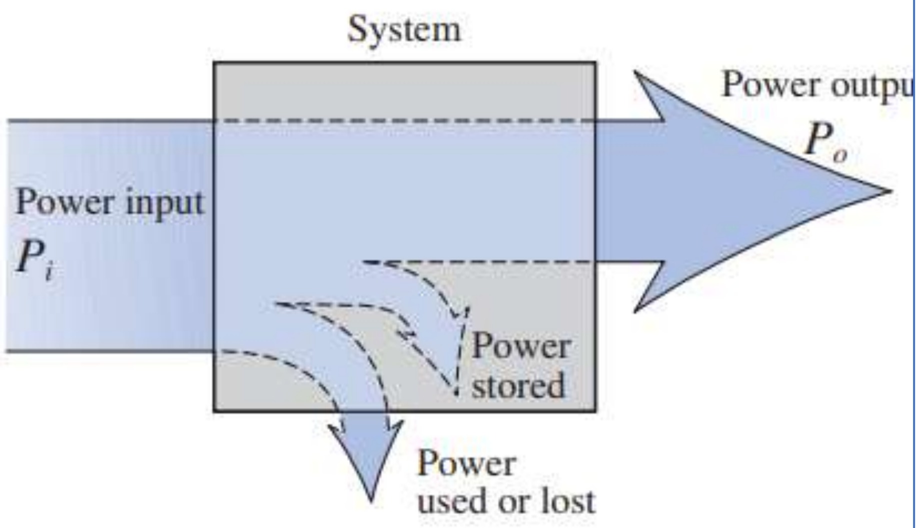


FIG. 4.20
Power flow through a system.

Efficiency

Since $P = W/t$, we have the following:

$$\boxed{P_i = P_o + P_{\text{used, lost or stored}}} \quad \text{(W)}$$

as depicted in Fig. 4.20.

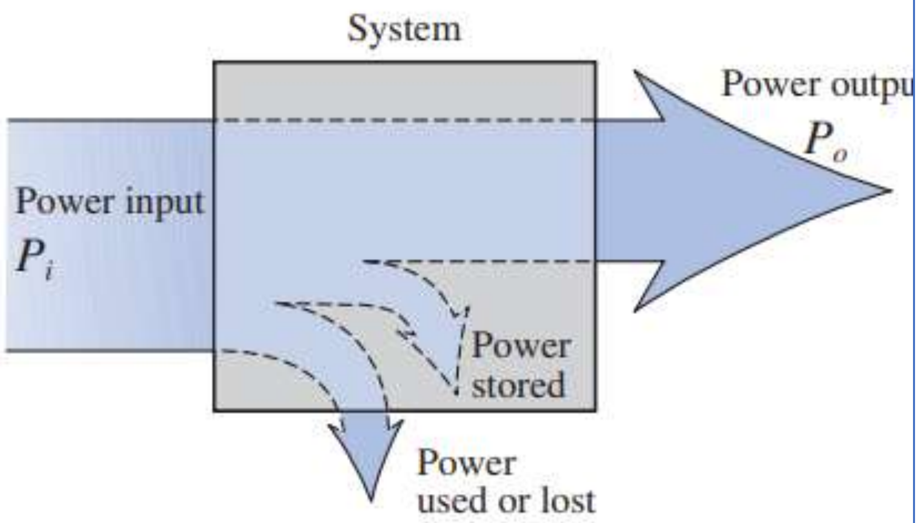


FIG. 4.20
Power flow through a system.

The **efficiency** (η) of the system is then determined by the following equation:

$$\text{Efficiency} = \frac{\text{power output}}{\text{power input}}$$

$$\boxed{\eta = \frac{P_o}{P_i}} \quad \text{(decimal number)} \qquad \textbf{(4.20)}$$

where η (the lowercase Greek letter *eta*) is a decimal number. Expressed as a percentage,

$$\boxed{\eta\% = \frac{P_o}{P_i} \times 100\%} \quad \text{(percent)} \qquad \textbf{(4.21)}$$

Efficiency

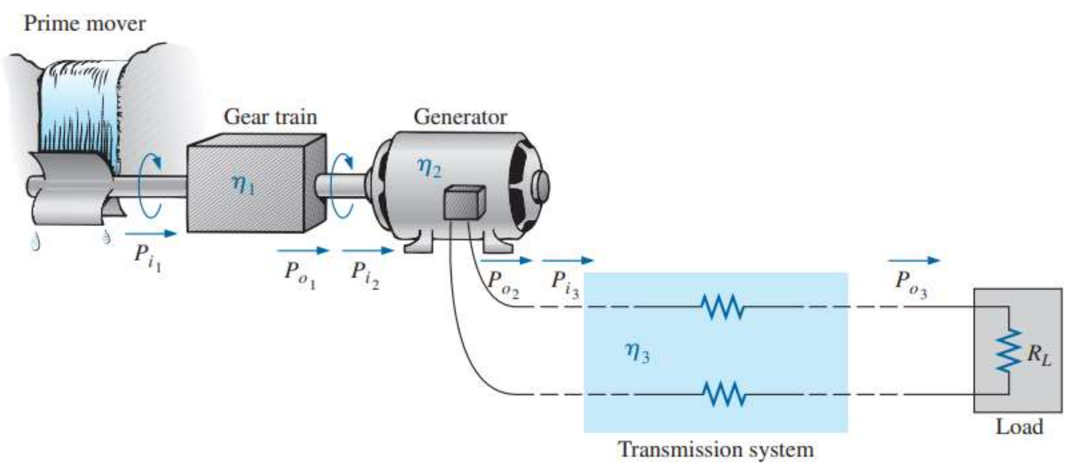


FIG. 4.21
Basic components of a generating system.

Efficiency will decrease in cascade systems

In general, for the representative cascaded system in Fig. 4.22,

$$\boxed{\eta_{total} = \eta_1 \cdot \eta_2 \cdot \eta_3 \dots \eta_n} \qquad \textbf{(4.22)}$$

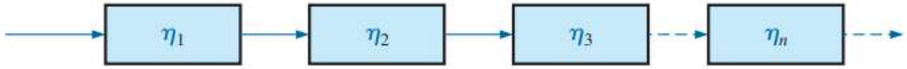
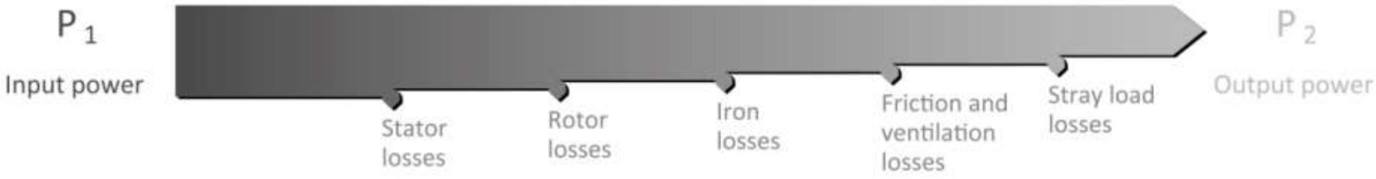
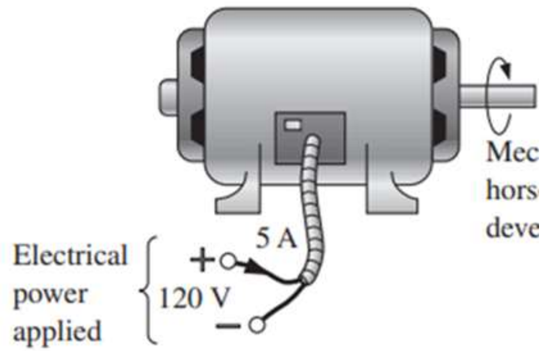


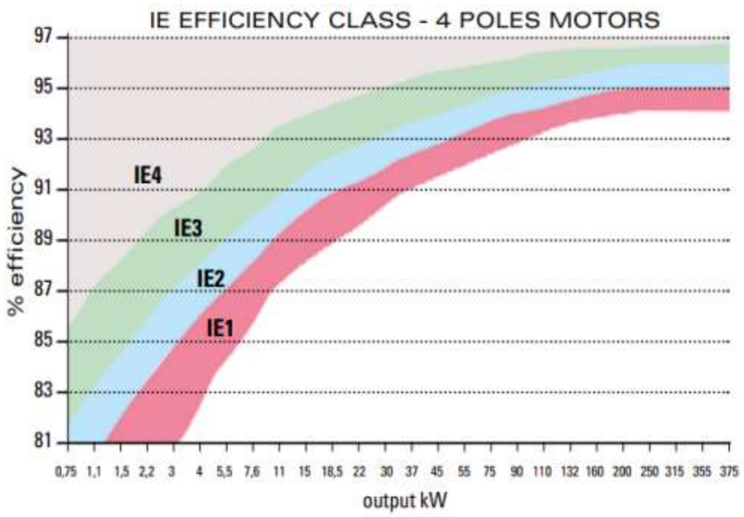
FIG. 4.22
Cascaded system.

Efficiency

ELECTRICAL MACHINE EFFICIENCY

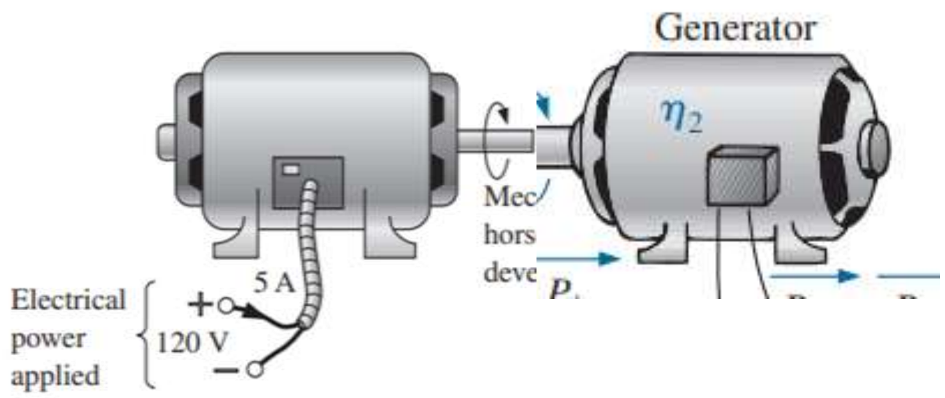






Code IEC 60034-30	Efficiency class
IE1	Standard Efficiency
IE2	High Efficiency
IE3	Premium Efficiency
IE4	Super Premium Efficiency

Efficiency

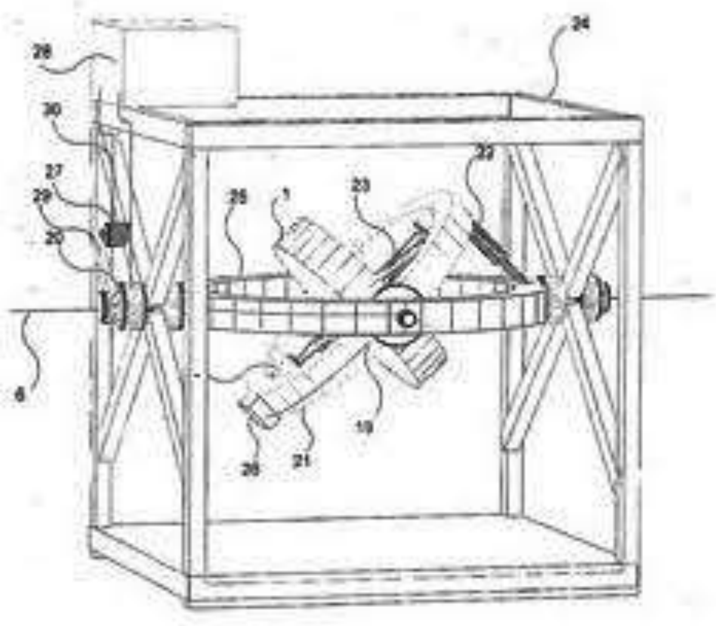


Generator output 120V

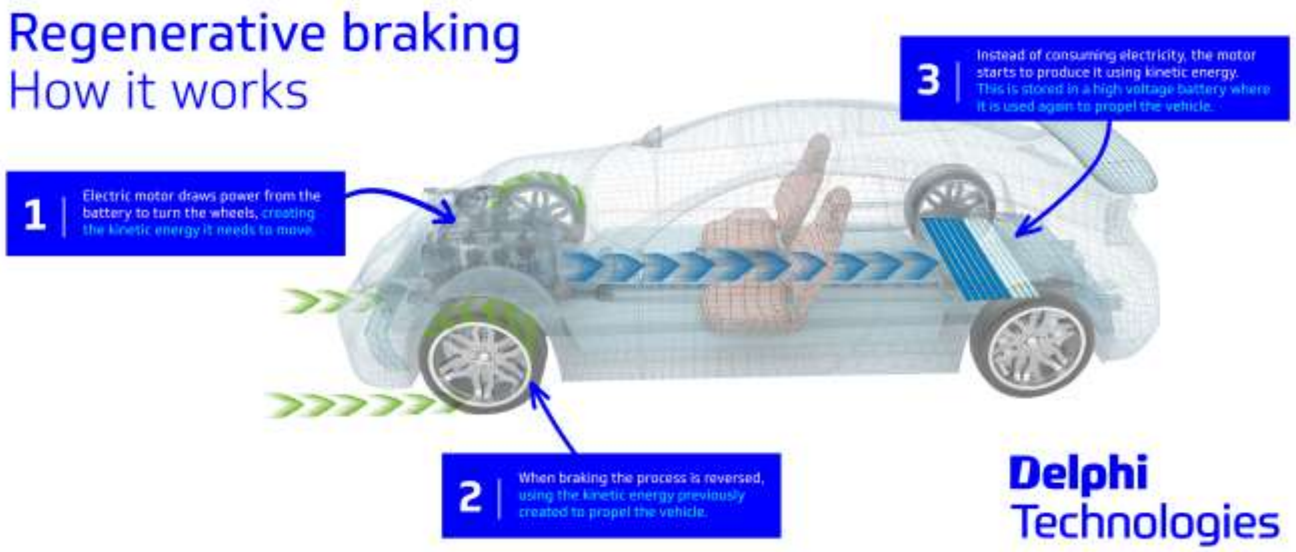
how about current ?
example output current is 4A
Po=120x4=480W
Pi=120x5=600W
n=480/600=0.8

n=Po/Pi < 1, for example 0.8-0.9

Perpetual machines



Perpetual machines



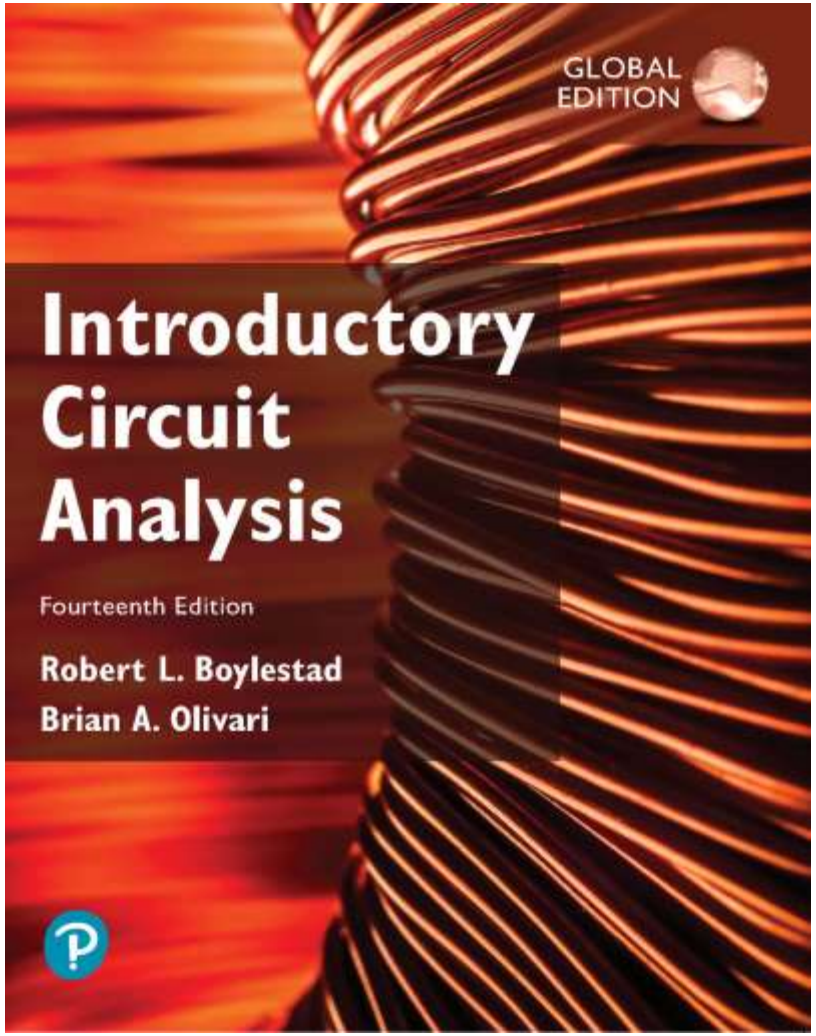
Assume that electric car has 100kW of power. If we connect 25kW generator to 4 wheel and charge the battery, can we go infinitely without charging the battery ?

NO. efficiency of an electrical machine is always less than 1. With 100kW input power you cannot generate 100kW power. Against to the conservation of the energy

Regenerative breaking works only when brakes are pressed or downhill.

Introductory Circuit Analysis

Fourteenth Edition, Global Edition

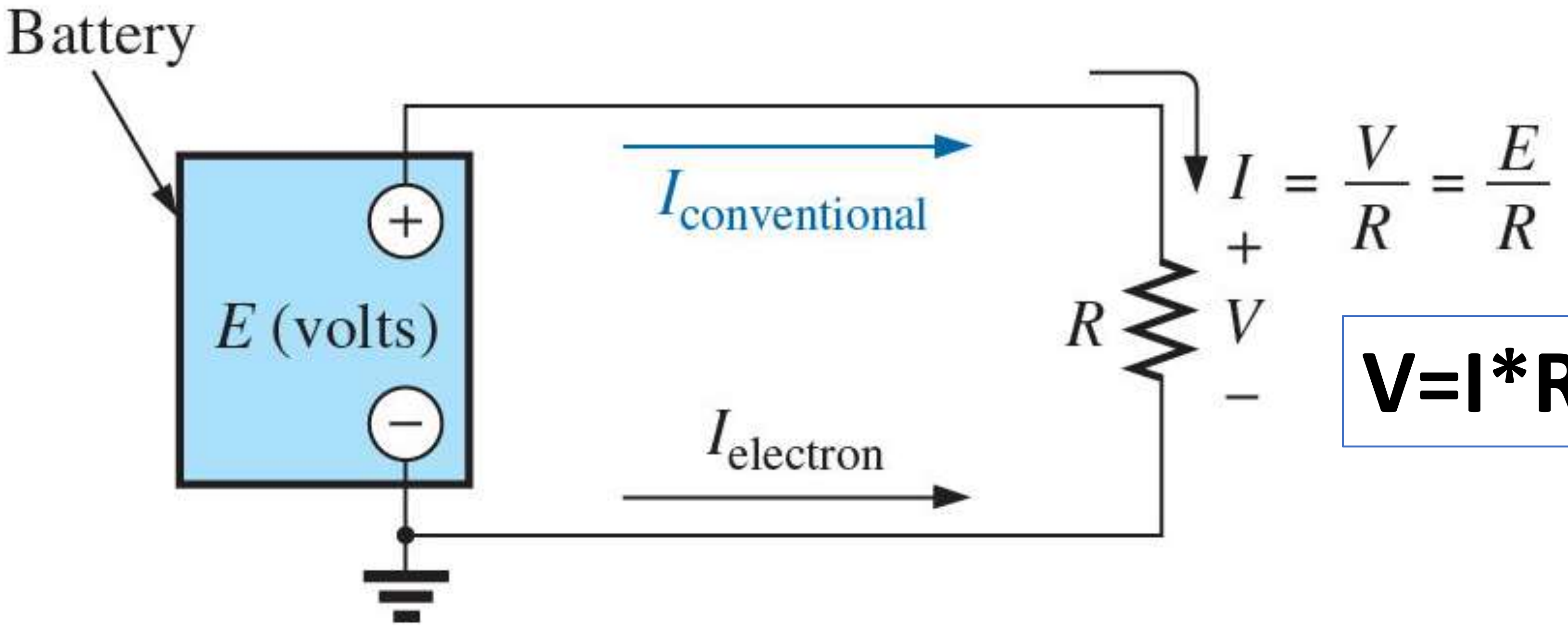


Chapter 5

Series dc Circuits

Introduction (2 of 4)

Fig. 5.1 *Introducing the basic components of an electric circuit.*

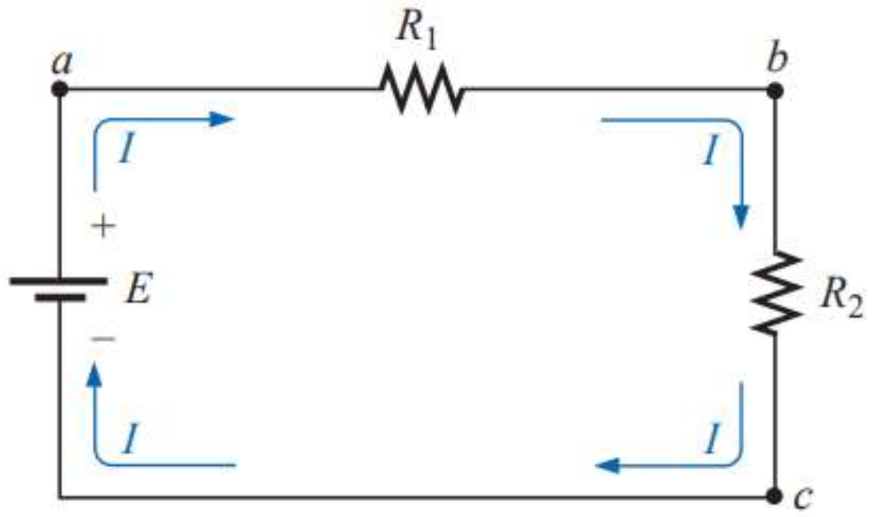


V=I*R

Series Resistors (1 of 8)

The current is the same through series elements.

The total resistance of a series circuit is the sum of the resistance levels.



(a) Series circuit

$$\boxed{R_T = R_1 + R_2 + R_3 + \cdots + R_N} \qquad \text{(ohms, } \Omega\text{)} \qquad \textbf{(5.1)}$$

$$\boxed{I_s = \frac{E}{R_T}} \qquad \text{(amperes, A)}$$

Series Resistors

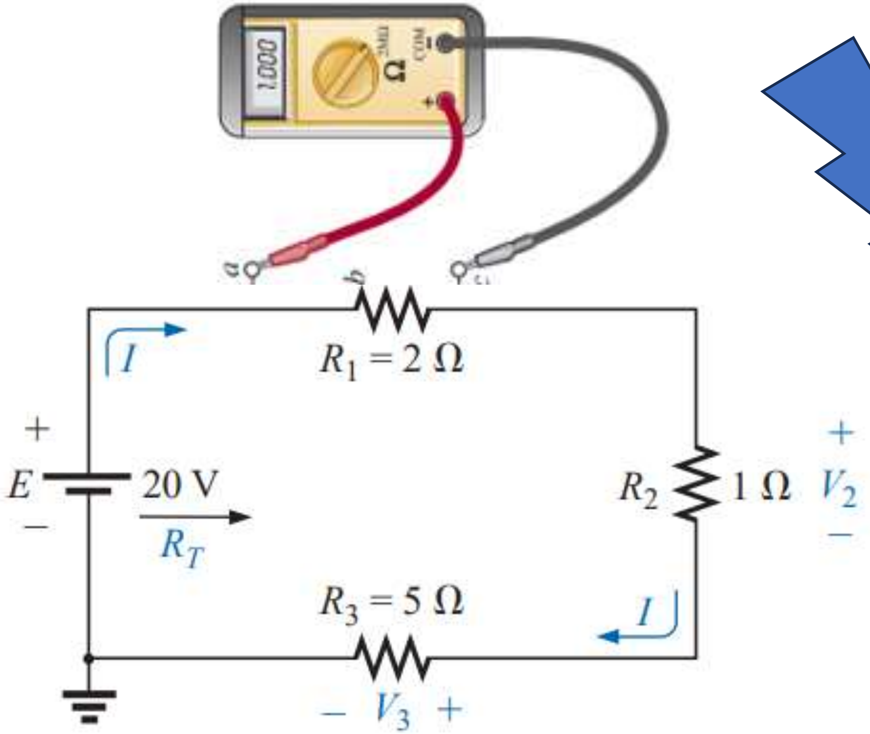


FIG. 5.7
Example 5.1.

EXAMPLE 5.1

a. Find the total resistance for the series circuit of Fig. 5.7.
b. Calculate the source current I_s.
c. Determine the voltages V_1, V_2, and V_3.
d. Calculate the power dissipated by R_1, R_2, and R_3.
e. Determine the power delivered by the source, and compare it to the sum of the power levels of part (d).

Solutions:

a. $R_T = R_1 + R_2 + R_3 = 2\ \Omega + 1\ \Omega + 5\ \Omega = \mathbf{8\ \Omega}$

b. $I_s = \dfrac{E}{R_T} = \dfrac{20\text{ V}}{8\ \Omega} = \mathbf{2.5\ A}$

c. $V_1 = IR_1 = (2.5\text{ A})(2\ \Omega) = \mathbf{5\ V}$
$V_2 = IR_2 = (2.5\text{ A})(1\ \Omega) = \mathbf{2.5\ V}$
$V_3 = IR_3 = (2.5\text{ A})(5\ \Omega) = \mathbf{12.5\ V}$

V=I*R
20V = I * (2 + 1 + 5)
I = 20/8 = 2.5A

V1=I * R1 = 2.5A * 2ohm = 5 volt

Series Resistors

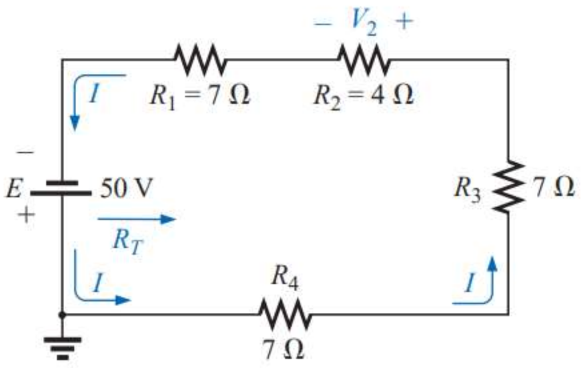


FIG. 5.8
Example 5.2.

EXAMPLE 5.2 Determine R_T, I, and V_2 for the circuit of Fig. 5.8.

Solution: Note the current direction as established by the battery and the polarity of the voltage drops across R_2 as determined by the current direction. Since $R_1 = R_3 = R_4$,

$$R_T = NR_1 + R_2 = (3)(7\ \Omega) + 4\ \Omega = 21\ \Omega + 4\ \Omega = \mathbf{25\ \Omega}$$

$$I = \frac{E}{R_T} = \frac{50\ \text{V}}{25\ \Omega} = \mathbf{2\ A}$$

$$V_2 = IR_2 = (2\ \text{A})(4\ \Omega) = \mathbf{8\ V}$$

V = I * R,   VOLT, AMPER, OHM

50V = I * (7 + 4 + 7 + 7)

I = 50/25=2 A

V2=I*R2=2*4=8V
V1=I*R1=2*7=14V
V3=I*R3=2*7=14V
V4=I*R4=2*7=14V
V1+V2+V3+V4=50V = E

Series Resistors

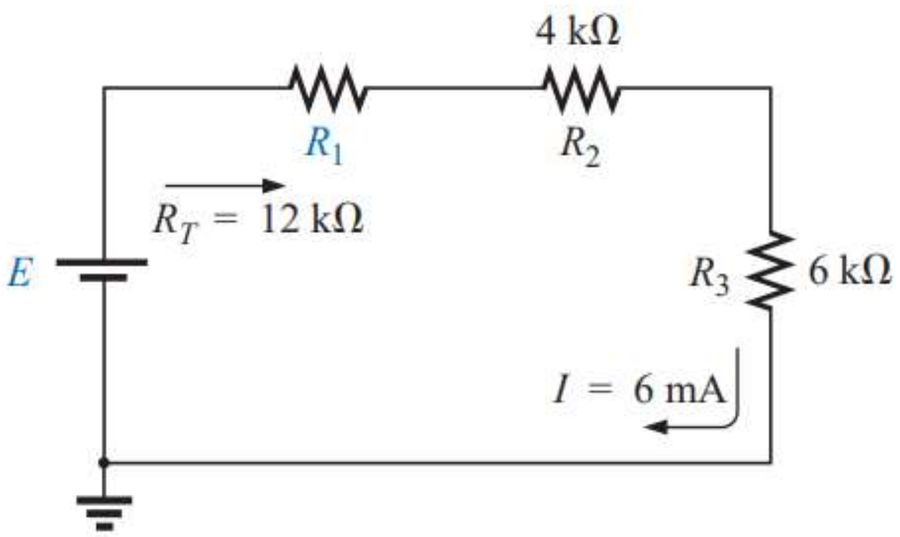


FIG. 5.9
Example 5.3.

EXAMPLE 5.3 Given R_T and I, calculate R_1 and E for the circuit of Fig. 5.9.

Solution:

$$R_T = R_1 + R_2 + R_3$$
$$12\text{ k}\Omega = R_1 + 4\text{ k}\Omega + 6\text{ k}\Omega$$
$$R_1 = 12\text{ k}\Omega - 10\text{ k}\Omega = \mathbf{2\text{ k}\Omega}$$
$$E = IR_T = (6 \times 10^{-3}\text{ A})(12 \times 10^{3}\ \Omega) = \mathbf{72\text{ V}}$$

V = I*R
V = 6mA * 12kOhm
V=72V

R1=?
12k = R1 + 4k + 6k
R1=2k

Series Resistors

the total resistance of resistors in series is unaffected by the order in which they are connected.

The result is that the total resistance in Fig. 5.10(a) is the same as in Fig. 5.10(b). Again, note that all the resistors are standard values.

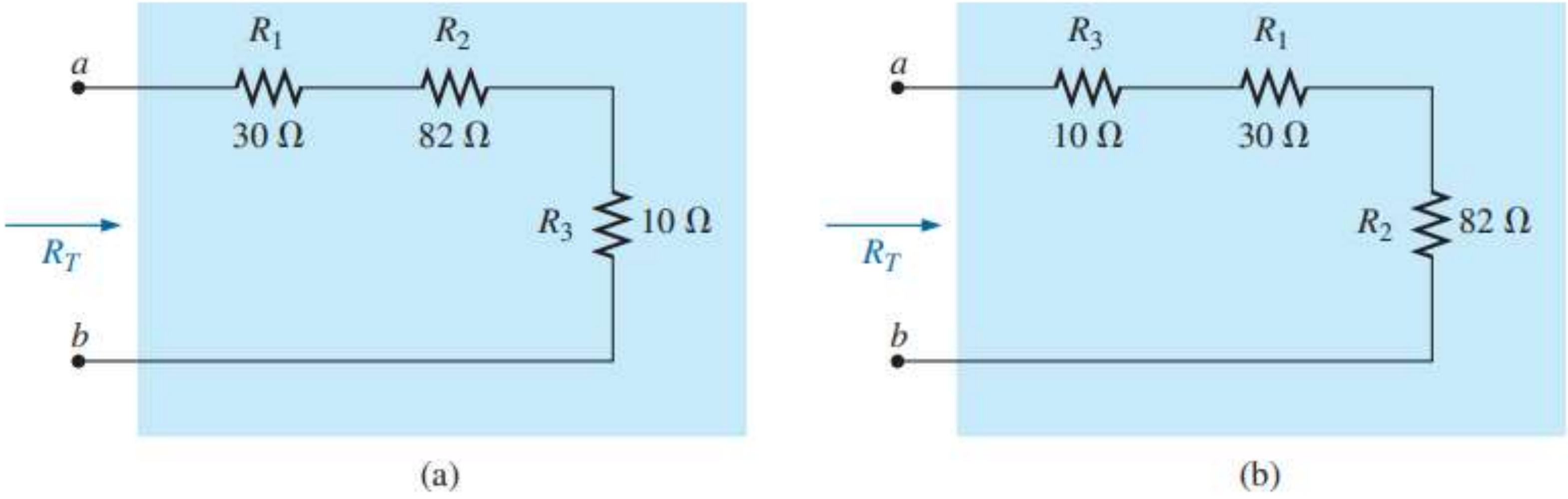


FIG. 5.10
Two series combinations of the same elements with the same total resistance.

Series Resistors

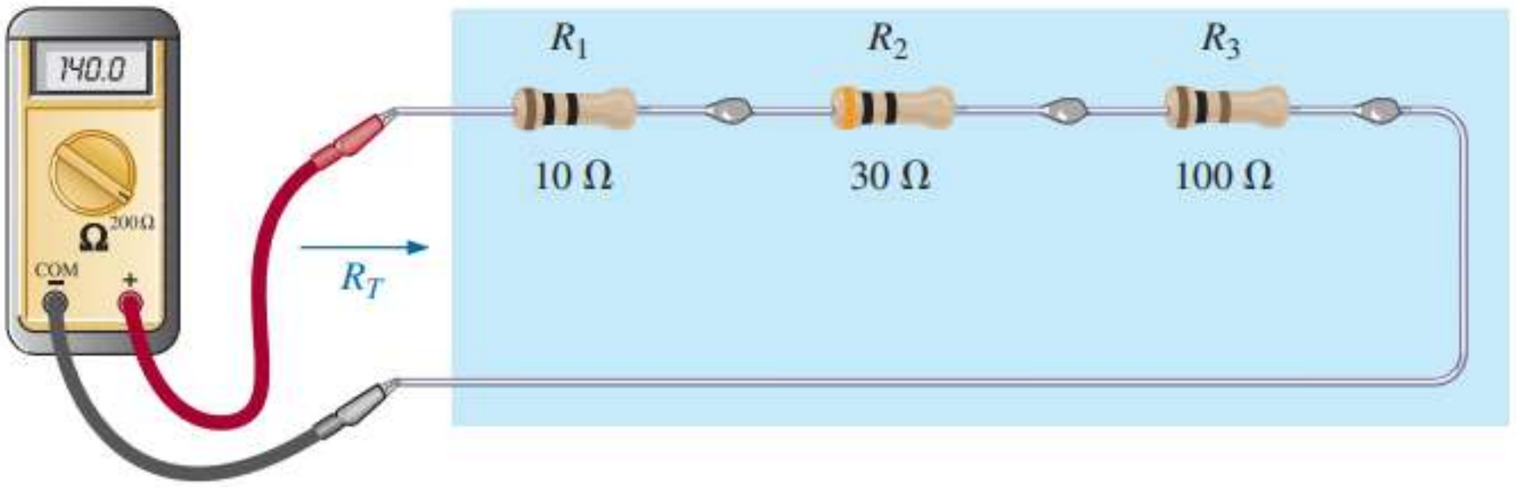


FIG. 5.13
Using an ohmmeter to measure the total resistance of a series circuit.

Series Resistors

EXAMPLE 5.4 For the series circuit in Fig. 5.17:

a. Find the total resistance R_T.
b. Calculate the resulting source current I_s.
c. Determine the voltage across each resistor.

Solutions:

a. $$\begin{aligned} R_T &= R_1 + R_2 + R_3 \\ &= 2\ \Omega + 1\ \Omega + 5\ \Omega \\ R_T &= \mathbf{8\ \Omega} \end{aligned}$$

b. $$I_s = \frac{E}{R_T} = \frac{20\ \text{V}}{8\ \Omega} = \mathbf{2.5\ A}$$

c. $$\begin{aligned} V_1 &= I_1R_1 = I_sR_1 = (2.5\ \text{A})(2\ \Omega) = \mathbf{5\ V} \\ V_2 &= I_2R_2 = I_sR_2 = (2.5\ \text{A})(1\ \Omega) = \mathbf{2.5\ V} \\ V_3 &= I_3R_3 = I_sR_3 = (2.5\ \text{A})(5\ \Omega) = \mathbf{12.5\ V} \end{aligned}$$

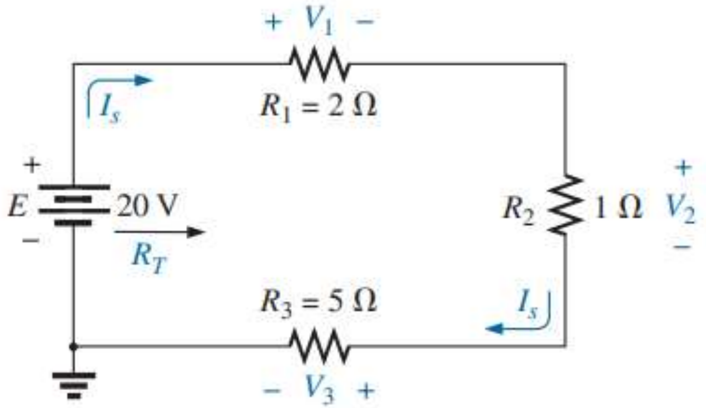


FIG. 5.17
Series circuit to be investigated in Example 5.4.

Series Resistors

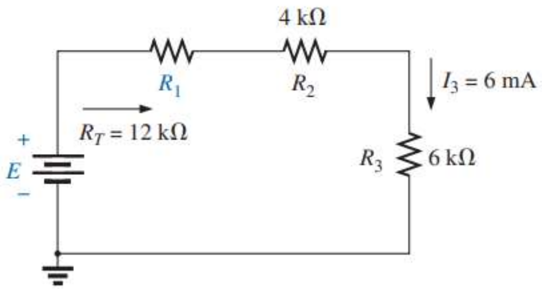


FIG. 5.20
Series circuit to be analyzed in Example 5.6.

EXAMPLE 5.6 Given R_T and I_3, calculate R_1 and E for the circuit in Fig. 5.20.

Solution: Since we are given the total resistance, it seems natural to first write the equation for the total resistance and then insert what we know:

$$R_T = R_1 + R_2 + R_3$$

We find that there is only one unknown, and it can be determined with some simple mathematical manipulations. That is,

$$12\ \text{k}\Omega = R_1 + 4\ \text{k}\Omega + 6\ \text{k}\Omega = R_1 + 10\ \text{k}\Omega$$

and $\quad 12\ \text{k}\Omega - 10\ \text{k}\Omega = R_1$

so that $\quad R_1 = \mathbf{2\ k\Omega}$

The dc voltage can be determined directly from Ohm's law:

$$E = I_s R_T = I_3 R_T = (6\ \text{mA})(12\ \text{k}\Omega) = \mathbf{72\ V}$$

Series Resistors

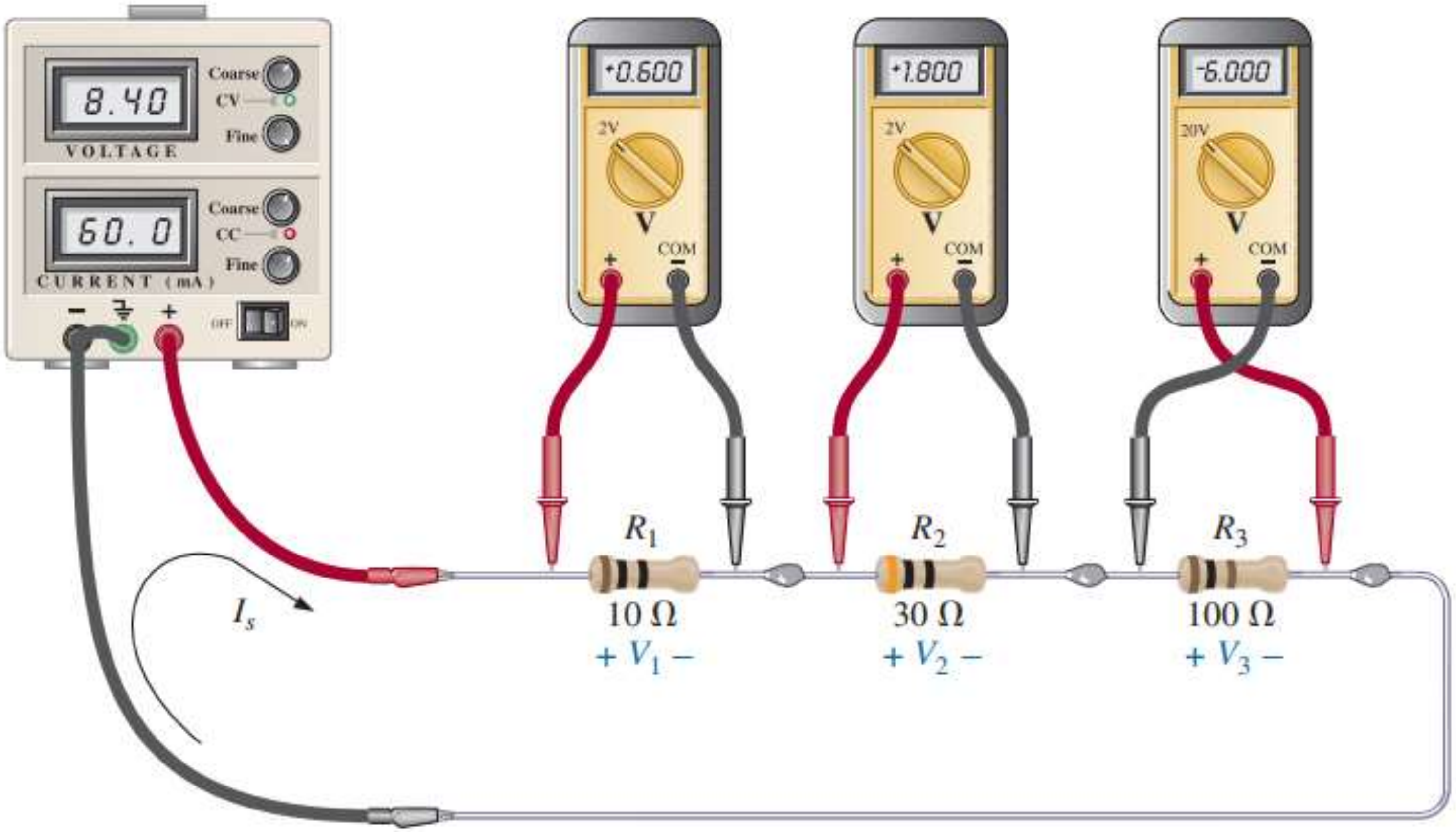


FIG. 5.21
Using voltmeters to measure the voltages across the resistors in Fig. 5.14.

Series Resistors

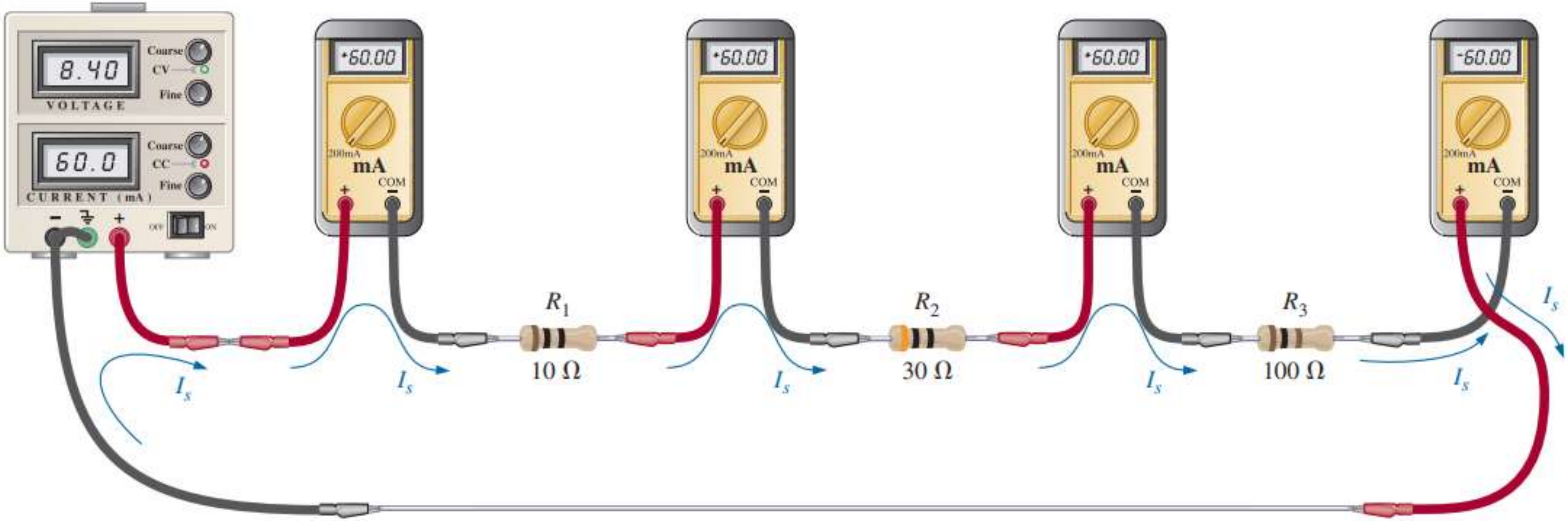


FIG. 5.22
Measuring the current throughout the series circuit in Fig. 5.14.

Kirchhoff’s Voltage Law

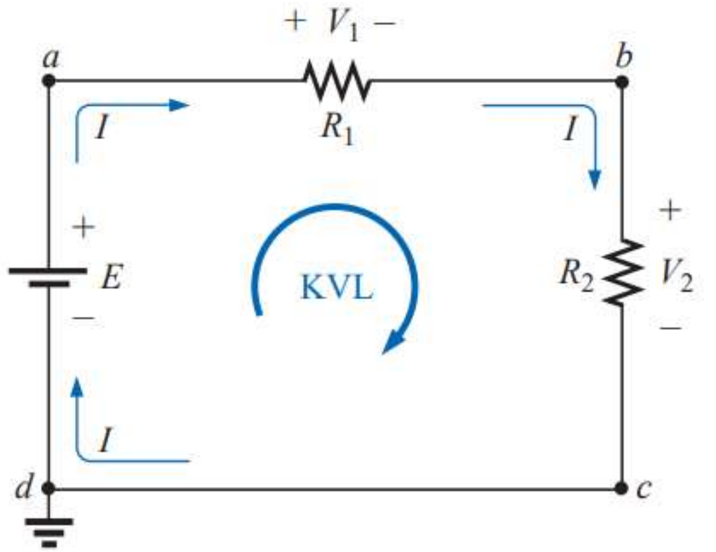


FIG. 5.12
Applying Kirchhoff’s voltage law to a series dc circuit.

$$\boxed{\Sigma_{\circlearrowright} V = 0}$$ (Kirchhoff’s voltage law in symbolic form)

-E + V1 + V2 = 0

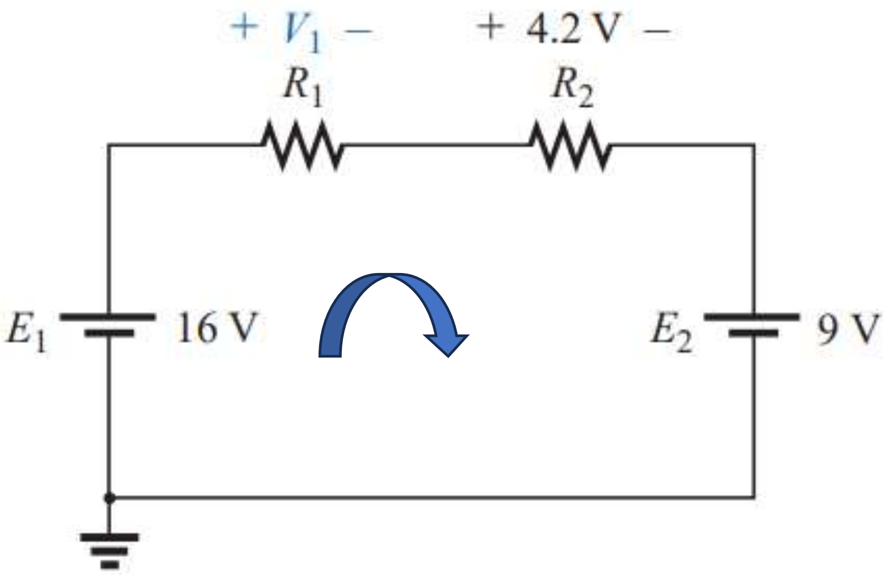
-E + I.R1 + I.R2 =0

Note Fig. 5.11.

Kirchhoff’s voltage law ***(KVL) states that the algebraic sum of the potential rises and drops around a closed loop (or path) is zero.***

Kirchhoff’s Voltage Law

EXAMPLE 5.4 Determine the unknown voltages for the networks of Fig. 5.14.



(a)

-16 + V1 + 4.2 + 9 = 0

-16 + V1 + 13.2 = 0

V1 – 2.8 = 0

V1 = 2.8V

Kirchhoff’s Voltage Law

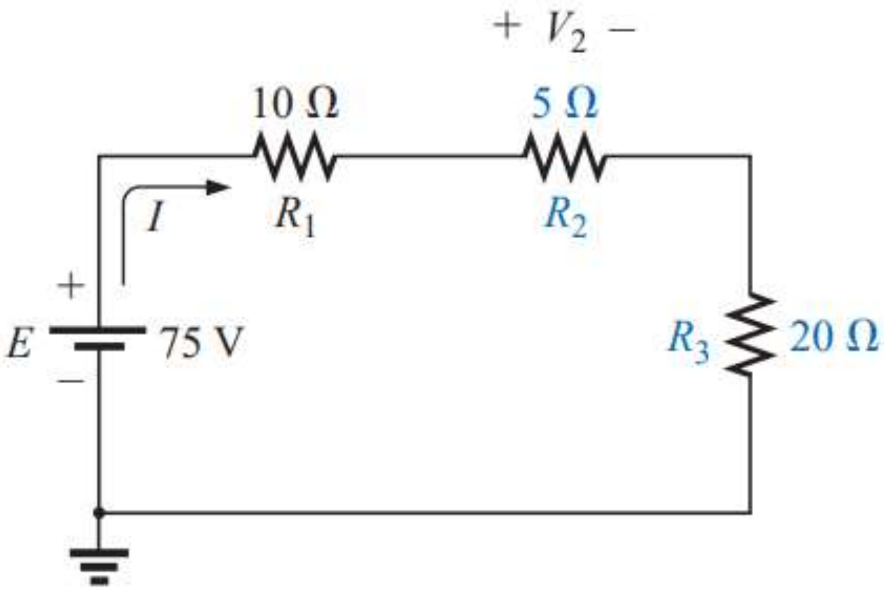


FIG. 5.19
Series dc circuit with elements to be interchanged.

Find V2?

KVL:

-75 + 10.I + 5.I + 20.I =0

-75 + 35.I =0

I=75/35 = 2.1A

V2= I. R2 = 2.1A x 5=10.5V

Kirchhoff’s Voltage Law

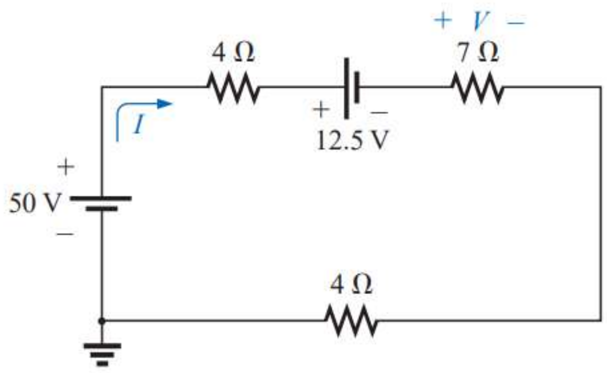


FIG. 5.21
Example 5.9.

EXAMPLE 5.9 Determine I and the voltage across the 7-Ω resistor for the network of Fig. 5.21.

Solution: The network is redrawn in Fig. 5.22.

$$R_T = (2)(4\ \Omega) + 7\ \Omega = 15\ \Omega$$

$$I = \frac{E}{R_T} = \frac{37.5\ \text{V}}{15\ \Omega} = \mathbf{2.5\ A}$$

$$V_{7\Omega} = IR = (2.5\ \text{A})(7\ \Omega) = \mathbf{17.5\ V}$$

Kirchhoff's Voltage Law

EXAMPLE 5.13 For the series circuit in Fig. 5.34:

a. Determine V_2 using Kirchhoff's voltage law.
b. Determine current I_2.
c. Find R_1 and R_3.

Solutions:

a. Applying Kirchhoff's voltage law in the clockwise direction starting at the negative terminal of the supply results in

$$-E + V_3 + V_2 + V_1 = 0$$

and $$E = V_1 + V_2 + V_3 \text{ (as expected)}$$

so that $$V_2 = E - V_1 - V_3 = 54 \text{ V} - 18 \text{ V} - 15 \text{ V}$$

and $$V_2 = \mathbf{21\ V}$$

b. $$I_2 = \frac{V_2}{R_2} = \frac{21 \text{ V}}{7\ \Omega}$$

$$I_2 = \mathbf{3\ A}$$

c. $$R_1 = \frac{V_1}{I_1} = \frac{18 \text{ V}}{3 \text{ A}} = \mathbf{6\ \Omega}$$

with $$R_3 = \frac{V_3}{I_3} = \frac{15 \text{ V}}{3 \text{ A}} = \mathbf{5\ \Omega}$$

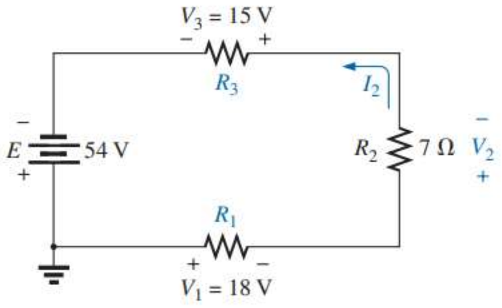


FIG. 5.34
Series configuration to be examined in Example 5.13.

Voltage Divider

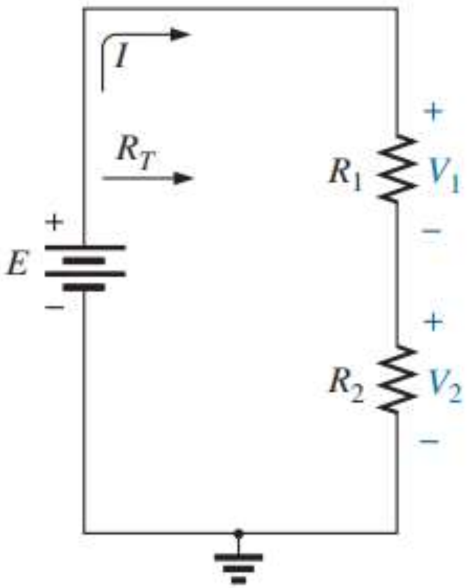


FIG. 5.38
Developing the voltage divider rule.

Voltage Divider Rule (VDR)

The **voltage divider rule (VDR)** permits the determination of voltage across a series resistor without first having to determi the current of the circuit. The rule itself can be derived by analyzing the simple series circuit in Fig. 5.38.

First, determine the total resistance as follows:

$$R_T = R_1 + R_2$$

Then
$$I_s = I_1 = I_2 = \frac{E}{R_T}$$

Apply Ohm's law to each resistor:

$$V_1 = I_1 R_1 = \left(\frac{E}{R_T}\right) R_1 = R_1 \frac{E}{R_T}$$

$$V_2 = I_2 R_2 = \left(\frac{E}{R_T}\right) R_2 = R_2 \frac{E}{R_T}$$

The resulting format for V_1 and V_2 is

$$\boxed{V_x = R_x \frac{E}{R_T}} \qquad \text{Voltage divider rule } (VDR) \qquad \textbf{(5.11)}$$

Voltage Divider

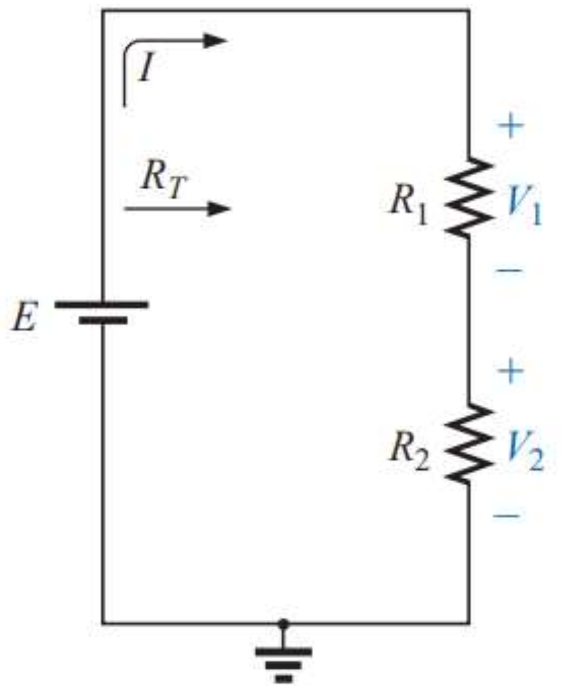


FIG. 5.26
Developing the voltage divider rule.

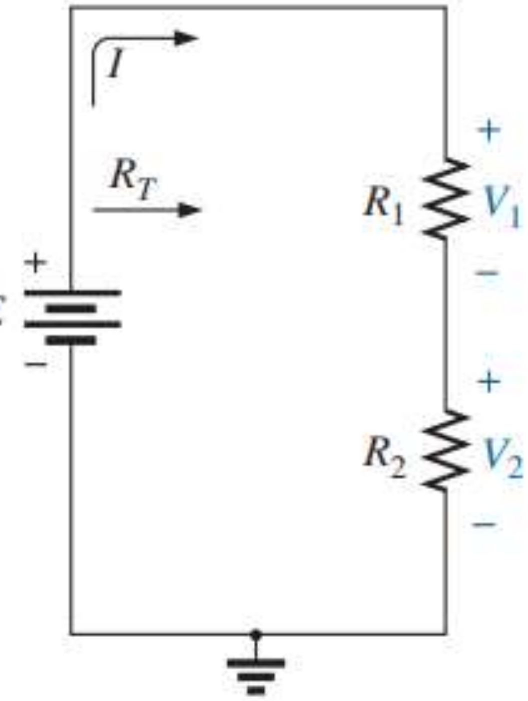
Voltage divider is used to adjust voltage of supply according to needs. For example, supply voltage is 9V battery but we want 5V. How can we get it ? What is V2 ?

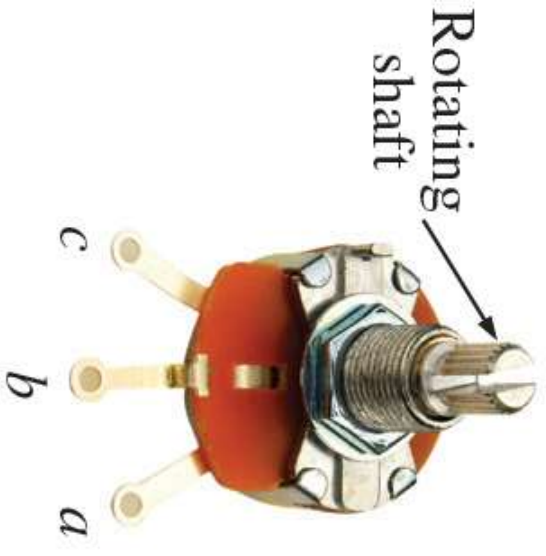
E=I. (R1+R2)
I=E/(R1+R2)

V2=E * R2 / (R2+R1)

Example: E=9V, R2=5K, R1=4K will give us V2=5V

Voltage Divider



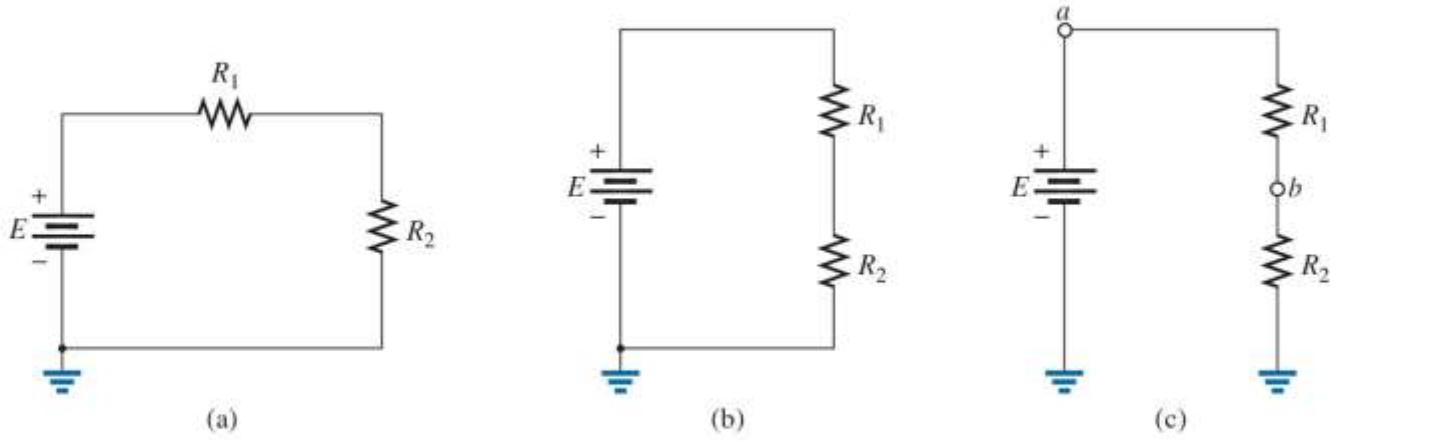


Voltage divider is used to adjust voltage of supply according to needs. For example, supply voltage is 9V battery but we want 5V. Use a 500ohm potentiometer. How can we get it ?
What is V2 ?

R1+R2=500 ohm
V2=E.R2/(R1+R2)
5=9.R2/500, R2=277ohm

Notation Voltage Sources and Ground

Fig. 5.48 *Three ways to sketch the same series dc circuit.*



Voltage Divider

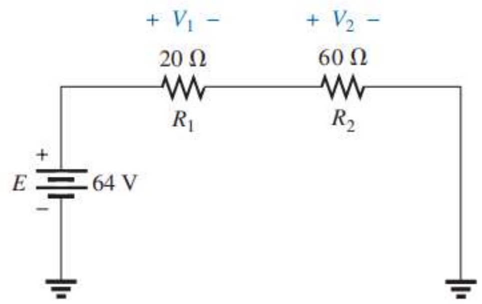


FIG. 5.39
Series circuit to be examined using the voltage divider rule in Example 5.16.

resistors.

EXAMPLE 5.16 For the series circuit in Fig. 5.39:

a. Without making any calculations, how much larger would you expect the voltage across R_2 to be compared to that across R_1?
b. Find the voltage V_1 using only the voltage divider rule.
c. Using the conclusion of part (a), determine the voltage across R_2.
d. Use the voltage divider rule to determine the voltage across R_2, and compare your answer to your conclusion in part (c).
e. How does the sum of V_1 and V_2 compare to the applied voltage?

Solutions:

a. Since resistor R_2 is three times R_1, it is expected that $V_2 = 3V_1$.

b. $V_1 = R_1\dfrac{E}{R_T} = 20\ \Omega\left(\dfrac{64\ \text{V}}{20\ \Omega + 60\ \Omega}\right) = 20\ \Omega\left(\dfrac{64\ \text{V}}{80\ \Omega}\right) = \mathbf{16\ V}$

c. $V_2 = 3V_1 = 3(16\ \text{V}) = \mathbf{48\ V}$

d. $V_2 = R_2\dfrac{E}{R_T} = (60\ \Omega)\left(\dfrac{64\ V}{80\ \Omega}\right) = \mathbf{48\ V}$

The results are an exact match.

e. $E = V_1 + V_2$

$$64\ \text{V} = 16\ \text{V} + 48\ \text{V} = \mathbf{64\ V}\ \ (\text{checks})$$

PT100 sensor measurements

We want measure temperature between -30C (88 ohm) to 130C (139 ohm) using a PT100 temperature sensor. VCC=12V. R1=100 ohm what is the voltage range measured ?

$Vout=VCC \times R1 / (R1+R2)$

$Vout=12 \times 88 (88 +100) = 5.6V$

$Vout=12 \times 139 (139 + 100) = 6.9V$

Find Relation between T and V2 ?

$T=A.V2 + B$

$130 = A. (6.9) + B$

$-30 = A. (5.6) +B$

-

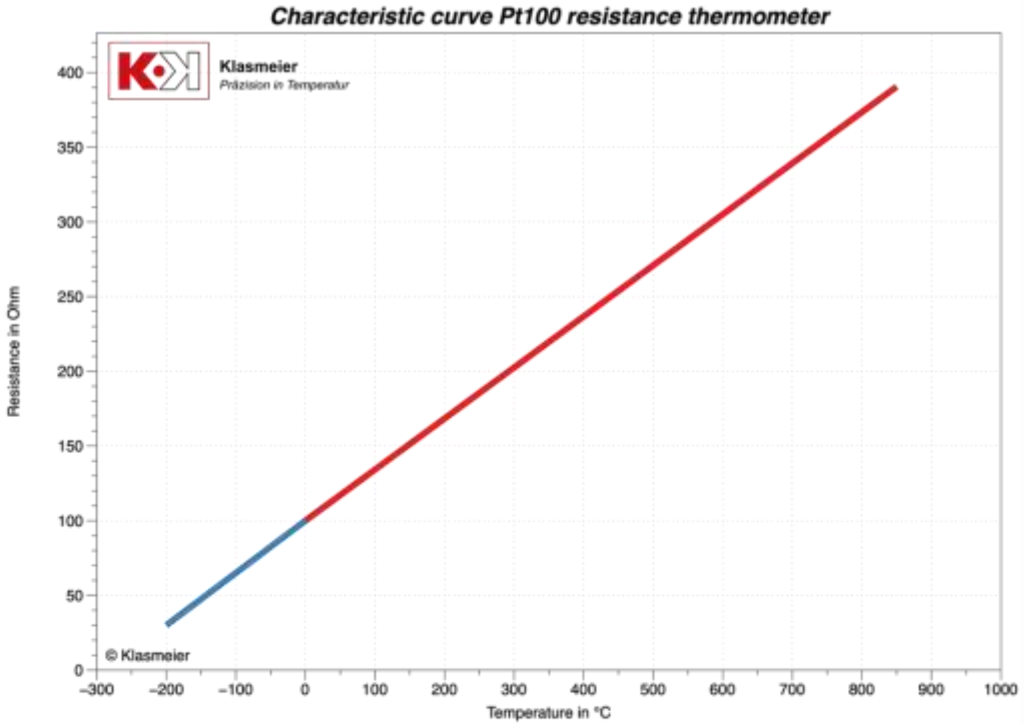
____

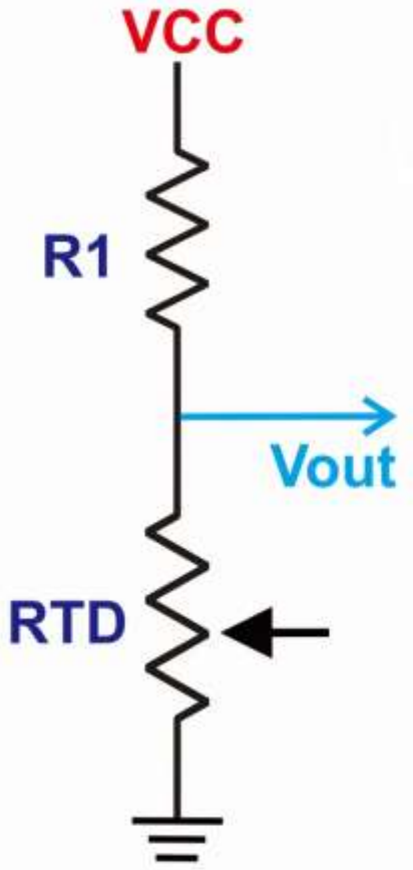
$160 = A(1.3), A=123$

$130=123 . (6.9) + B$

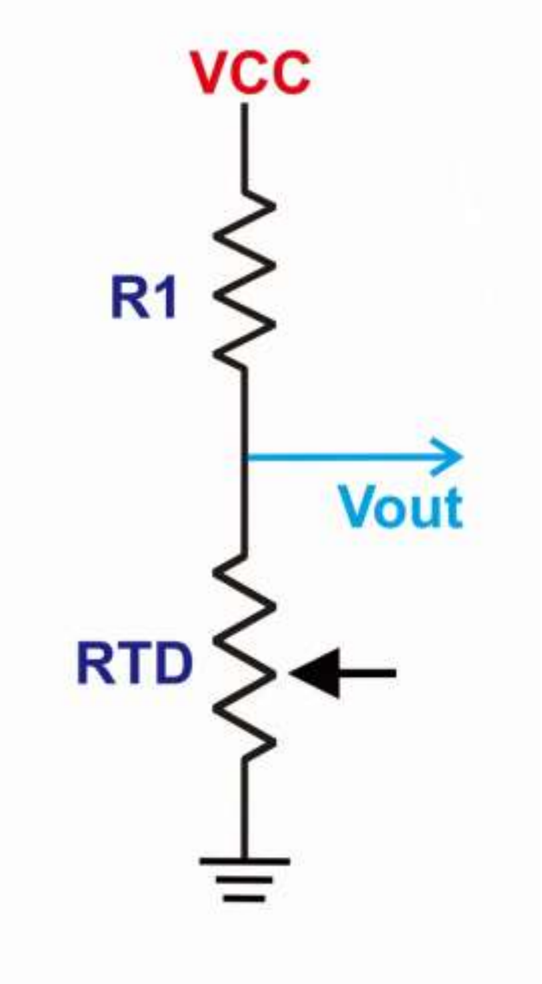
$B=-719$

T = 123.**V2** - 719





Voltage Divider

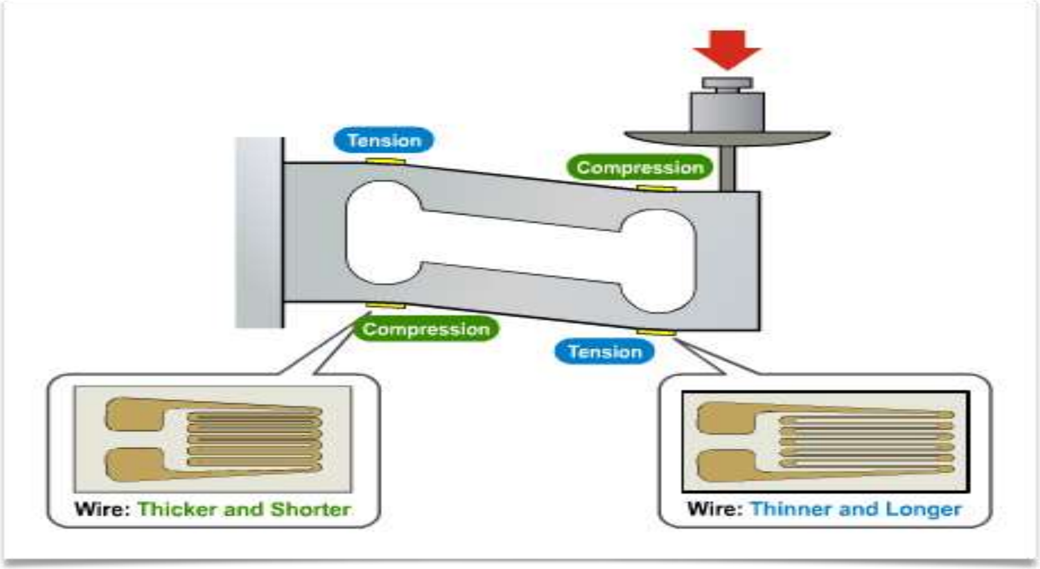


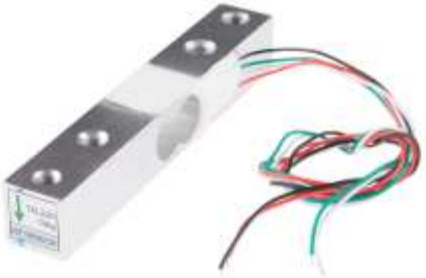
We want measure temperature between -30C to 130C. VCC=12V what shall be the value of R1 to have voltage between 0.5-4.5V for -30C to 130C

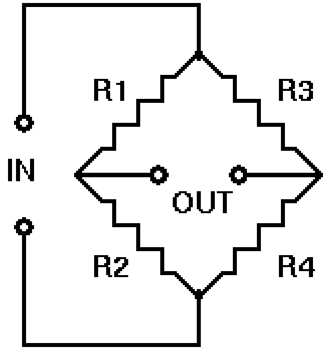
130C is 139 ohm, must give **4.5V**
Vout=VCC x R1 / (R1+R2)
4.5=12 x 139 / (139 + R1)
139 + R1 = 12x139/4.5 = 370.6
R1=240.6 ohm

what happens at -30C, 88 ohm
Vout=12 x 88 / (88 +240.6) = **3.2V**

Strain Gauge Voltage







$$V_{out} = [R2/(R1 + R2) - R4/(R3 + R4)] \times V_{in}$$

Normal resistances of a strain gauge is 1Kohm

if resistance changes 1% with bending, with 3V suplly how much Vout is expected?

answer: Vo=0 at rest position

at 1% change
Vo=3V (1010/2000 – 990/2000)
Vo=3V (20/2000)=0.03V = 30mV

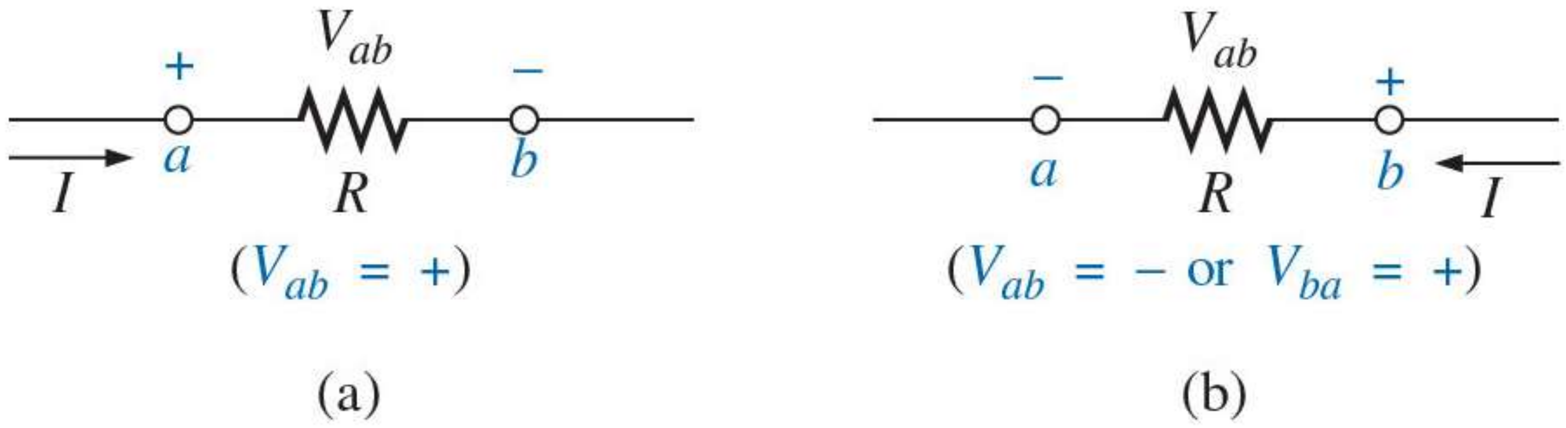
[Getting Started with Load Cells - SparkFun Learn]

[Strain Gauge Load Cell | How it works and how to choose | FUTEK]

Notation Double-Subscript Notation

- The fact that voltage exists between two points has resulted in a double-subscript notation that defines the first subscript as the higher potential.

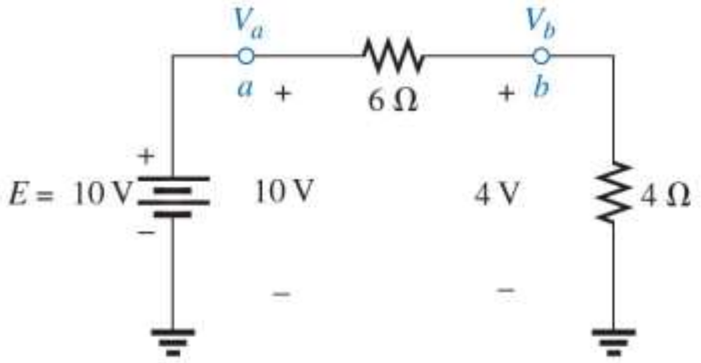
Fig. 5.52 *Defining the sign for double-subscript notation.*



Notation Single-Subscript Notation

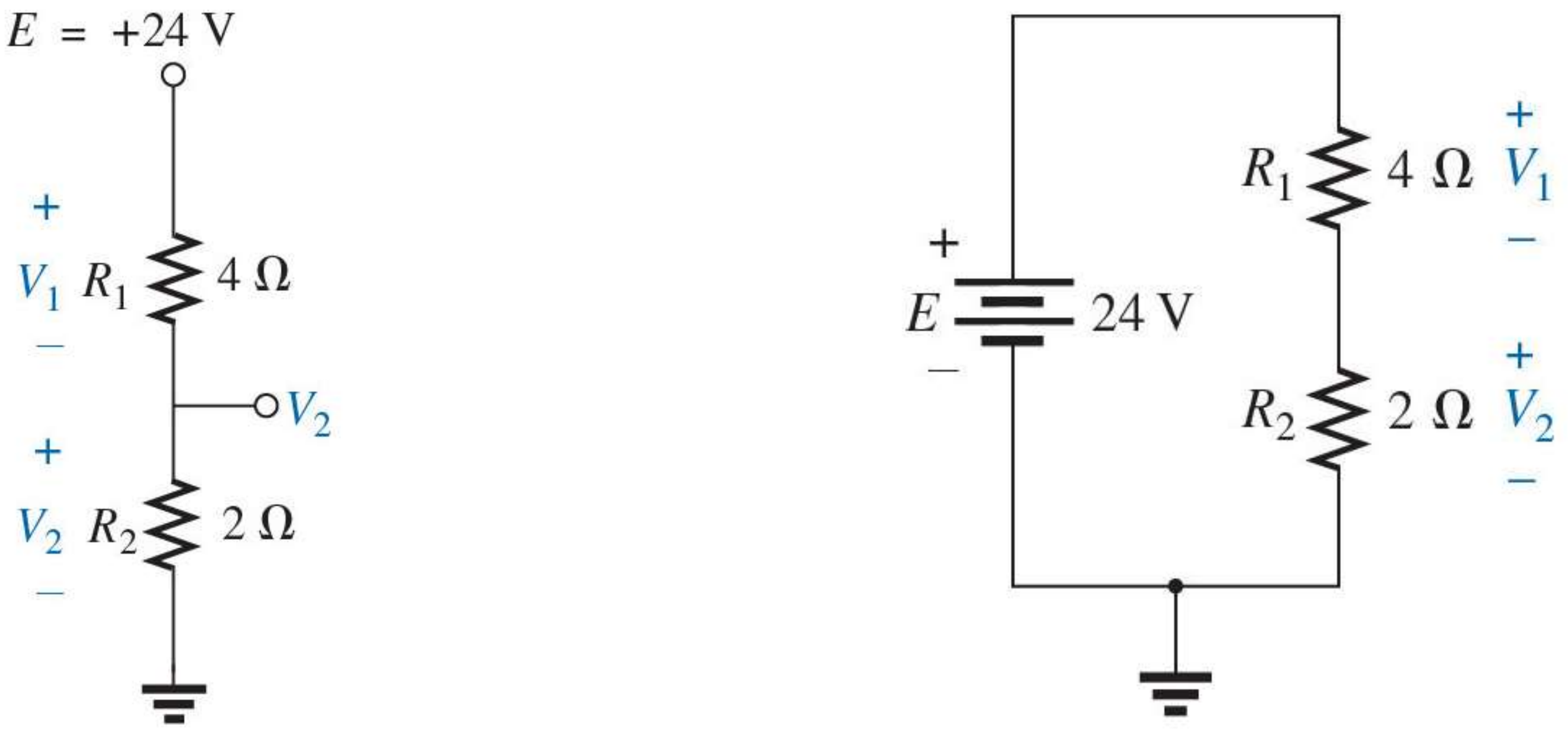
- The single-subscript notation V_a specifies the voltage at point "a" with respect to ground. If the voltage is less than zero volts, a negative sign must be associated with the magnitude of V_a.

Fig. 5.53 *Defining the use of single-subscript notation for voltage levels.*



Notation General Comments

Fig. 5.65 *Circuit of Fig. 5.64 redrawn.*

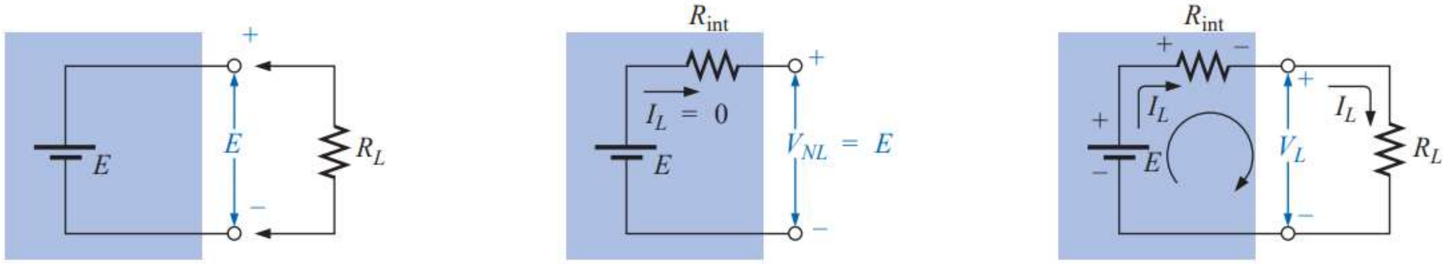


Voltage Regulation & Internal Resistance of Voltage Sources (1 of 8)

When you use a dc supply such as the generator, battery, or supply you initially assume that it will provide the desired voltage for any resistive load you may hook up to the supply.

Fig. 5.70 *(a) Sources of dc voltage; (b) equivalent circuit.*

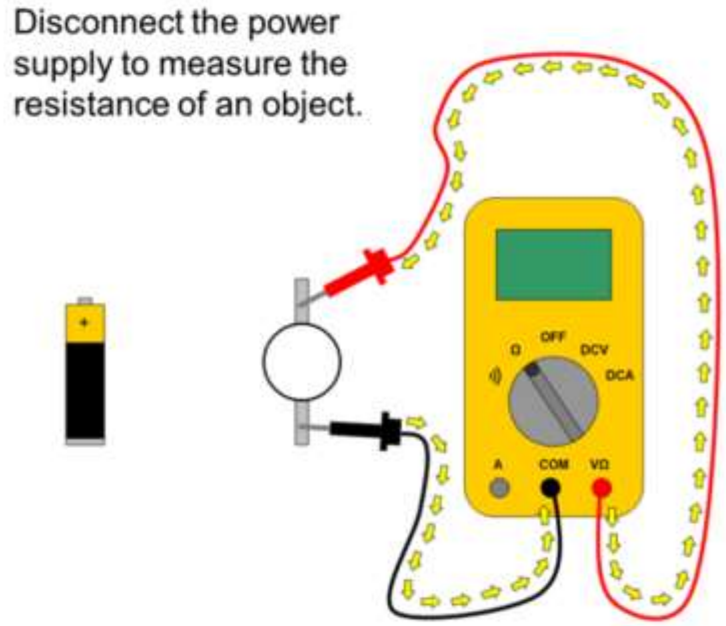
(a) (b)

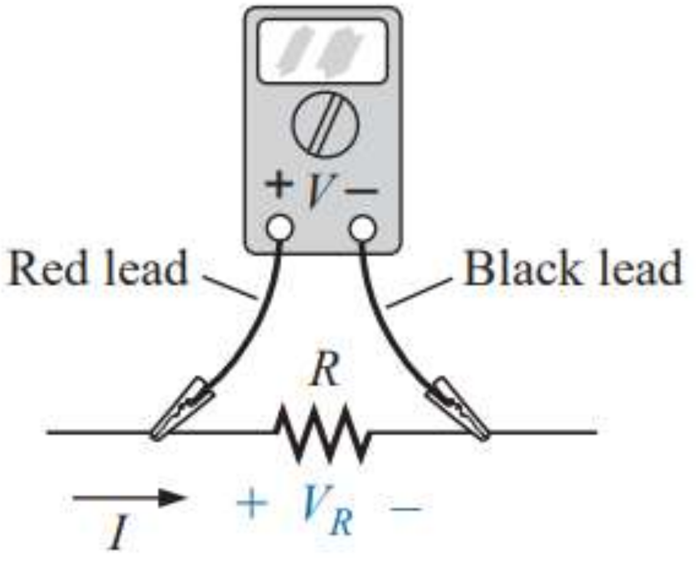


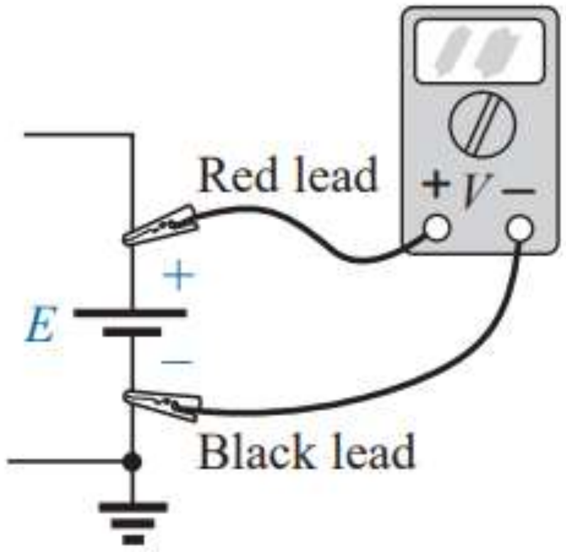
(a) (b) (c)

FIG. 5.52
Voltage source: (a) ideal, $R_{int} = 0\ \Omega$; (b) determining V_{NL}; (c) determining R_{int}.

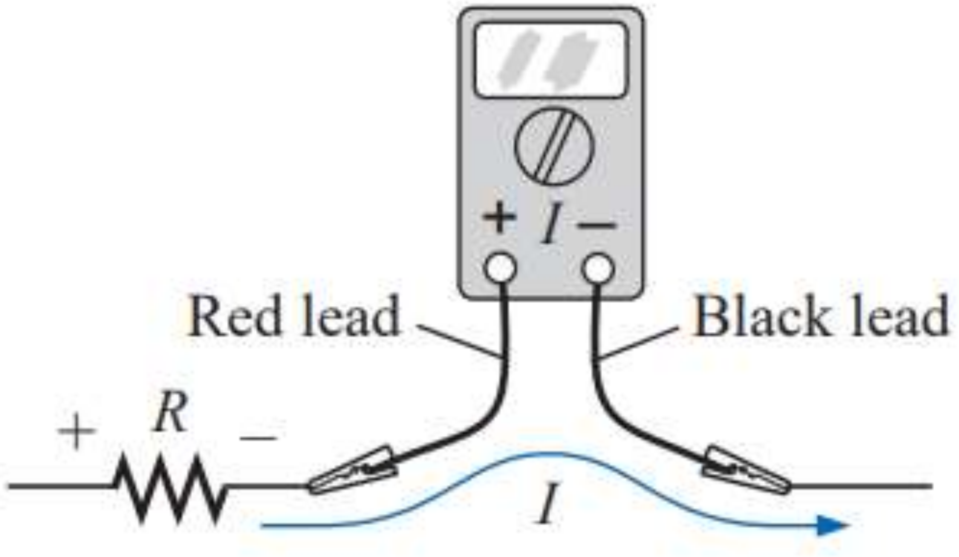
MEASUREMENT TECHNIQUES







MEASUREMENT TECHNIQUES



MEASUREMENT TECHNIQUES

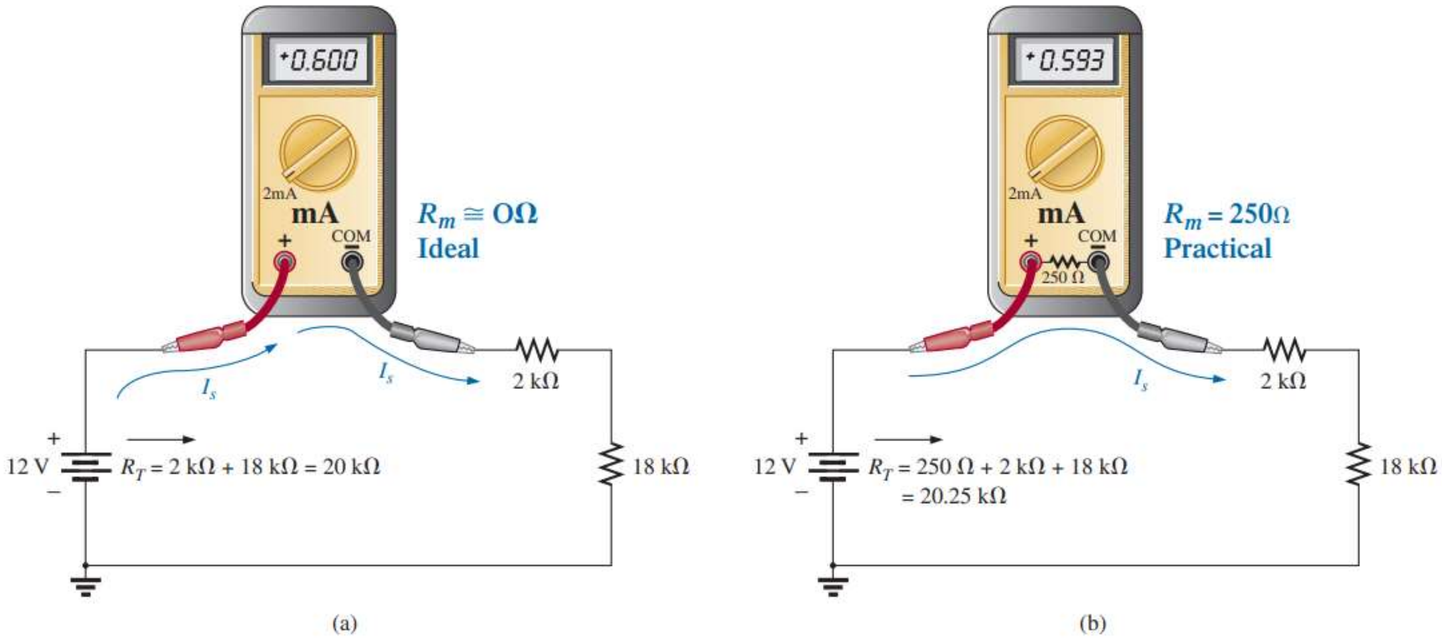


FIG. 5.79

Applying an ammeter set on the 2 mA scale to a circuit with resistors in the kilohm range: (a) ideal; (b) practical.

MEASUREMENT TECHNIQUES

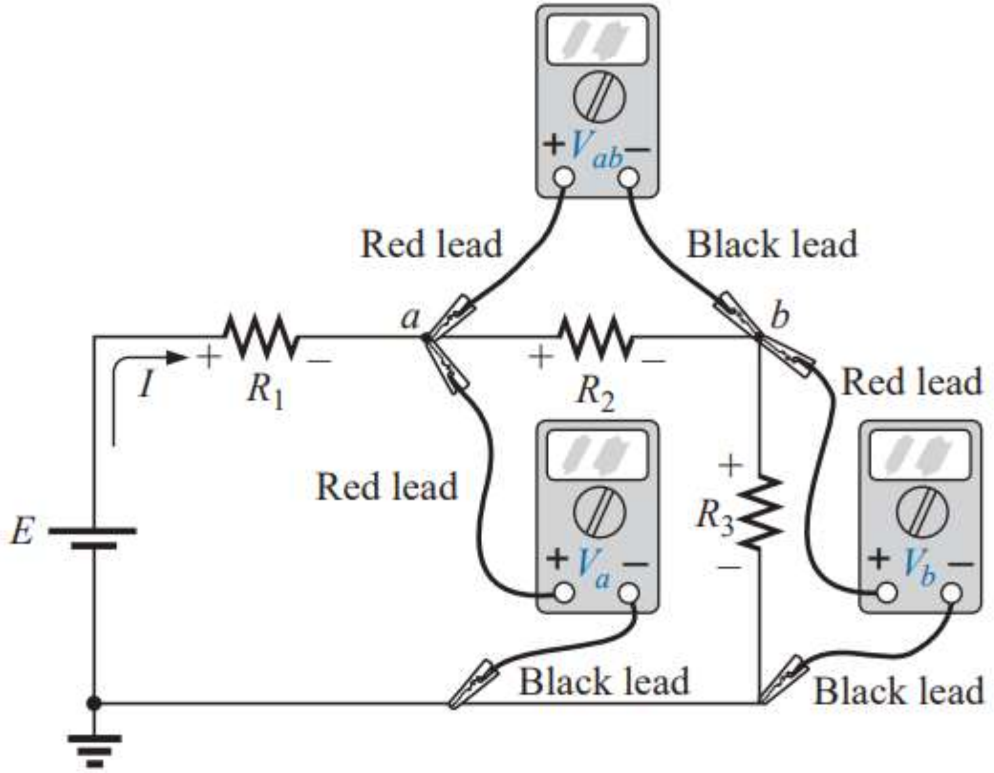


FIG. 5.60
Measuring voltages with double- and single-subscript notation.

MEASUREMENT TECHNIQUES

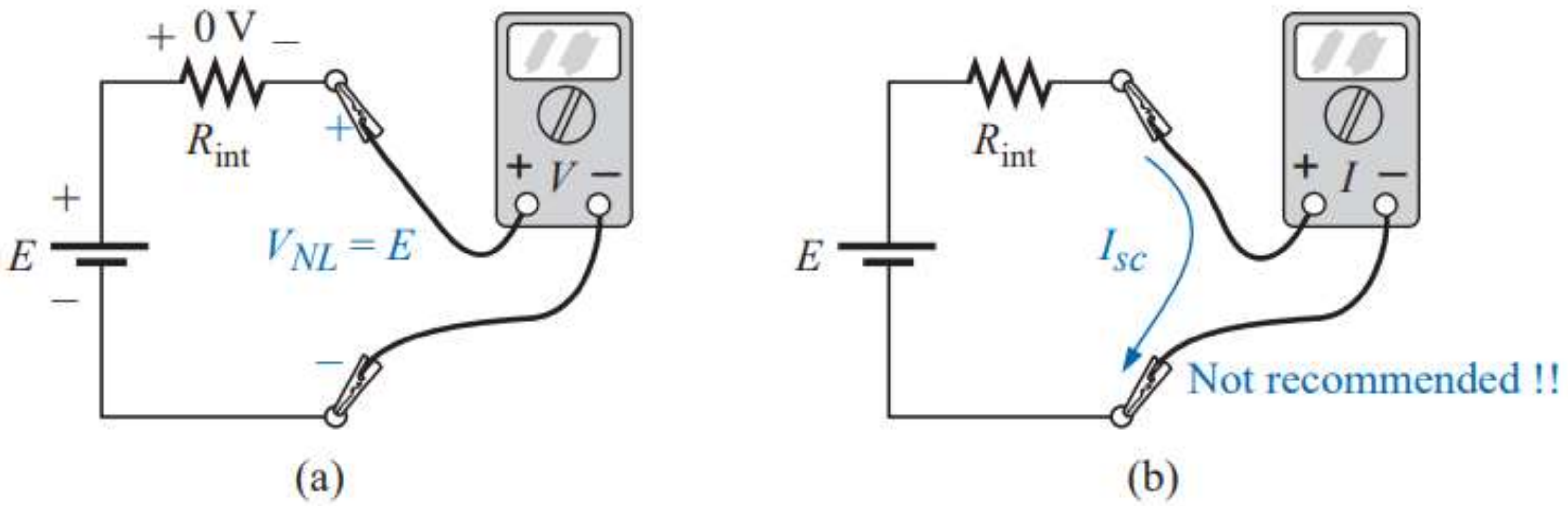


FIG. 5.61

(a) Measuring the no-load voltage E; (b) measuring the short-circuit current.

NO LOAD VOLTAGE vs LOAD VOLTAGE

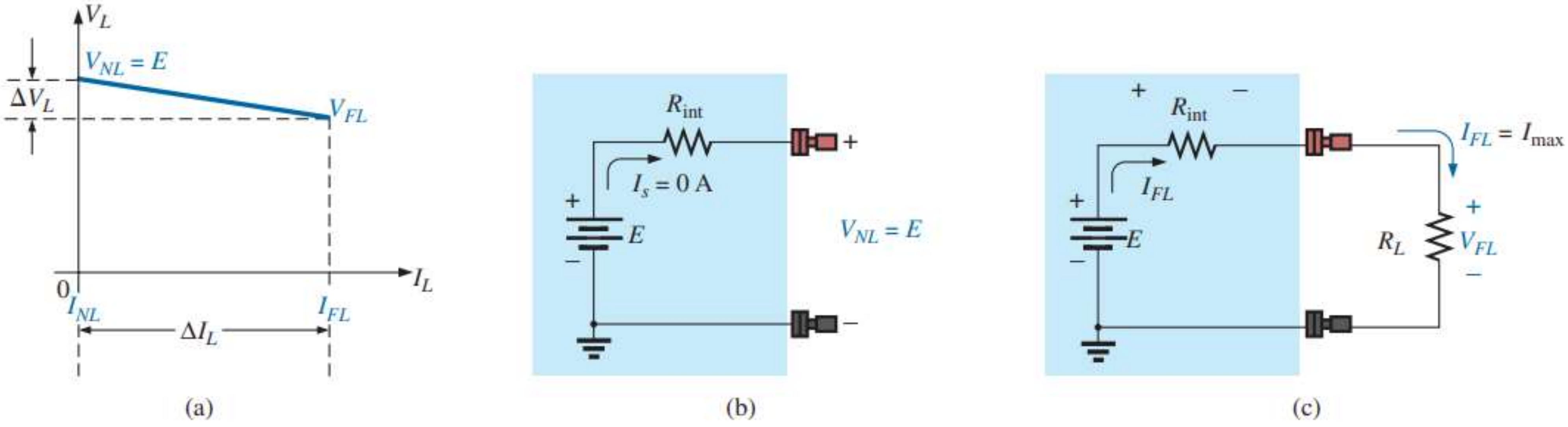
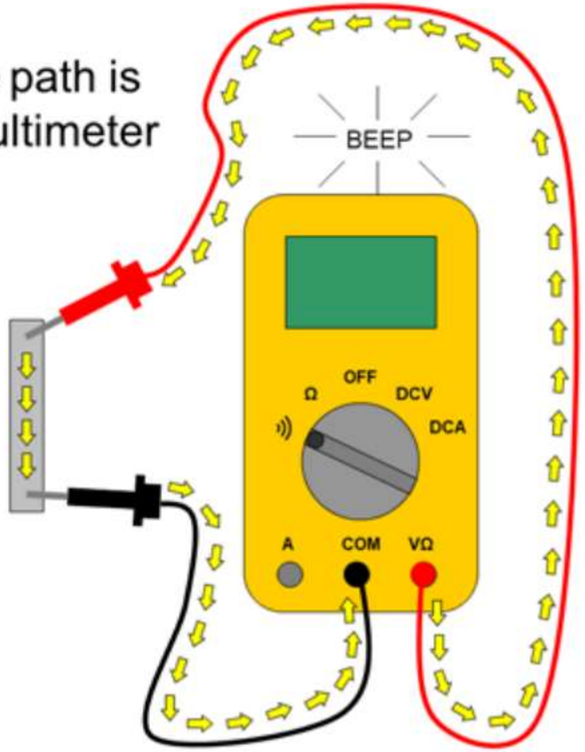


FIG. 5.73

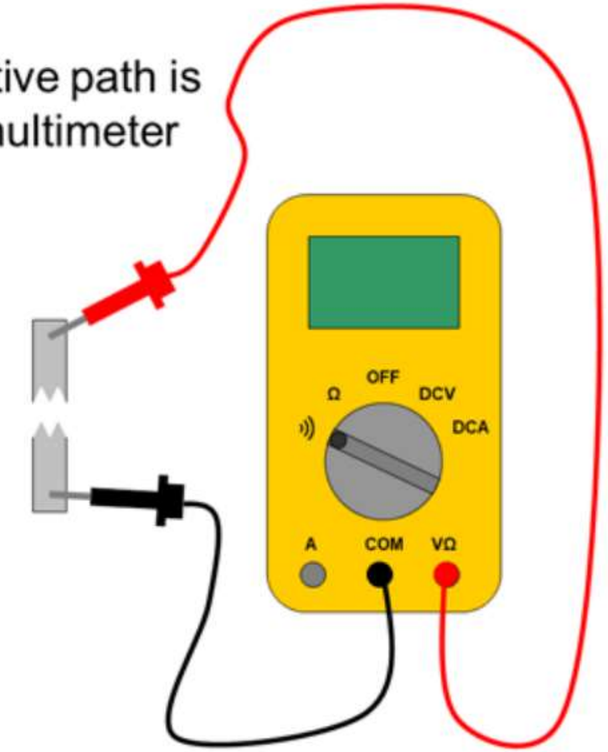
Defining the properties of importance for a power supply.

MEASUREMENT TECHNIQUES

If a conductive path is formed, the multimeter will beep.

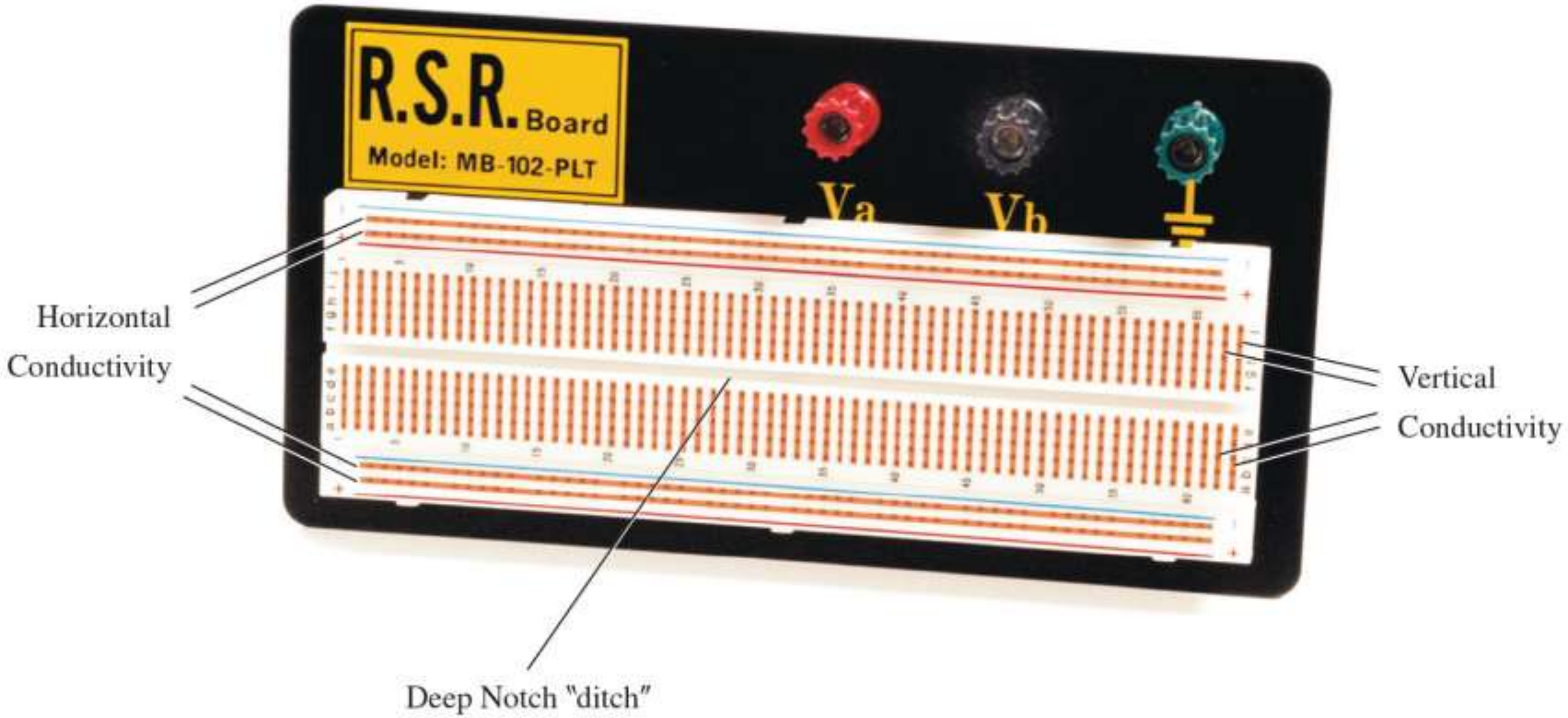


If the conductive path is broken, the multimeter will not beep.



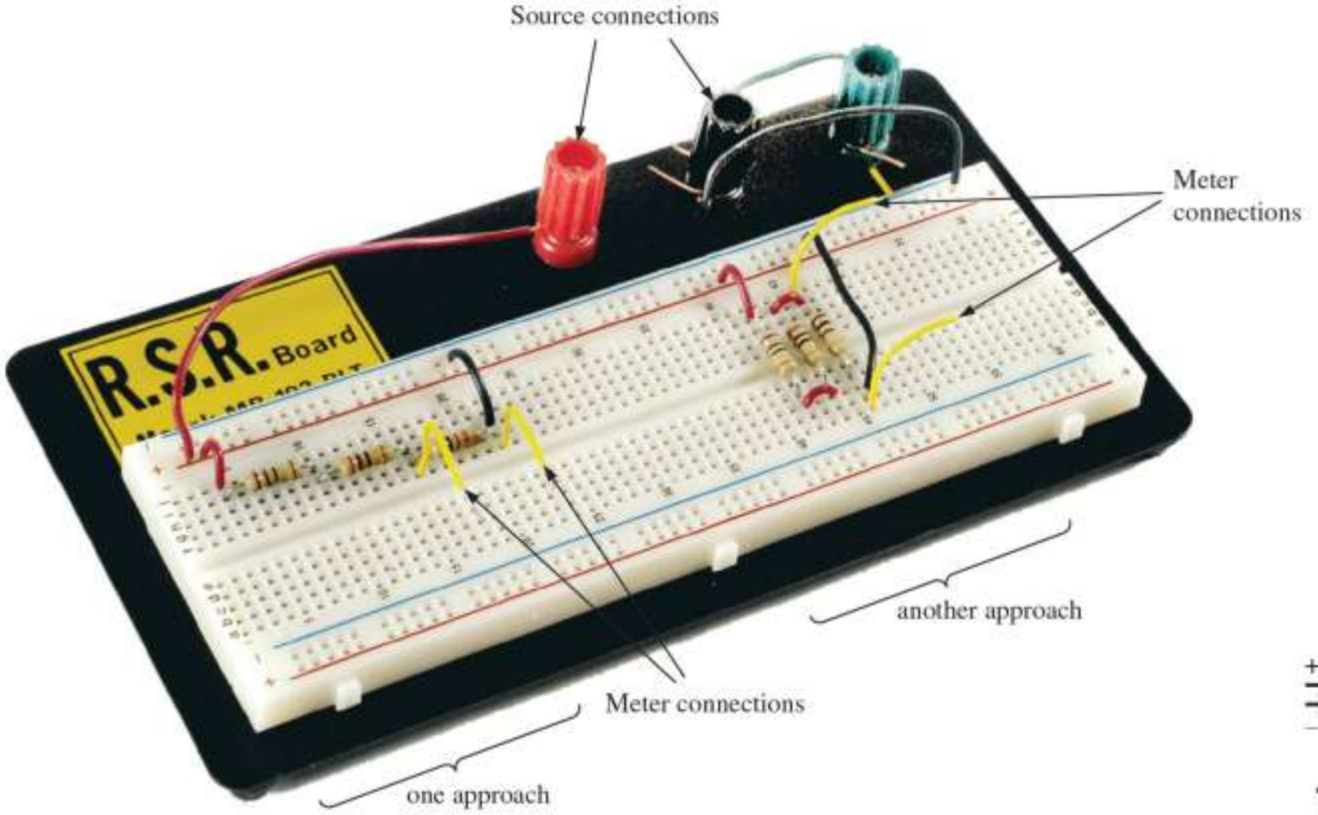
Protoboards (Breadboards) (2 of 3)

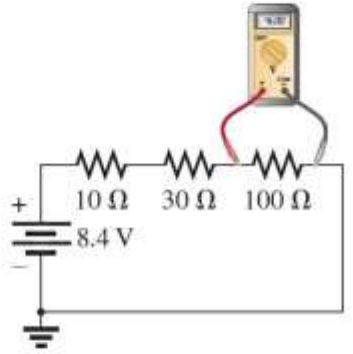
Fig. 5.80 *Protoboard with areas of conductivity defined using two different approaches.*



Protoboards (Breadboards) (3 of 3)

Fig. 5.81 *Two setups for the network in Fig. 5.14 on a protoboard with yellow leads added to each configuration to measure voltage V_3 with a voltmeter.*





Problems

3. Find the total resistance R_T for each configuration in Fig. 5.89. Note that only standard resistor values were used.

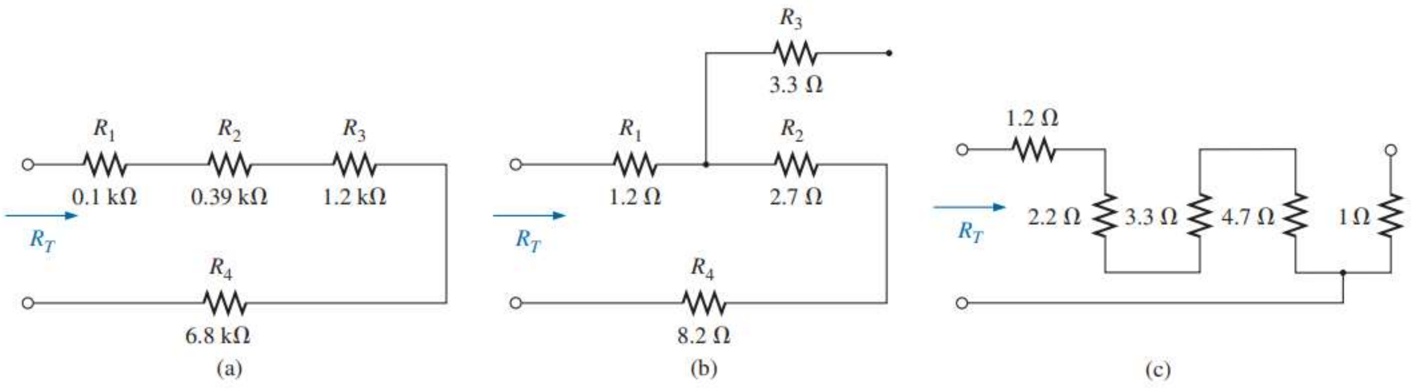


FIG. 5.89
Problem 3.

Problems

9. What is the ohmmeter reading for each configuration in Fig. 5.95?

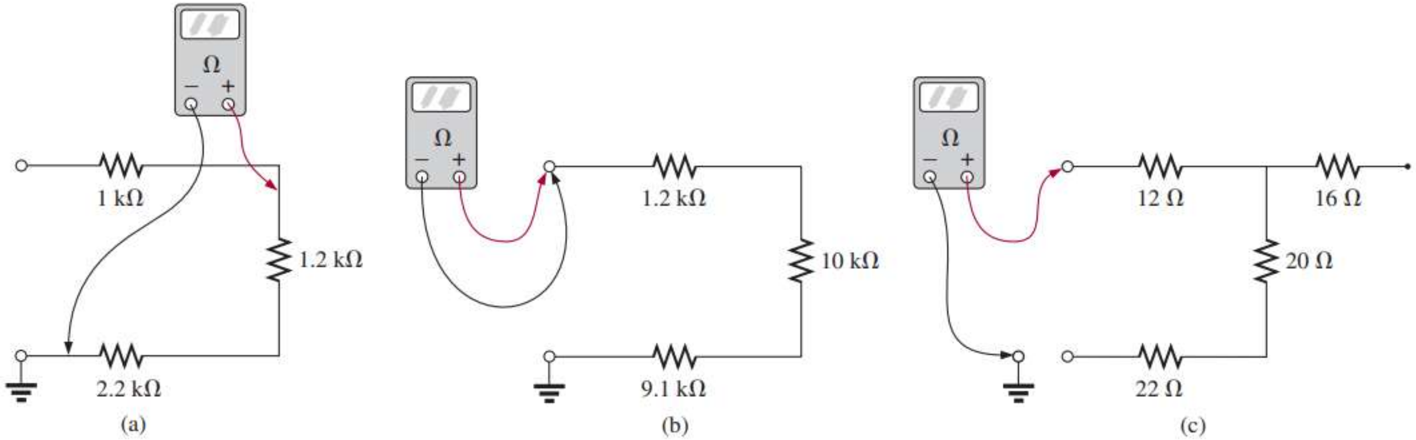


FIG. 5.95
Problem 9.

Problems

10. For the series configuration in Fig. 5.96, constructed of standard values:
    a. Find the total resistance.
    b. Calculate the current.
    c. Find the voltage across each resistive element.
    d. Calculate the power delivered by the source.
    e. Find the power delivered to the 20 Ω resistor.

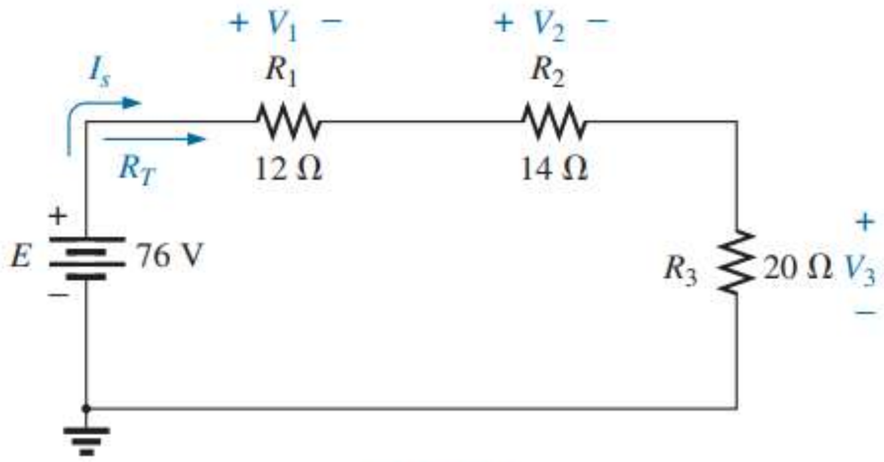
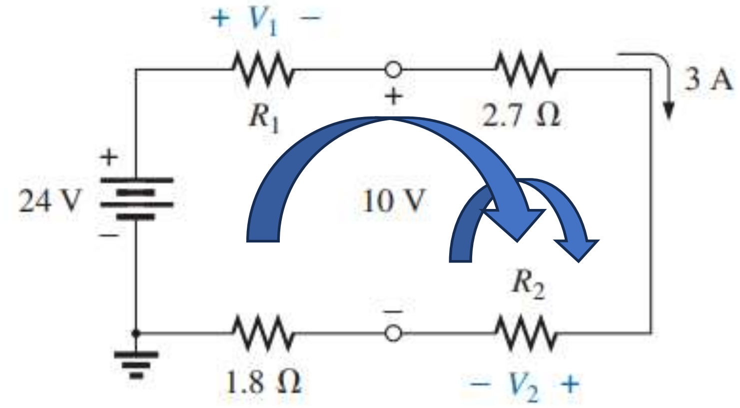


FIG. 5.96
Problem 10.

Problems

27. Using Kirchhoff's voltage law, find the unknown voltages for the configurations in Fig. 5.113.



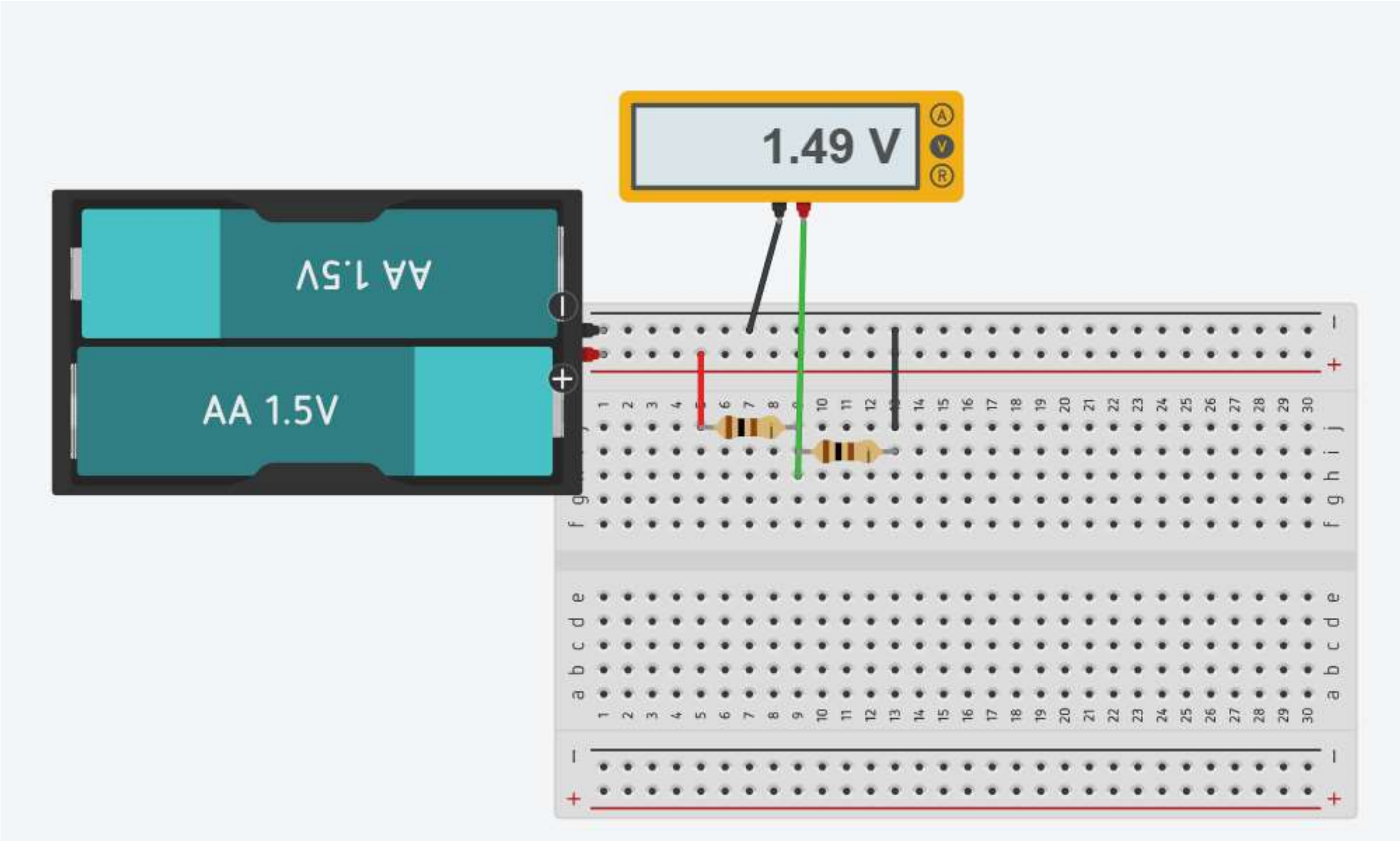
(a)

KVL1
I=3A
-24 + 3.R1 + 3x2.7 + 3.R2 +3x1.8 = 0

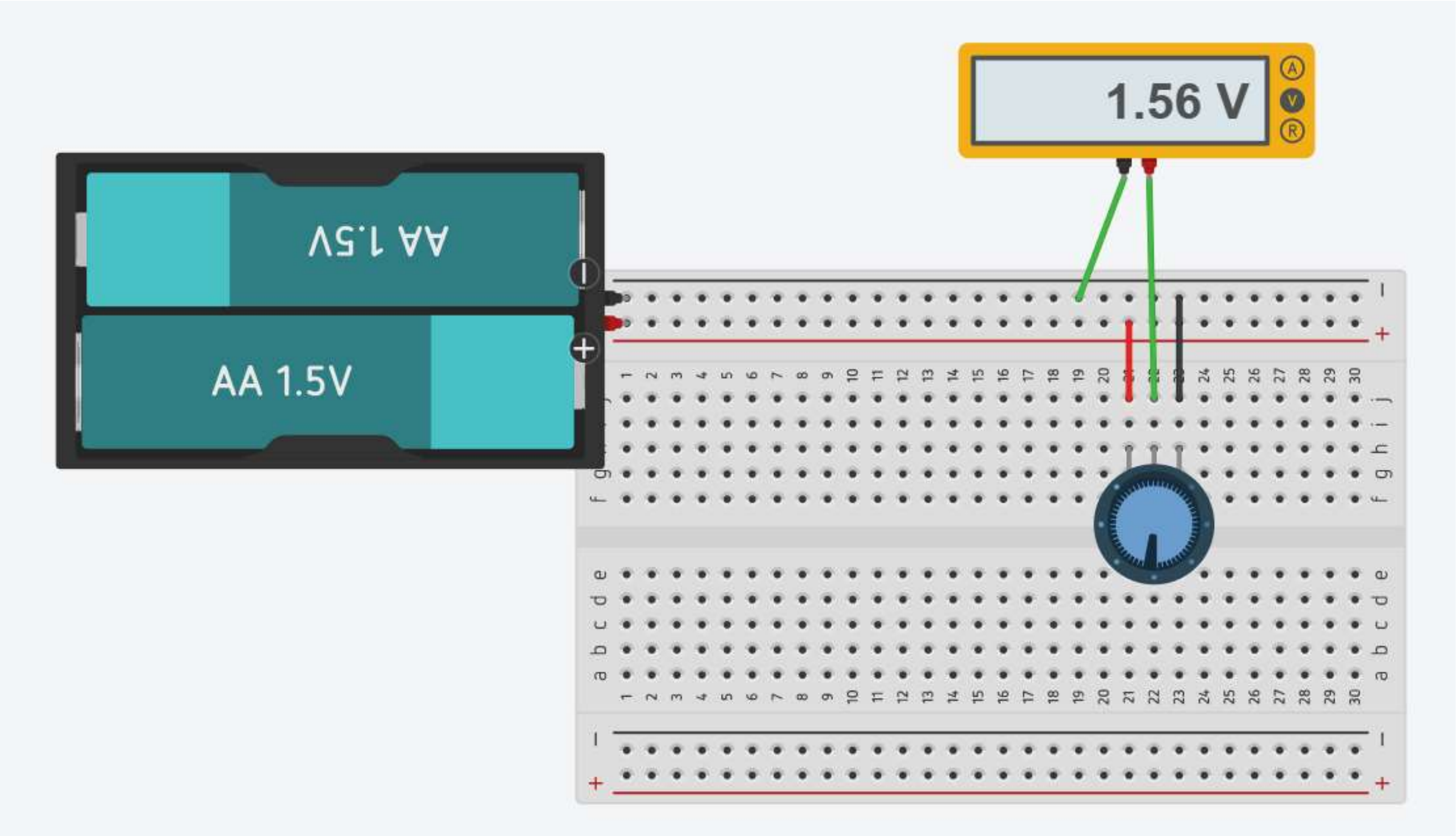
KVL2 in the right loop
-10 + 3x2.7V + 3.R2 = 0
-10 + 8.1 + 3.R2 = 0
R2=1.9/3=1.64 ohm
V2=1.9V

use R2 in KVL1
-24+V1+8.1+1.9+5.4=0
V1=8.6V
R1=8.6/3=2.87 ohm

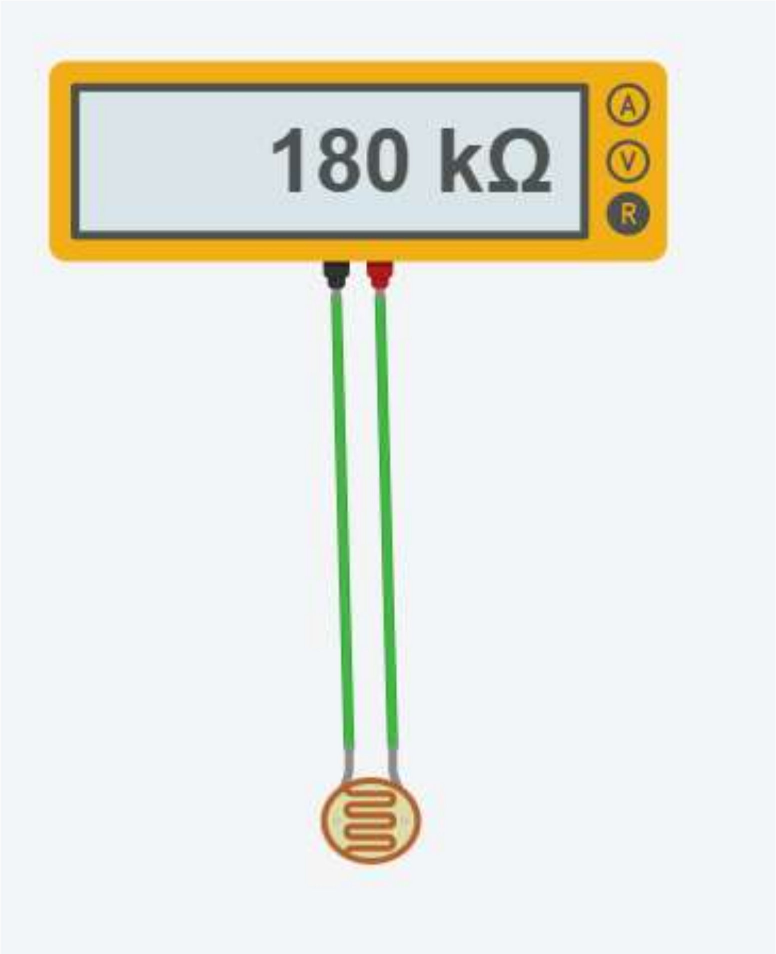
Voltage Divider



Potentiometer

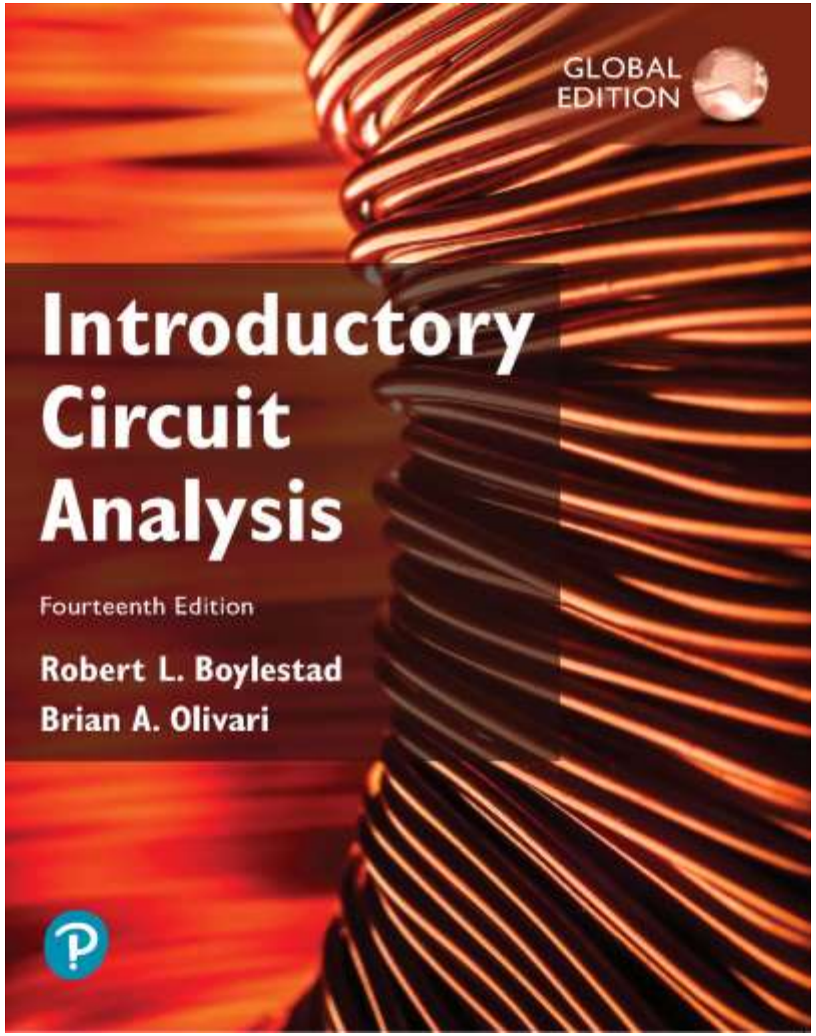


Temperature Measurement PT100, LDR



Introductory Circuit Analysis

Fourteenth Edition, Global Edition

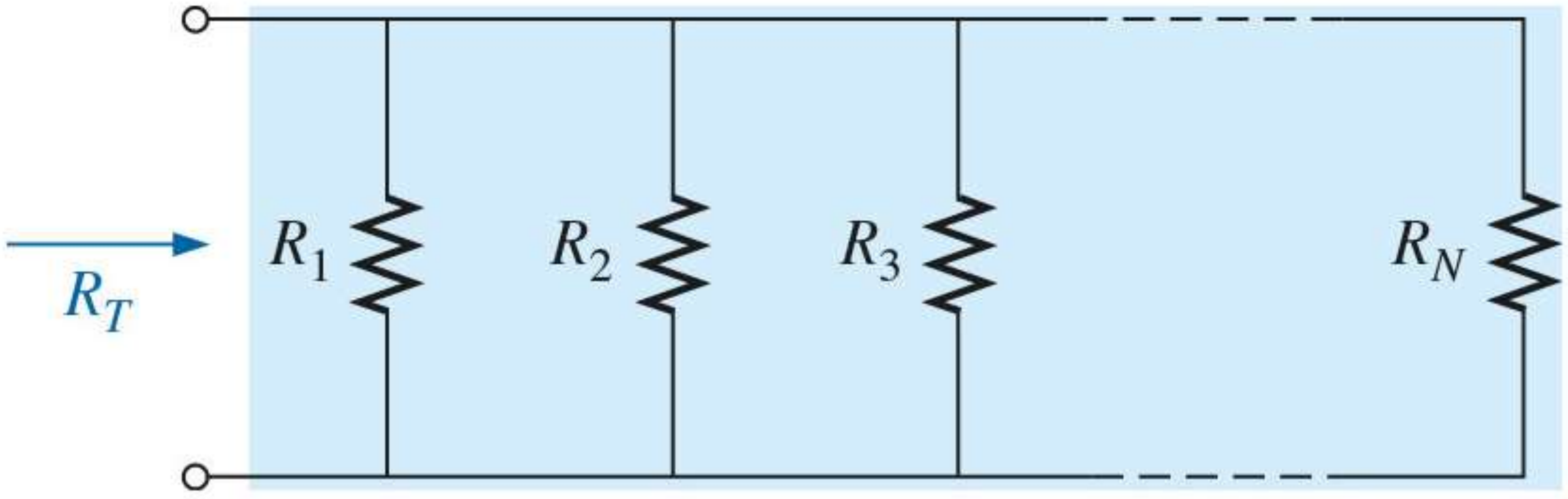


Chapter 6

Parallel dc Circuits

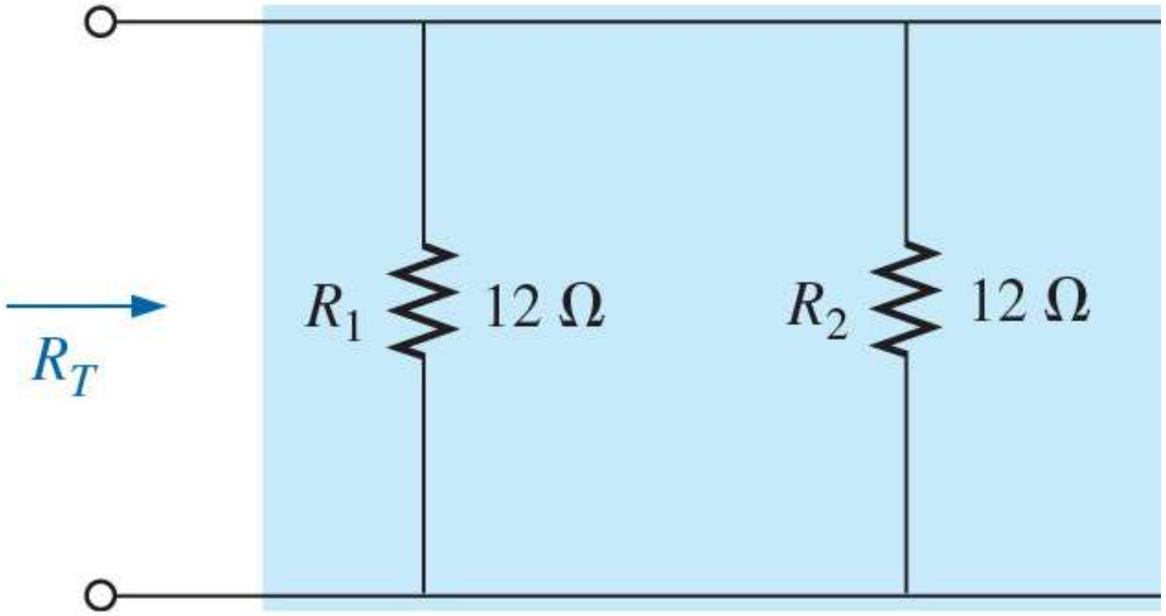
Parallel Resistors (4 of 9)

Fig. 6.3 *Parallel combination of resistors.*



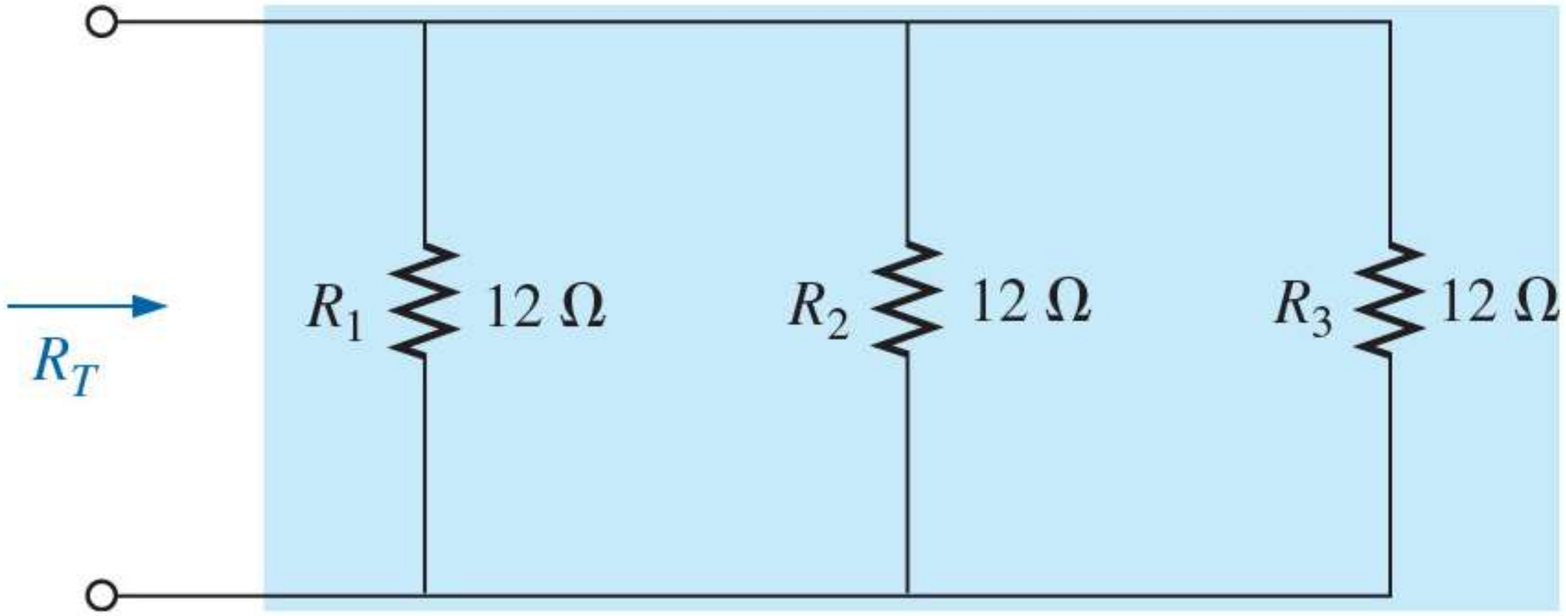
$$\boxed{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_N}} \qquad (6.2)$$

Parallel Resistors: Special Case- Equal Parallel Resistors



$$
\begin{aligned}
1/RT &= 1/12 + 1/12 \\
&= 2/12 \\
&= 1/6 \\
RT &= 6 \text{ ohm}
\end{aligned}
$$

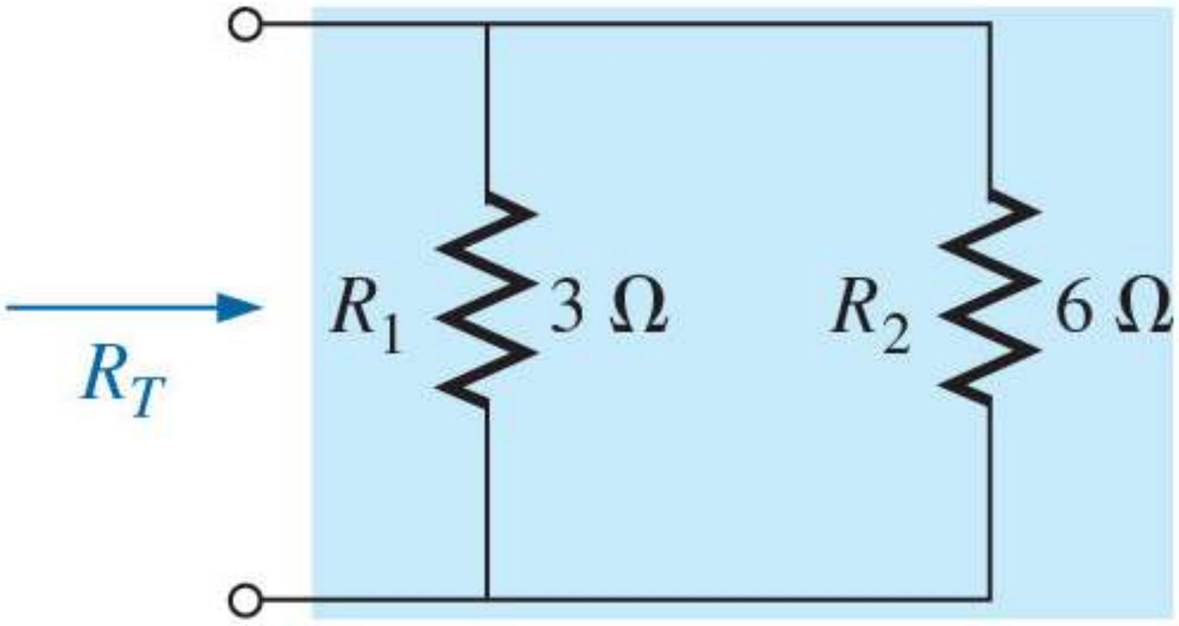
Parallel Resistors: Special Case- Equal Parallel Resistors



1/RT = 1/12 + 1/12 + 1/12
= 3/12
= 1/4
RT = 4 ohm

Parallel Resistors (5 of 9)

Fig. 6.4 *Parallel resistors for Example 6.1.*



$1/RT = 1/3 + 1/6$

$= 3/6$

$= 1/2$

$RT = 2$ ohm

RT is always smaller than the smallest one in parallel resistors

Parallel Resistors

EXAMPLE 6.8 Determine the value of R_2 in Fig. 6.15 to establish a total resistance of 9 kΩ.

Solution:

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$

$$R_T(R_1 + R_2) = R_1 R_2$$

$$R_T R_1 + R_T R_2 = R_1 R_2$$

$$R_T R_1 = R_1 R_2 - R_T R_2$$

$$R_T R_1 = (R_1 - R_T) R_2$$

and

$$\boxed{R_2 = \frac{R_T R_1}{R_1 - R_T}} \qquad \textbf{(6.7)}$$

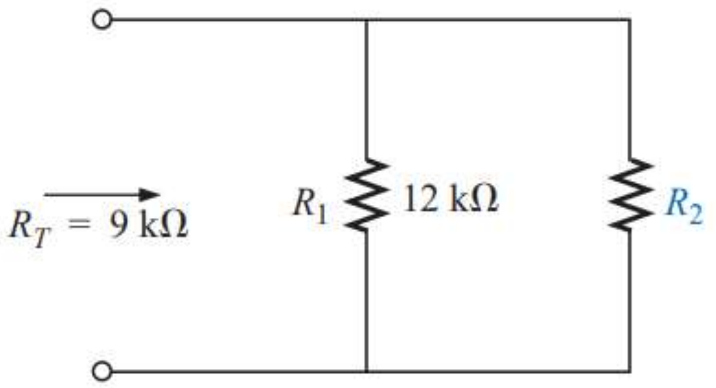


FIG. 6.15
Example 6.8.

Kirchhoff’s Current Law (2 of 10)

- Kirchhoff is also credited with developing the following equally important relationship between the currents of a network, called Kirchhoff’s current law (KCL):
  - The algebraic sum of the currents entering and leaving a junction (or region) of a network is zero.

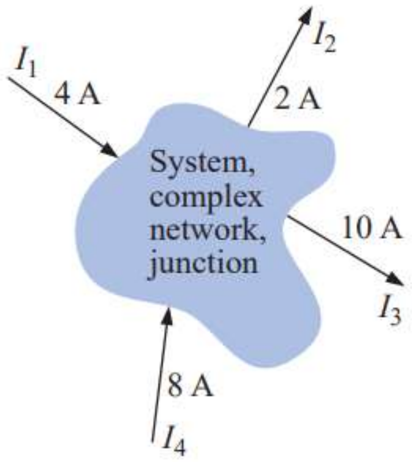


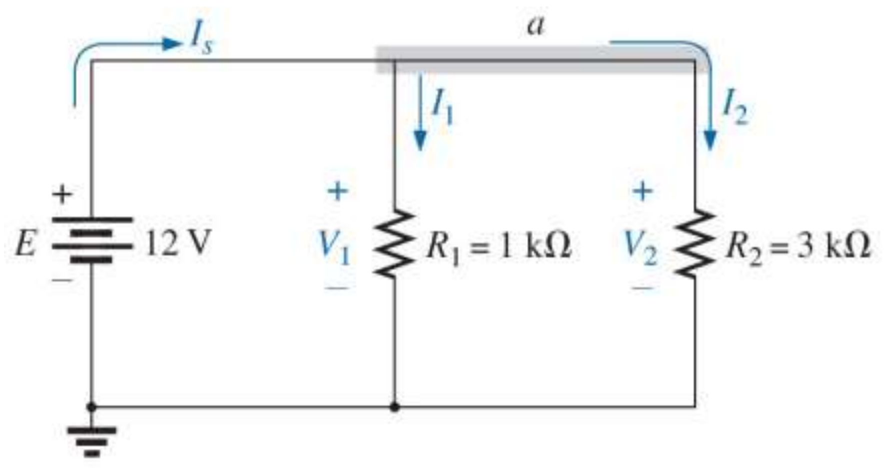
FIG. 6.25
Introducing Kirchhoff’s current law.

$$\boxed{\Sigma I_{\text{entering}} = \Sigma I_{\text{leaving}}} \tag{6.8}$$

Parallel Circuits (1 of 8)

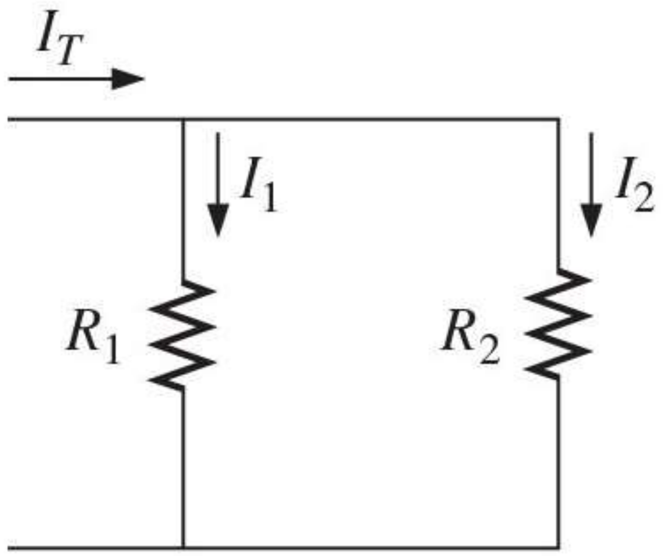
Fig. 6.18 *Parallel network.*

- A parallel circuit can now be established by connecting a supply across a set of parallel resistors as shown in Fig. 6.18.
- The positive terminal of the supply is directly connected to the top of each resistor, while the negative terminal is connected to the bottom of each resistor.



Parallel Circuits (5 of 8)

- For single-source parallel networks, the source current (I_s) is always equal to the sum of the individual branch currents.



$$I_T = I_1 + I_2$$

(a)

Parallel Circuits

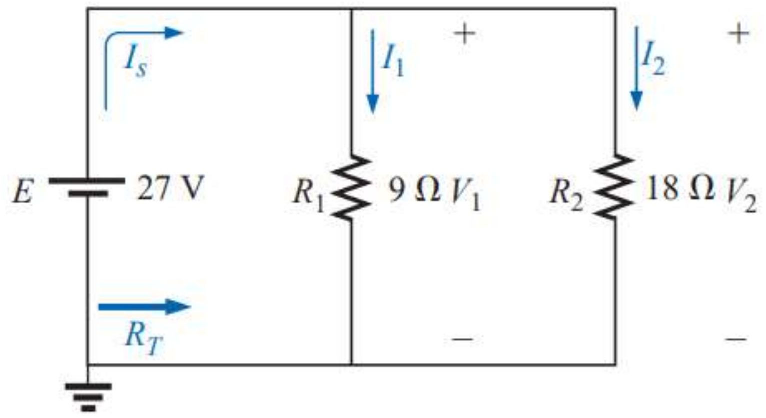


FIG. 6.22
Example 6.11.

EXAMPLE 6.11 For the parallel network of Fig. 6.22:

a. Calculate R_T.
b. Determine I_s.
c. Calculate I_1 and I_2, and demonstrate that $I_s = I_1 + I_2$.
d. Determine the power to each resistive load.
e. Determine the power delivered by the source, and compare it to the total power dissipated by the resistive elements.

Solutions:

a. $$R_T = \frac{R_1R_2}{R_1 + R_2} = \frac{(9\ \Omega)(18\ \Omega)}{9\ \Omega + 18\ \Omega} = \frac{162\ \Omega}{27} = \mathbf{6\ \Omega}$$

b. $$I_s = \frac{E}{R_T} = \frac{27\ \text{V}}{6\ \Omega} = \mathbf{4.5\ A}$$

c. $$I_1 = \frac{V_1}{R_1} = \frac{E}{R_1} = \frac{27\ \text{V}}{9\ \Omega} = \mathbf{3\ A}$$

$$I_2 = \frac{V_2}{R_2} = \frac{E}{R_2} = \frac{27\ \text{V}}{18\ \Omega} = \mathbf{1.5\ A}$$

$$I_s = I_1 + I_2$$

$$4.5\ \text{A} = 3\ \text{A} + 1.5\ \text{A}$$

$$\mathbf{4.5\ A} = \mathbf{4.5\ A} \quad \text{(checks)}$$

Parallel Circuits

EXAMPLE 6.12 Given the information provided in Fig. 6.23:

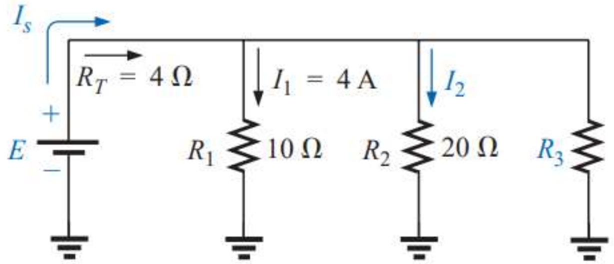


FIG. 6.23
Example 6.12.

a. Determine R_3.
b. Calculate E.
c. Find I_s.
d. Find I_2.
e. Determine P_2.

Solutions:

a. $$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{4\ \Omega} = \frac{1}{10\ \Omega} + \frac{1}{20\ \Omega} + \frac{1}{R_3}$$

$$0.25\text{ S} = 0.1\text{ S} + 0.05\text{ S} + \frac{1}{R_3}$$

$$0.25\text{ S} = 0.15\text{ S} + \frac{1}{R_3}$$

$$\frac{1}{R_3} = 0.1\text{ S}$$

$$R_3 = \frac{1}{0.1\text{ S}} = \mathbf{10\ \Omega}$$

b. $E = V_1 = I_1R_1 = (4\text{ A})(10\ \Omega) = \mathbf{40\ V}$

c. $$I_s = \frac{E}{R_T} = \frac{40\text{ V}}{4\ \Omega} = \mathbf{10\ A}$$

d. $$I_2 = \frac{V_2}{R_2} = \frac{E}{R_2} = \frac{40\text{ V}}{20\ \Omega} = \mathbf{2\ A}$$

Parallel Circuits

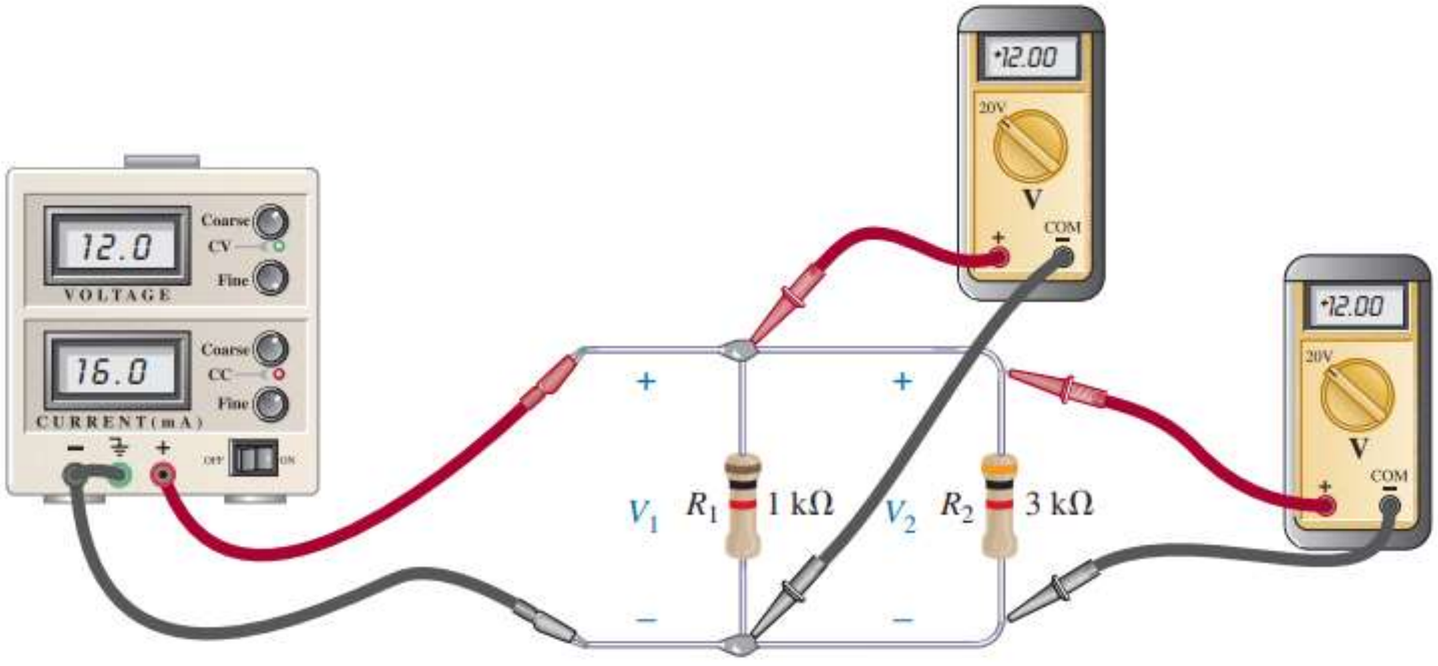


FIG. 6.25
Measuring the voltages of a parallel dc network.

Parallel Circuits

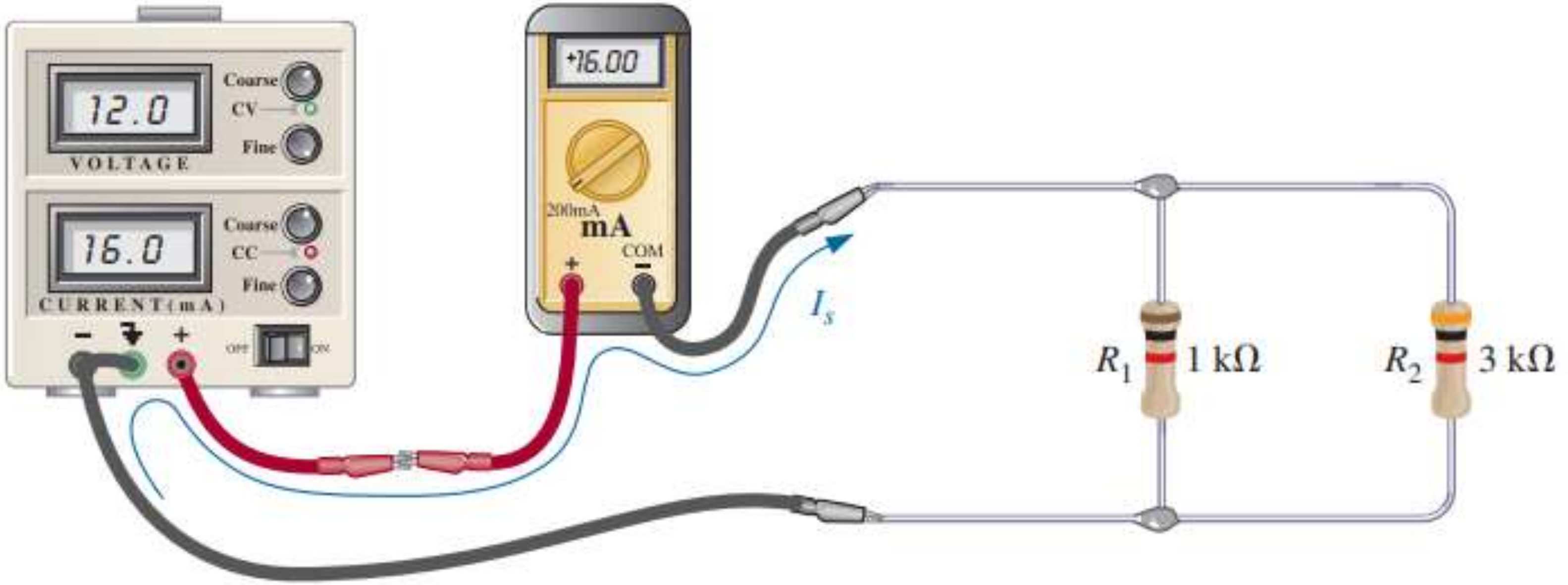


FIG. 6.26
Measuring the source current of a parallel network.

Parallel Circuits

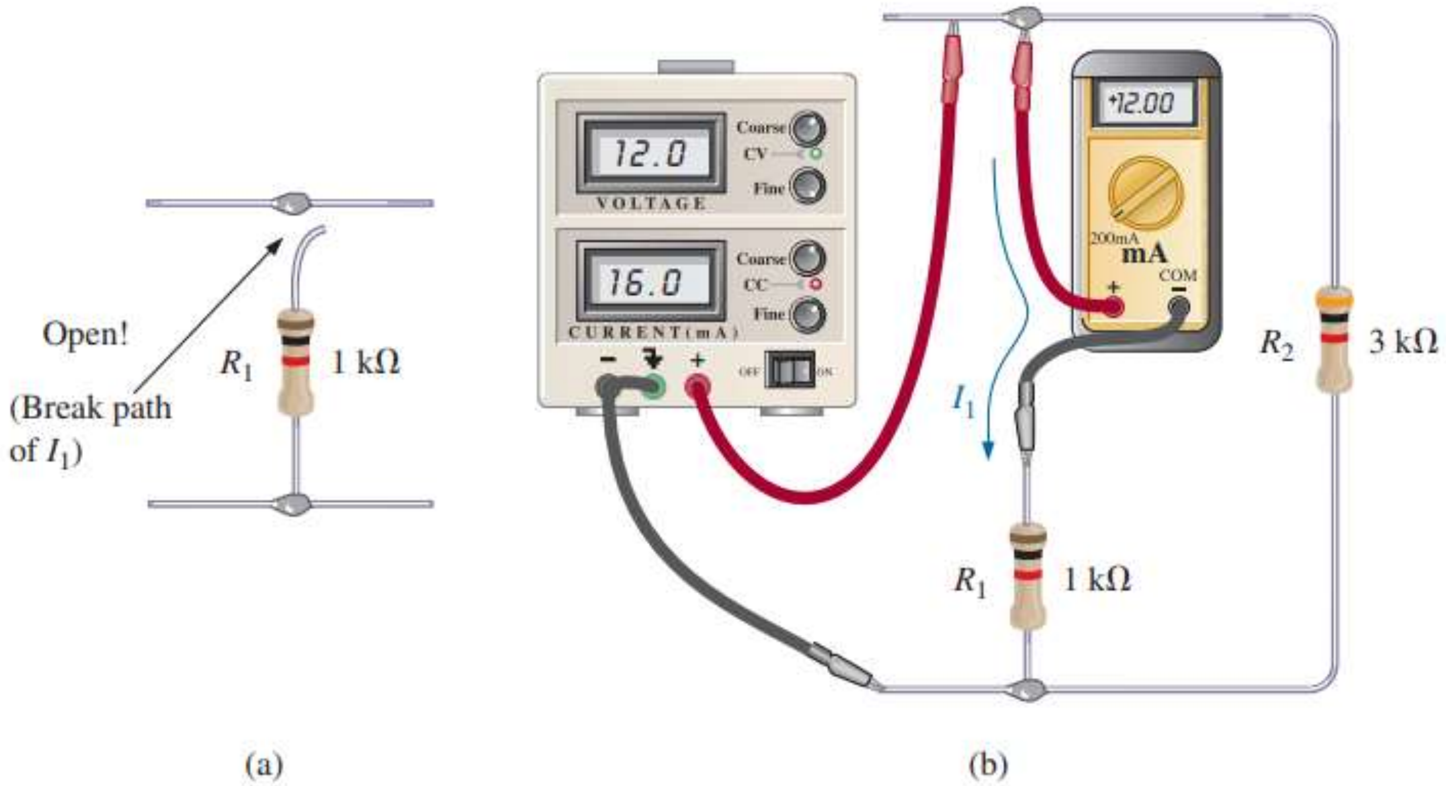


FIG. 6.27
Measuring the current through resistor R_1.

Kirchhoff's Current Law (2 of 10)

- Kirchhoff is also credited with developing the following equally important relationship between the currents of a network, called Kirchhoff's current law (KCL):
  - The algebraic sum of the currents entering and leaving a junction (or region) of a network is zero.

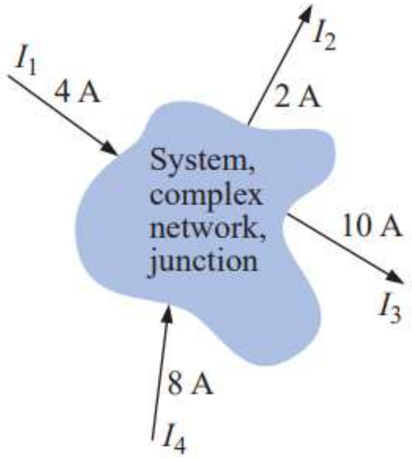


FIG. 6.25
Introducing Kirchhoff's current law.

$$\boxed{\Sigma\, I_{\text{entering}} = \Sigma\, I_{\text{leaving}}} \tag{6.8}$$

Kirchhoff’s Current Law

Current seeks the path of least resistance.

That is,

1. More current passes through the smaller of two parallel resistors.
2. The current entering any number of parallel resistors divides into these resistors as the inverse ratio of their ohmic values. This relationship is depicted in Fig. 6.39.

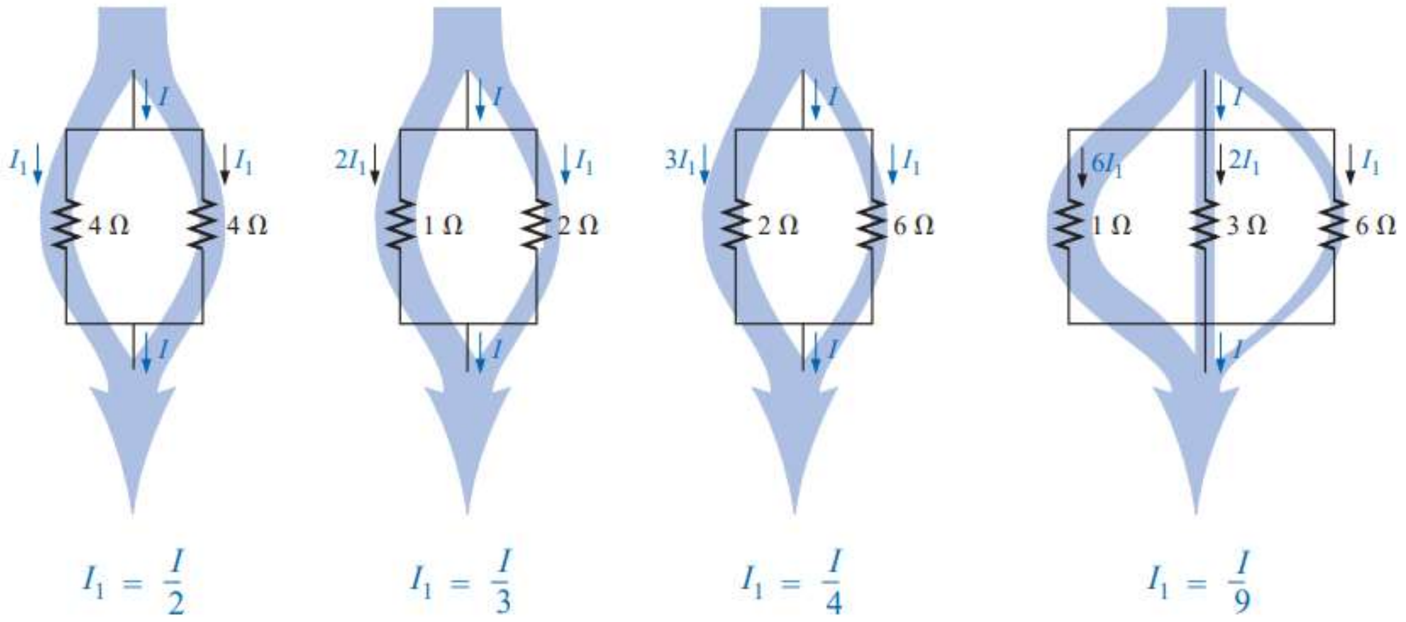


FIG. 6.39
Current division through parallel branches.

Kirchhoff's Current Law

EXAMPLE 6.19 For the parallel dc network in Fig. 6.35:

a. Determine the source current I_s.
b. Find the source voltage E.
c. Determine R_3.
d. Calculate R_T.

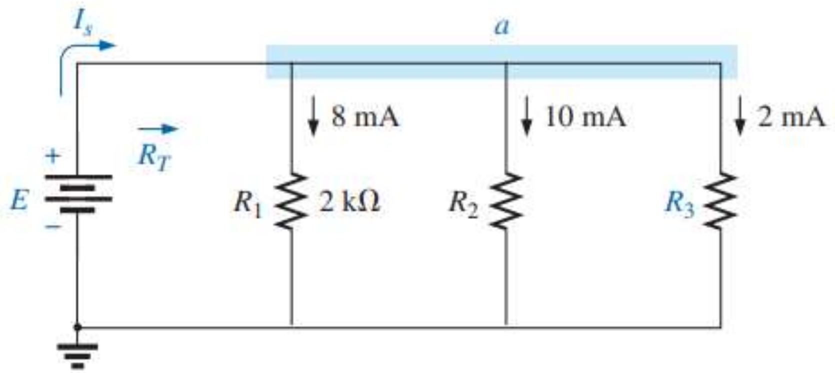


FIG. 6.35
Parallel network for Example 6.19.

Solutions:

a. First apply Eq. (6.13) at node a. Although node a in Fig. 6.35 may not initially appear as a single junction, it can be redrawn as shown in Fig. 6.36, where it is clearly a common point for all the branches.

The result is

$$\Sigma I_i = \Sigma I_o$$

$$I_s = I_1 + I_2 + I_3$$

Substituting values: $I_s = 8\text{ mA} + 10\text{ mA} + 2\text{ mA} = \mathbf{20\text{ mA}}$

Note in this solution that you do not need to know the resistor values or the voltage applied. The solution is determined solely by the current levels.

b. Applying Ohm's law gives

$$E = V_1 = I_1R_1 = (8\text{ mA})(2\text{ k}\Omega) = \mathbf{16\text{ V}}$$

c. Applying Ohm's law in a different form gives

$$R_3 = \frac{V_3}{I_3} = \frac{E}{I_3} = \frac{16\text{ V}}{2\text{ mA}} = \mathbf{8\text{ k}\Omega}$$

d. Applying Ohm's law again gives

$$R_T = \frac{E}{I_s} = \frac{16\text{ V}}{20\text{ mA}} = \mathbf{0.8\text{ k}\Omega}$$

Voltage Sources in Parallel

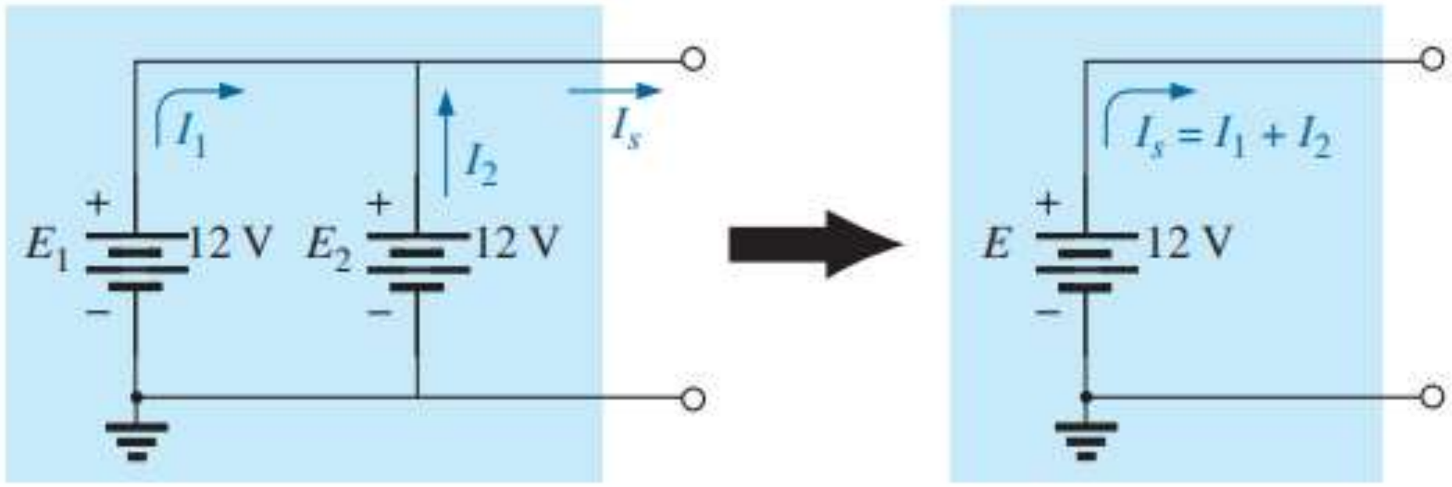
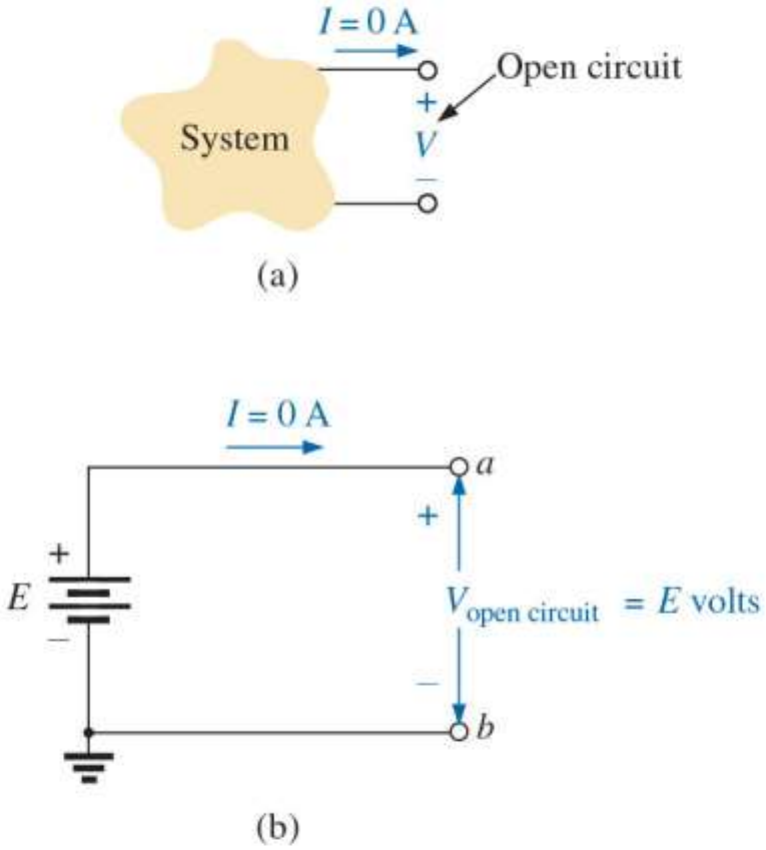


FIG. 6.46
Demonstrating the effect of placing two ideal supplies of the same voltage in parallel.

Open and Short Circuits (3 of 8)

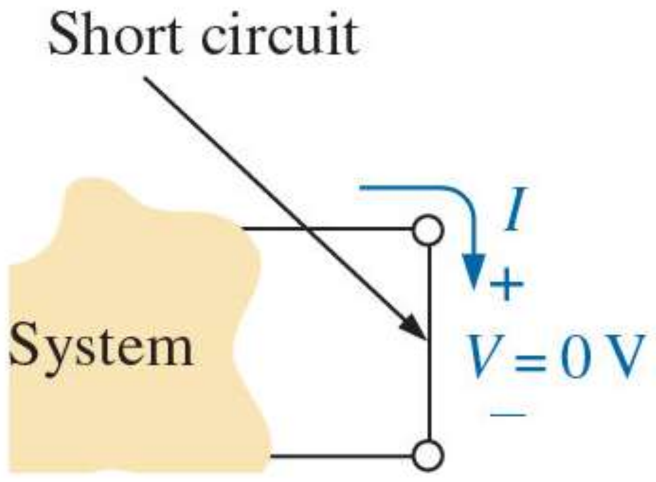
Fig. 6.48 *Defining an open circuit.*



Open and Short Circuits (5 of 8)

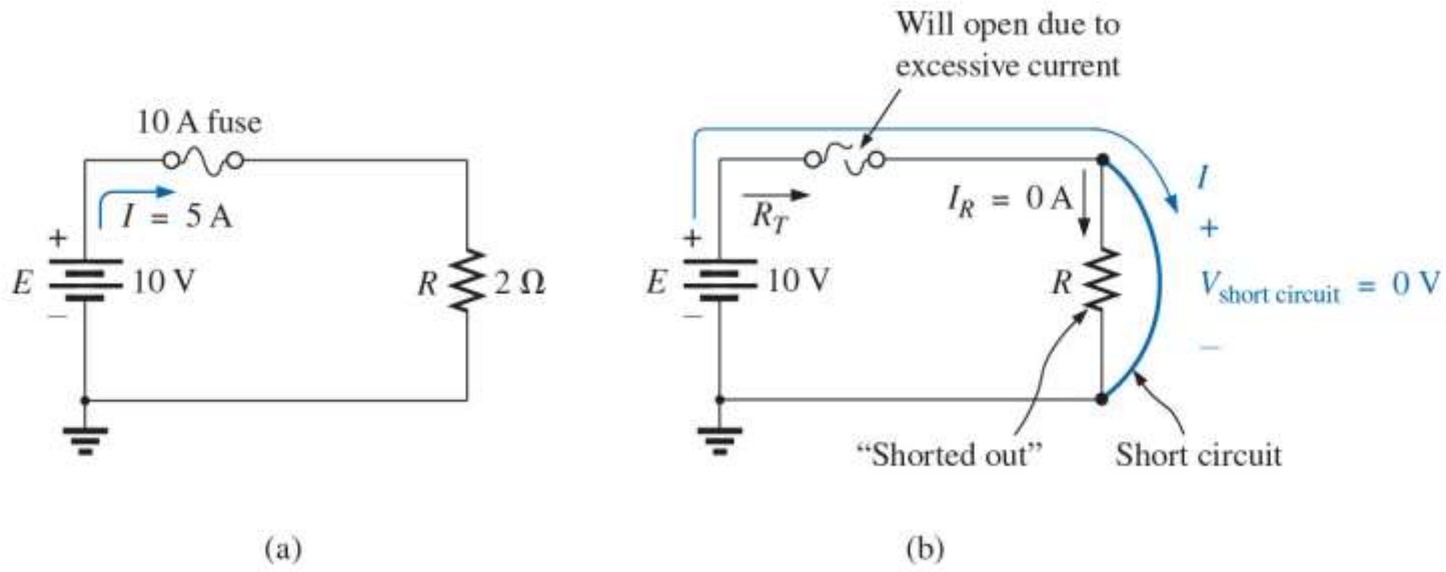
- A short circuit is a very low resistance, direct connection between two terminals of a network.

Fig. 6.50 *Defining a short circuit.*

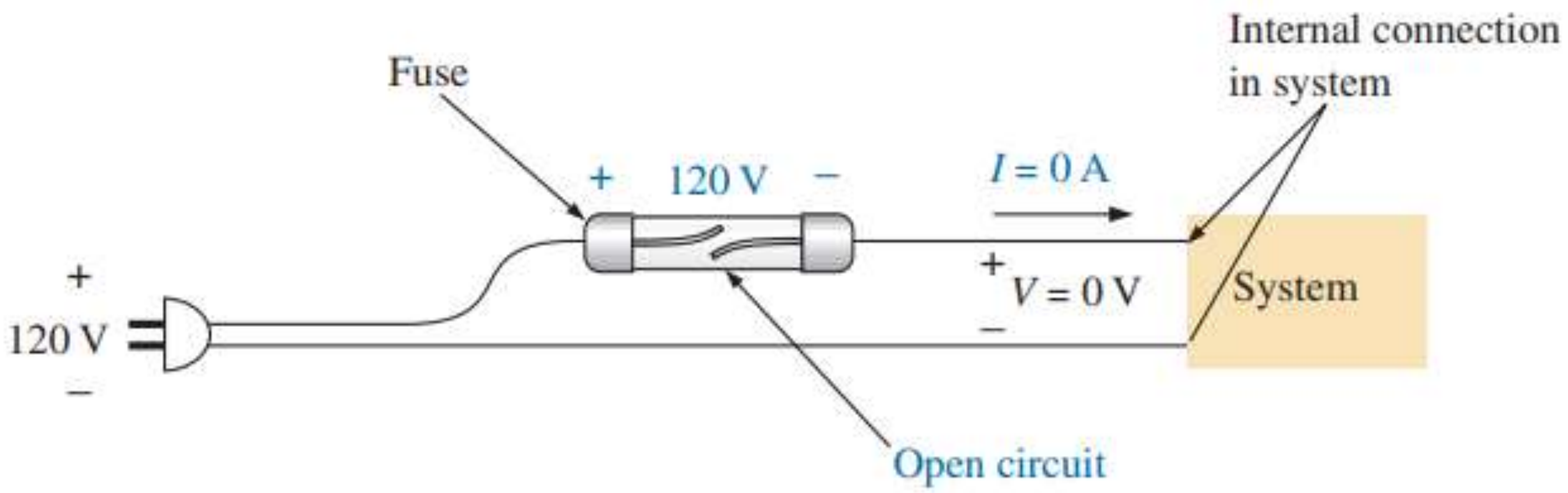


Open and Short Circuits (7 of 8)

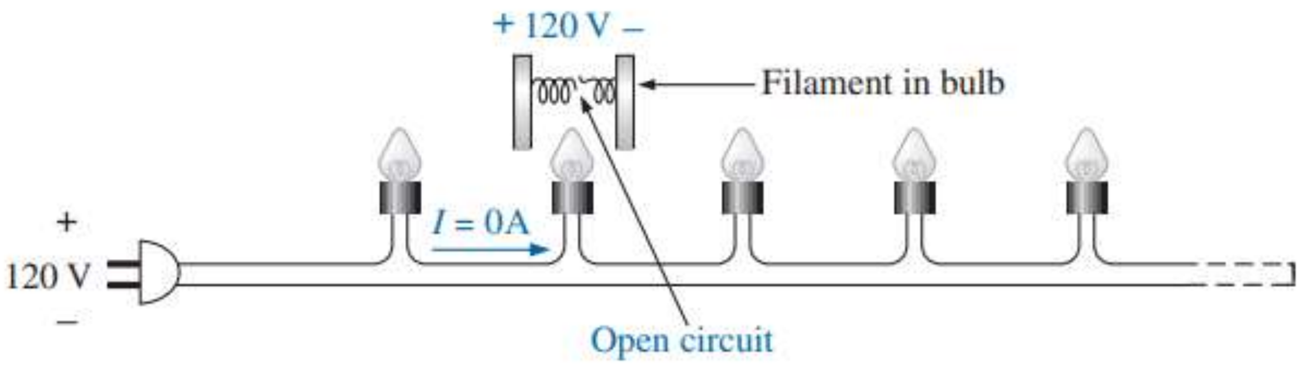
Fig. 6.51 *Demonstrating the effect of a short circuit on current levels.*



Open and Short Circuits (7 of 8)



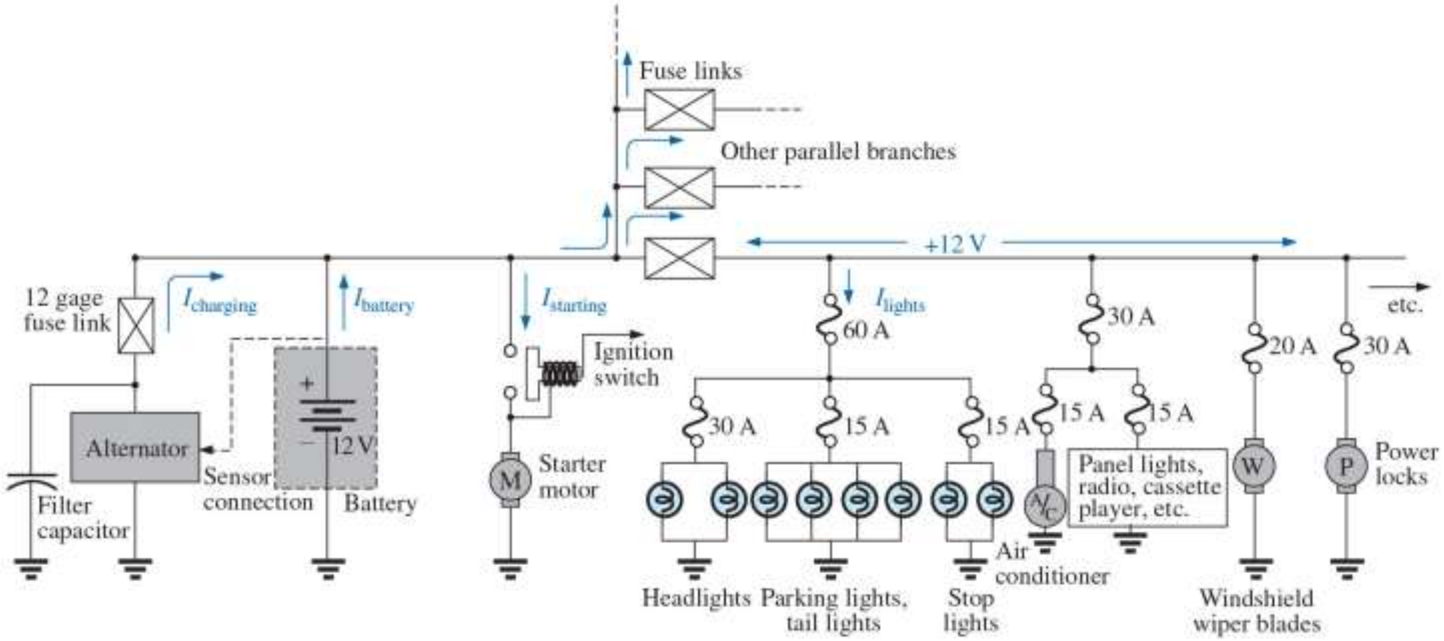
(a)



(c)

Applications Car System (1 of 2)

Fig. 6.57 *Expanded view of an automobile's electrical system.*



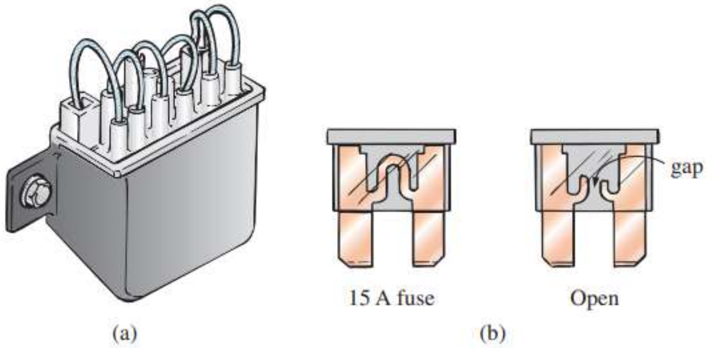
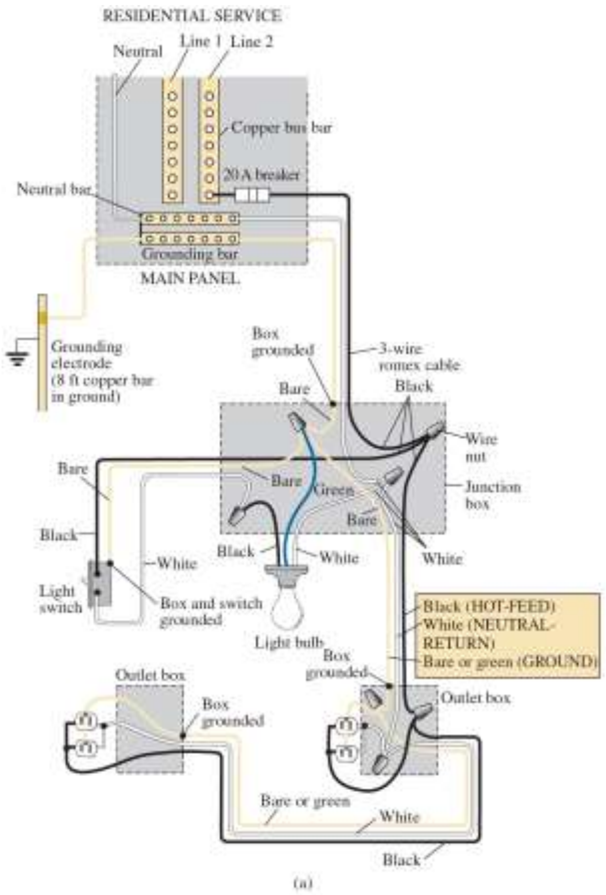
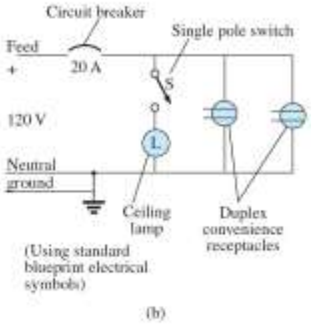


FIG. 6.58
Car fuses: (a) fuse link; (b) plug-in.

Applications House Wiring (1 of 2)

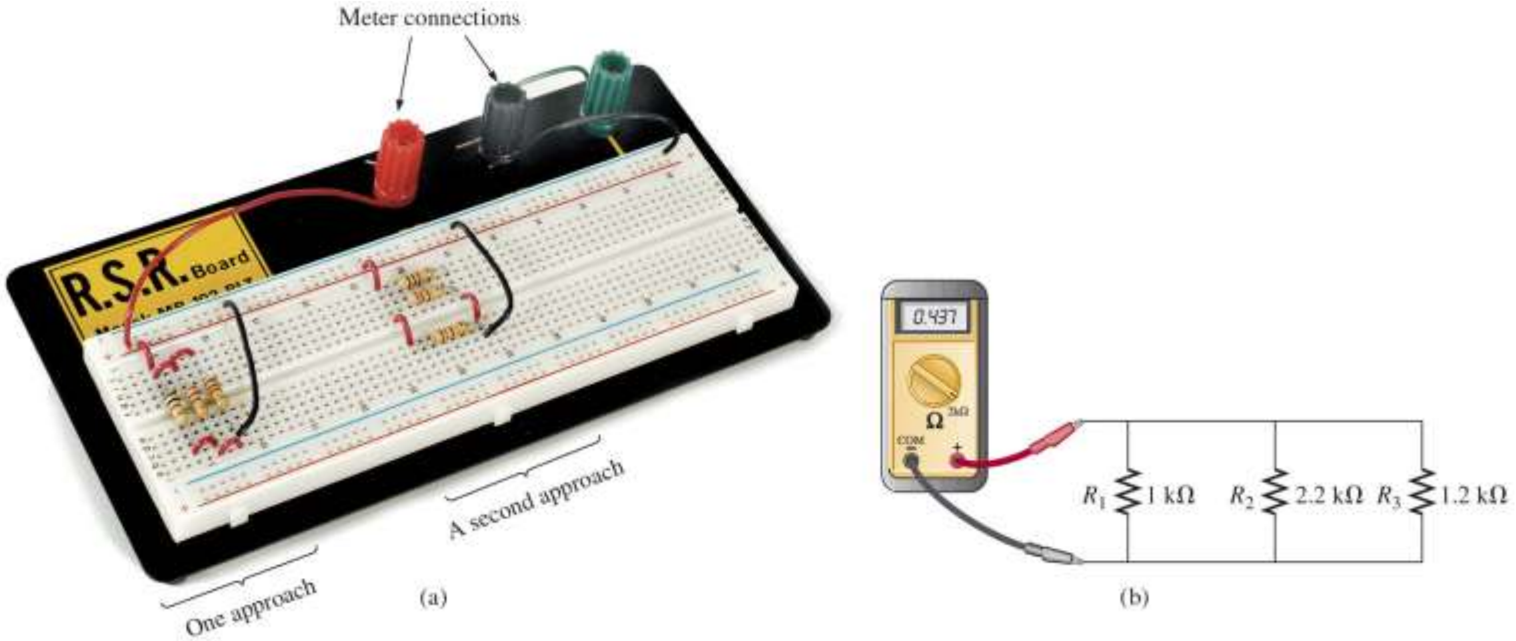
Fig. 6.59 *Single phase of house wiring: (a) physical details; (b) schematic representation.*





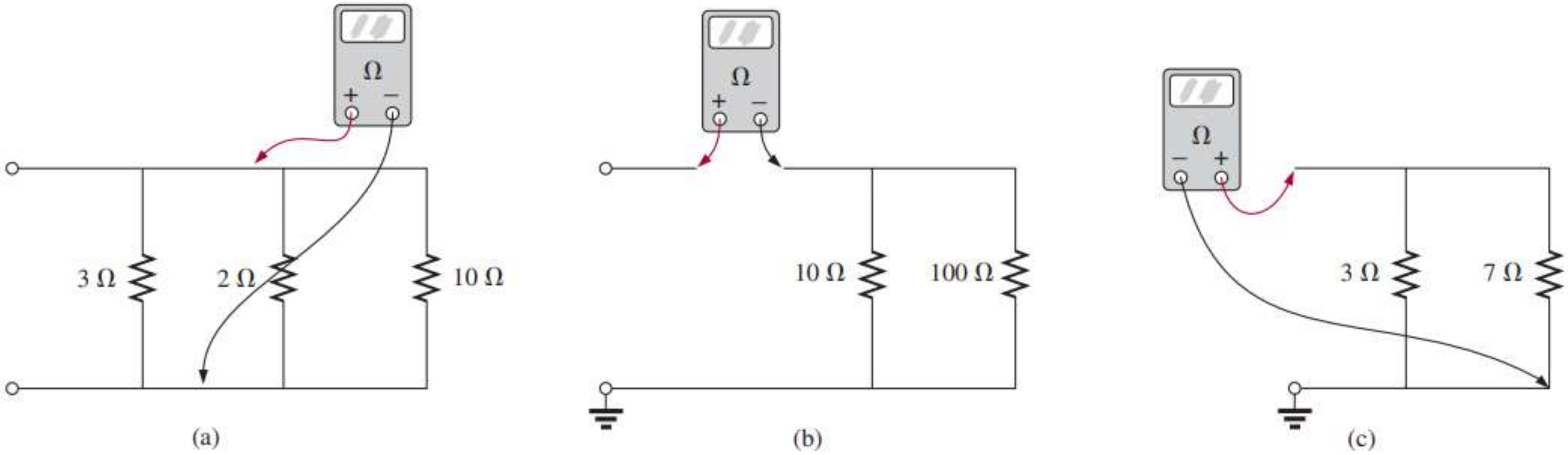
Protoboards (Breadboards)

Fig. 6.56 *Using a protoboard to set up the circuit in Fig. 6.17.*



Problems

10. What is the ohmmeter reading for each configuration in Fig. 6.70?



Problems

12. For the parallel network in Fig. 6.72:

a. Find the total resistance.

b. What is the voltage across each branch?

c. Determine the source current and the current through each branch.

d. Verify that the source current equals the sum of the branch currents.

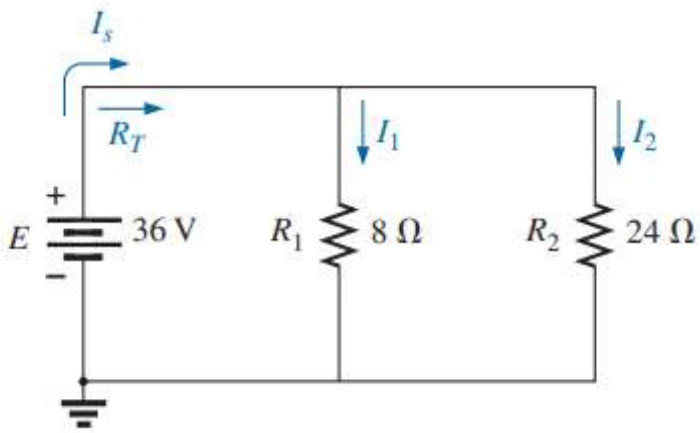


FIG. 6.72
Problem 12.

Problems

17. Use the information in Fig. 6.77 to calculate:

a. The source voltage E.
b. The resistance R_2.
c. The current I_1.
d. The source current I_s.
e. The power supplied by the source.
f. The power supplied to the resistors R_1 and R_2.
g. Compare the power calculated in part (e) to the sum of the power delivered to all the resistors.

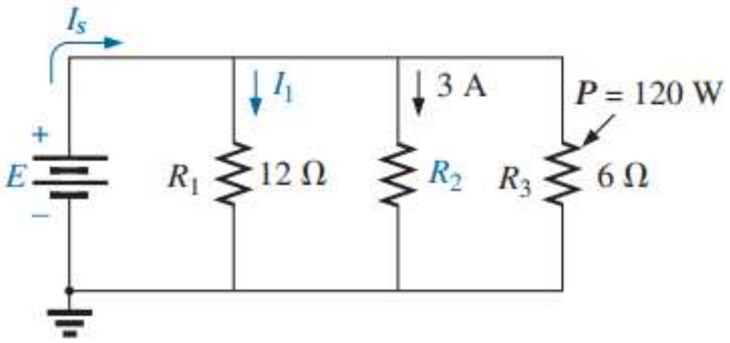


FIG. 6.77
Problem 17.

Problems

25. A portion of a residential service to a home is depicted in Fig. 6.84.
    a. Determine the current through each parallel branch of the system.
    b. Calculate the current drawn from the 120 V source. Will the 20 A breaker trip?
    c. What is the total resistance of the network?
    d. Determine the power delivered by the source. How does it compare to the sum of the wattage ratings appearing in Fig. 6.84?

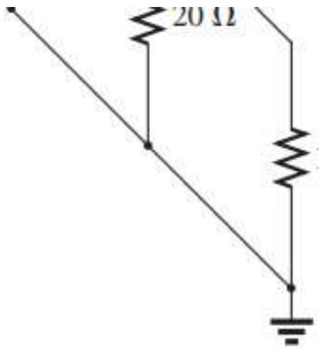


FIG. 6.83
Problem 24.

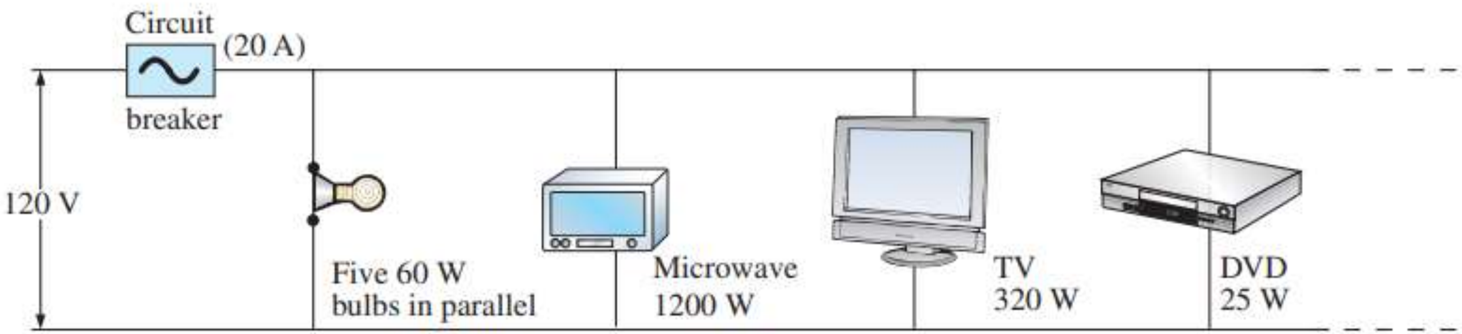
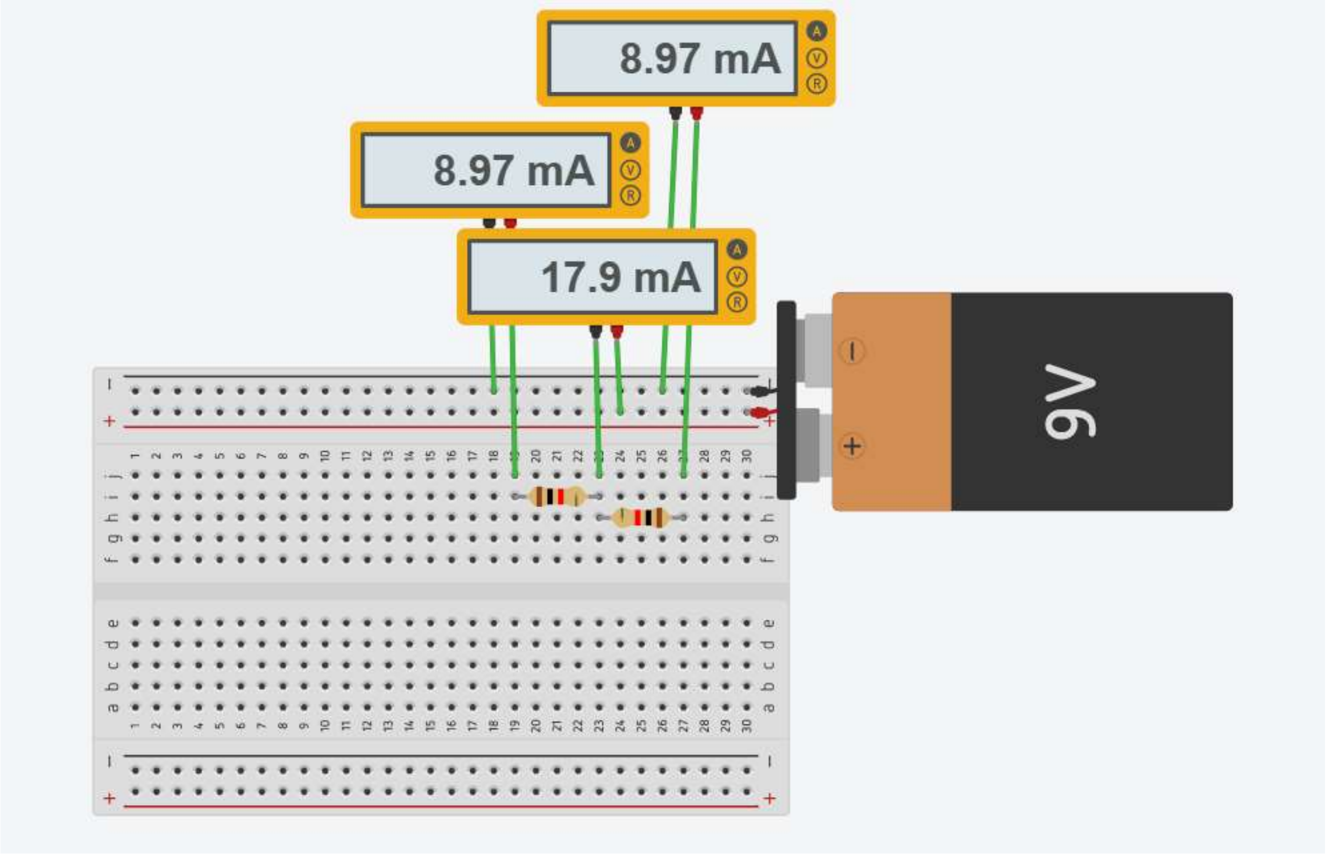
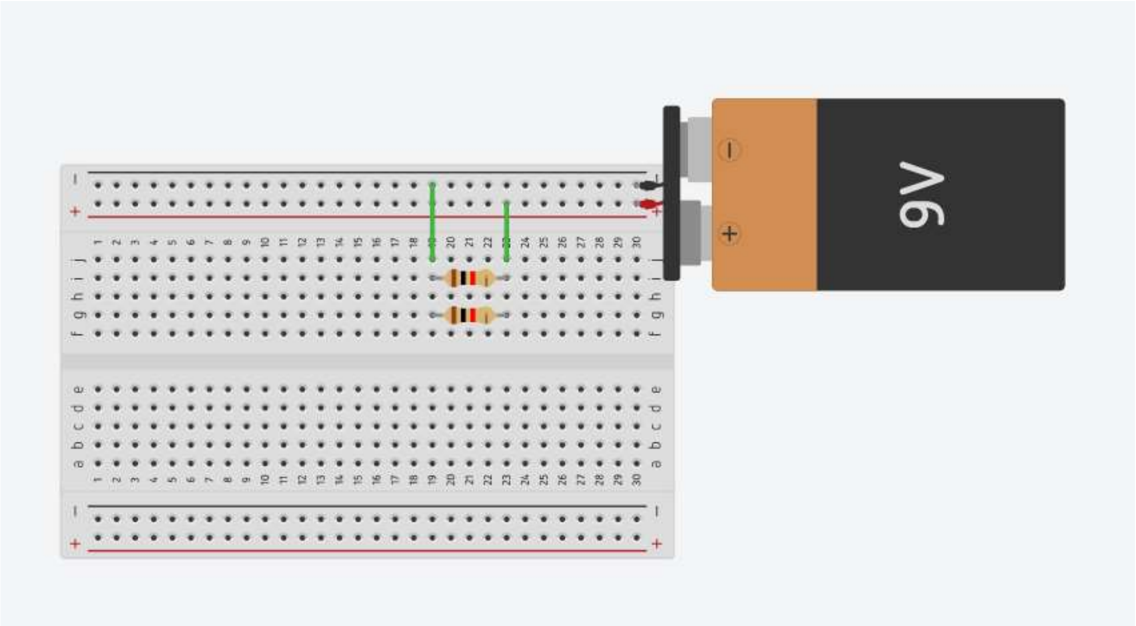


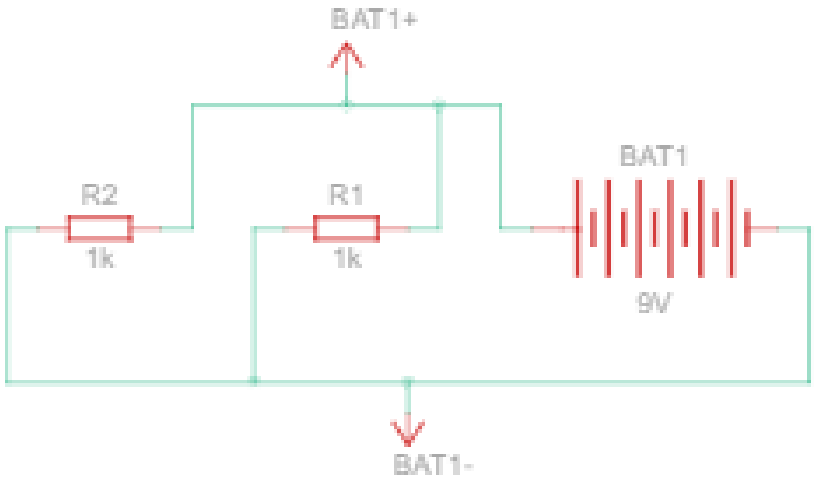
FIG. 6.84
Problem 25.

Tinkercad



Tinkercad





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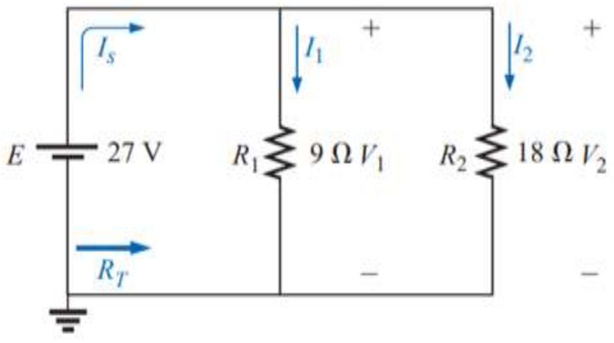


FIG. 6.22
Example 6.11.

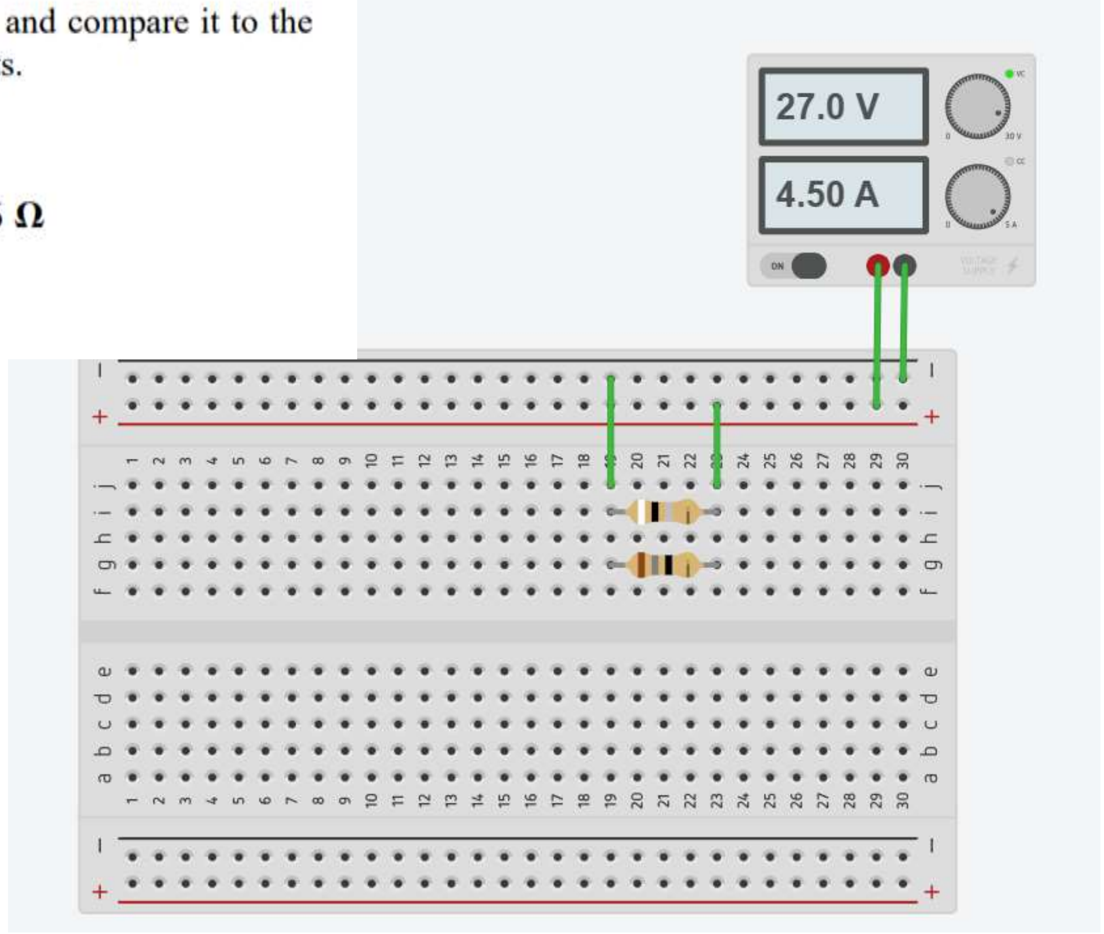
EXAMPLE 6.11 For the parallel network of Fig. 6.22:

a. Calculate R_T.
b. Determine I_s.
c. Calculate I_1 and I_2, and demonstrate that $I_s = I_1 + I_2$.
d. Determine the power to each resistive load.
e. Determine the power delivered by the source, and compare it to the total power dissipated by the resistive elements.

Solutions:

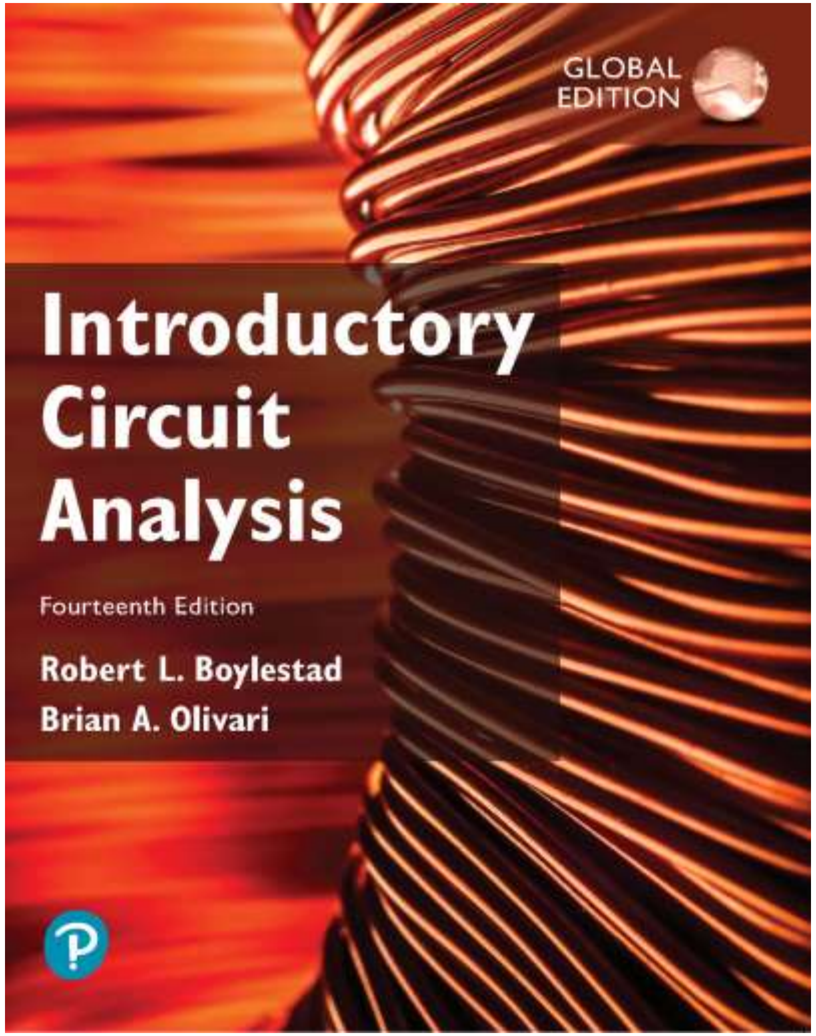
a. $R_T = \dfrac{R_1 R_2}{R_1 + R_2} = \dfrac{(9\ \Omega)(18\ \Omega)}{9\ \Omega + 18\ \Omega} = \dfrac{162\ \Omega}{27} = \mathbf{6\ \Omega}$

b. $I_s = \dfrac{E}{R_T} = \dfrac{27\ \text{V}}{6\ \Omega} = \mathbf{4.5\ A}$



Introductory Circuit Analysis

Fourteenth Edition, Global Edition



Chapter 7

Series-Parallel Circuits

Block Diagram Approach

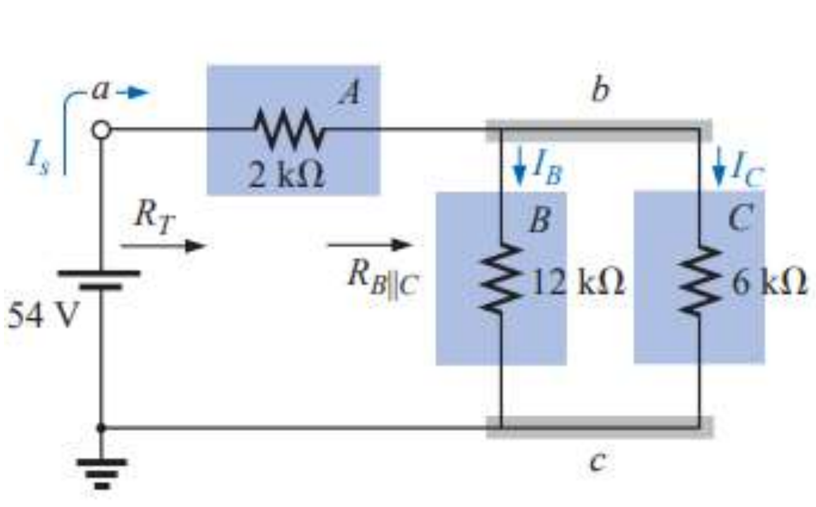


FIG. 7.3
Example 7.1.

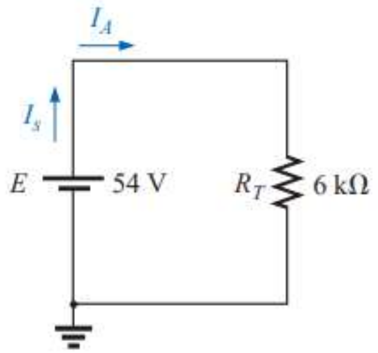


FIG. 7.4
Reduced equivalent of Fig. 7.3.

1/RBC = 1/12 + 1/6
= 3/12
= 1/4
RBC = 4 K
RT = 2 + 4 = 6 K

(V, K,mA) or (V,ohm,A)
Is = 54/6
= 9 mA

Vb=54-9x2=36V
IB=36/12=3mA
IC=36/6=6mA

Kirchhoff's Voltage and Current Laws

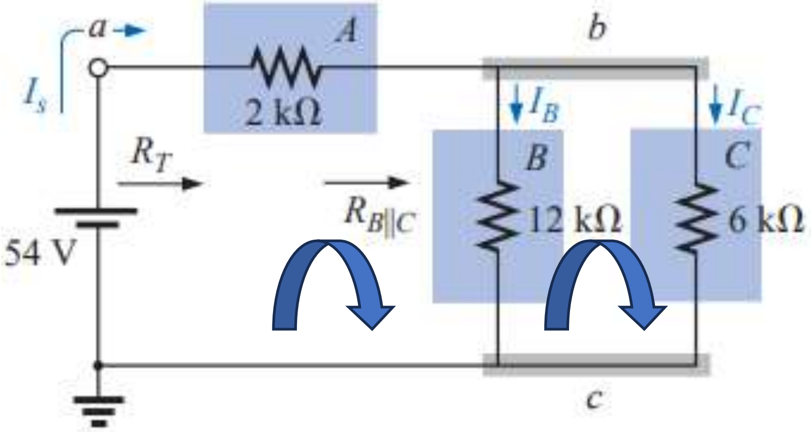


FIG. 7.3
Example 7.1.

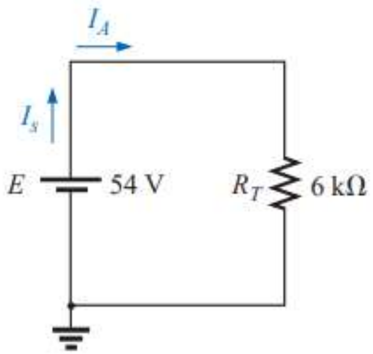


FIG. 7.4
Reduced equivalent of Fig. 7.3.

KVL

-54 + Isx2 + IBx12 = 0

-IBx12 + ICx6 = 0

KCL

Is = IB + IC

-54 + 2x(IB+IC) + 12xIB = 0

14xIB + 2xIC = 54

-12xIB + 6xIC = 0 (/3)

14xIB + 2xIC = 54

-4xIB + 2xIC = 0 (-)

18xIB = 54

IB = 54/18 = 3mA

-12xIB + 6xIC = 0

IC = 36/6 = 6mA

IS=IB+IC=9mA

Using KVL and KCL all type of resistor circuit can be solved. This method is used by SPICE programs

Block Diagram Approach

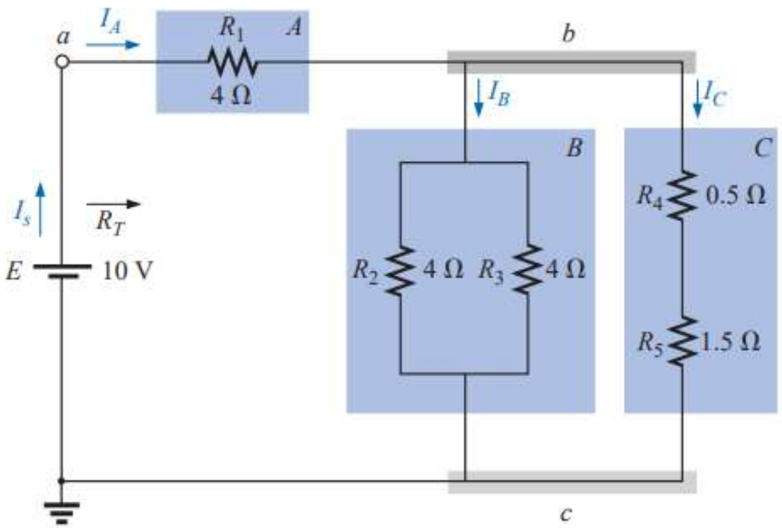


FIG. 7.6
Example 7.2.

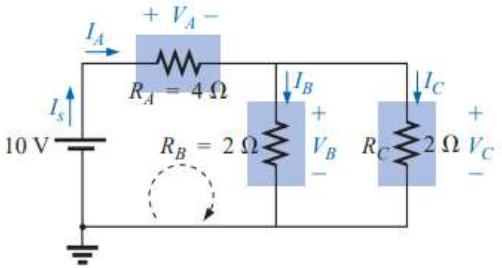


FIG. 7.7
Reduced equivalent of Fig. 7.6.

EXAMPLE 7.2 It is also possible that the blocks A, B, and C of Fig. 7.2 contain the elements and configurations of Fig. 7.6. Working with each region:

$$A:\quad R_A = 4\ \Omega$$

$$B:\quad R_B = R_2 \parallel R_3 = R_{2\|3} = \frac{R}{N} = \frac{4\ \Omega}{2} = 2\ \Omega$$

$$C:\quad R_C = R_4 + R_5 = R_{4,5} = 0.5\ \Omega + 1.5\ \Omega = 2\ \Omega$$

Blocks B and C are still in parallel, and

$$R_{B\|C} = \frac{R}{N} = \frac{2\ \Omega}{2} = 1\ \Omega$$

$$R_T = R_A + R_{B\|C} = 4\ \Omega + 1\ \Omega = \mathbf{5\ \Omega}$$

(Note the similarity between this equation and that obtained for Example 7.1.)

and
$$I_s = \frac{E}{R_T} = \frac{10\ \text{V}}{5\ \Omega} = \mathbf{2\ A}$$

We can find the currents I_A, I_B, and I_C using the reduction of the network of Fig. 7.6 (recall Step 3) as found in Fig. 7.7. Note that I_A, I_B, and I_C are the same in Figs. 7.6 and 7.7 and therefore also appear in Fig. 7.7. In other words, the currents I_A, I_B, and I_C of Fig. 7.7 will have the same magnitude as the same currents of Fig. 7.6.

$$I_A = I_s = \mathbf{2\ A}$$

and
$$I_B = I_C = \frac{I_A}{2} = \frac{I_s}{2} = \frac{2\ \text{A}}{2} = \mathbf{1\ A}$$

Returning to the network of Fig. 7.6, we have

$$I_{R_2} = I_{R_3} = \frac{I_B}{2} = \mathbf{0.5\ A}$$

The voltages V_A, V_B, and V_C from either figure are

$$V_A = I_A R_A = (2\ \text{A})(4\ \Omega) = \mathbf{8\ V}$$
$$V_B = I_B R_B = (1\ \text{A})(2\ \Omega) = \mathbf{2\ V}$$
$$V_C = V_B = \mathbf{2\ V}$$

Applying Kirchhoff's voltage law for the loop indicated in Fig. 7.7, we obtain

$$\Sigma_{\circlearrowright} V = E - V_A - V_B = 0$$
$$E = V_A + V_B = 8\ \text{V} + 2\ \text{V}$$

or
$$10\ \text{V} = 10\ \text{V} \quad \text{(checks)}$$

Block Diagram Approach

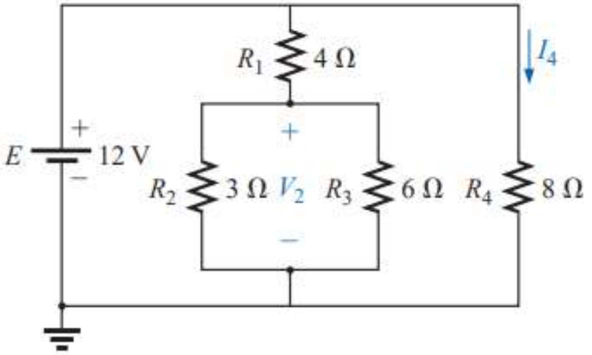


FIG. 7.10
Example 7.4.

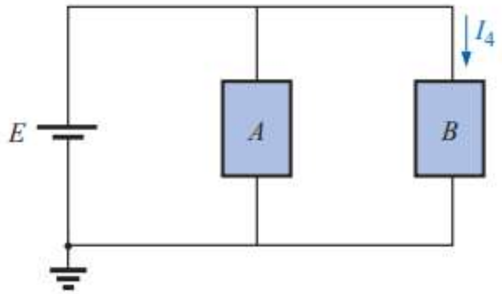


FIG. 7.11
Block diagram of Fig. 7.10.

EXAMPLE 7.4 Find the current I_4 and the voltage V_2 for the network of Fig. 7.10.

Applying Ohm's law,

$$I_4 = \frac{E}{R_B} = \frac{E}{R_4} = \frac{12\ \text{V}}{8\ \Omega} = \mathbf{1.5\ A}$$

Combining the resistors R_2 and R_3 of Fig. 7.10 will result in

$$R_D = R_2 \parallel R_3 = 3\ \Omega \parallel 6\ \Omega = \frac{(3\ \Omega)(6\ \Omega)}{3\ \Omega + 6\ \Omega} = \frac{18\ \Omega}{9} = 2\ \Omega$$

and, applying the voltage divider rule,

$$V_2 = \frac{R_D E}{R_D + R_C} = \frac{(2\ \Omega)(12\ \text{V})}{2\ \Omega + 4\ \Omega} = \frac{24\ \text{V}}{6} = \mathbf{4\ V}$$

Block Diagram Approach

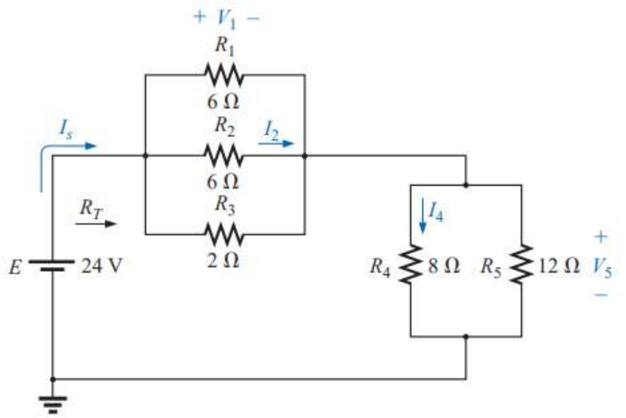


FIG. 7.13
Example 7.5.

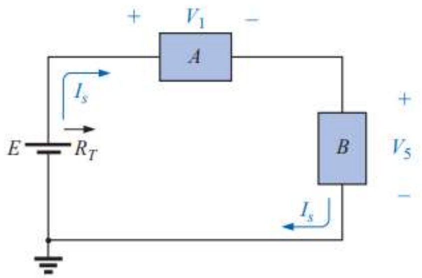


FIG. 7.14
Block diagram for Fig. 7.13.

EXAMPLE 7.5 Find the indicated currents and voltages for the network of Fig. 7.13.

$$R_{1\|2} = \frac{R}{N} = \frac{6\ \Omega}{2} = 3\ \Omega$$

$$R_A = R_{1\|2\|3} = \frac{(3\ \Omega)(2\ \Omega)}{3\ \Omega + 2\ \Omega} = \frac{6\ \Omega}{5} = 1.2\ \Omega$$

$$R_B = R_{4\|5} = \frac{(8\ \Omega)(12\ \Omega)}{8\ \Omega + 12\ \Omega} = \frac{96\ \Omega}{20} = 4.8\ \Omega$$

The reduced form of Fig. 7.13 will then appear as shown in Fig. 7.15, and

$$R_T = R_{1\|2\|3} + R_{4\|5} = 1.2\ \Omega + 4.8\ \Omega = \mathbf{6\ \Omega}$$

$$I_s = \frac{E}{R_T} = \frac{24\ \text{V}}{6\ \Omega} = \mathbf{4\ A}$$

with

$$V_1 = I_s R_{1\|2\|3} = (4\ \text{A})(1.2\ \Omega) = \mathbf{4.8\ V}$$

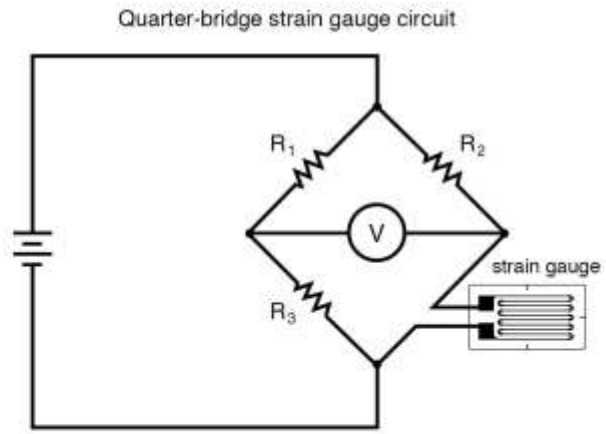
$$V_5 = I_s R_{4\|5} = (4\ \text{A})(4.8\ \Omega) = \mathbf{19.2\ V}$$

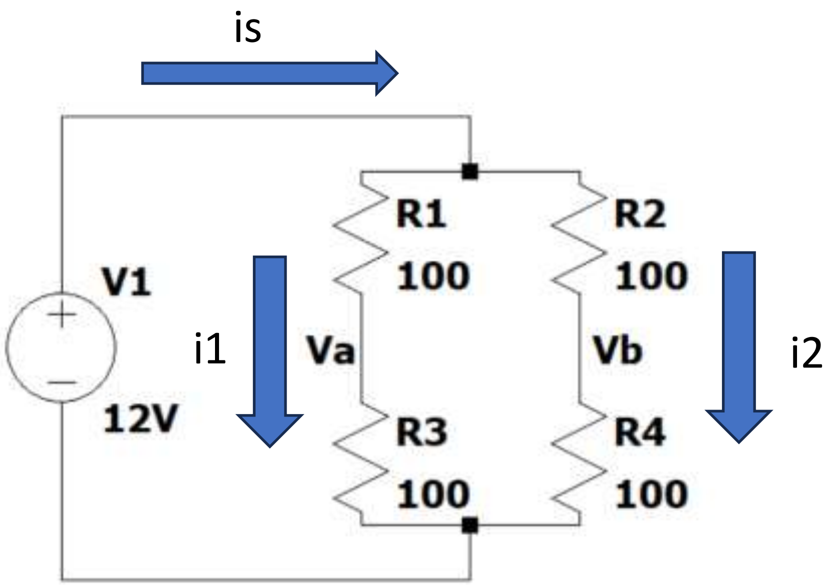
Applying Ohm's law,

$$I_4 = \frac{V_5}{R_4} = \frac{19.2\ \text{V}}{8\ \Omega} = \mathbf{2.4\ A}$$

$$I_2 = \frac{V_2}{R_2} = \frac{V_1}{R_2} = \frac{4.8\ \text{V}}{6\ \Omega} = \mathbf{0.8\ A}$$

Strain Gauge Resistors





E=12V, R1=R2=R3=Rs=100 ohm

a) What is V ?

b) if Rs=110 ohm what is V

a) i1=12/200 = 0.06A

i2=i1=0.06A

Va=i1 x 100 = 6V

Vb=i2 x 100 = 6V

Vab=0V

b) i1=12/200=0.06A

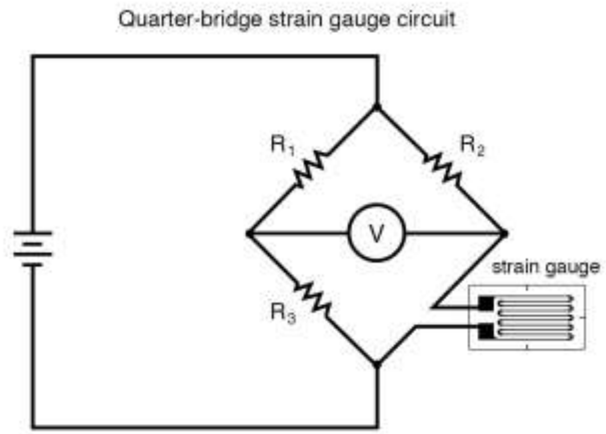
i2=12/210=0.057A

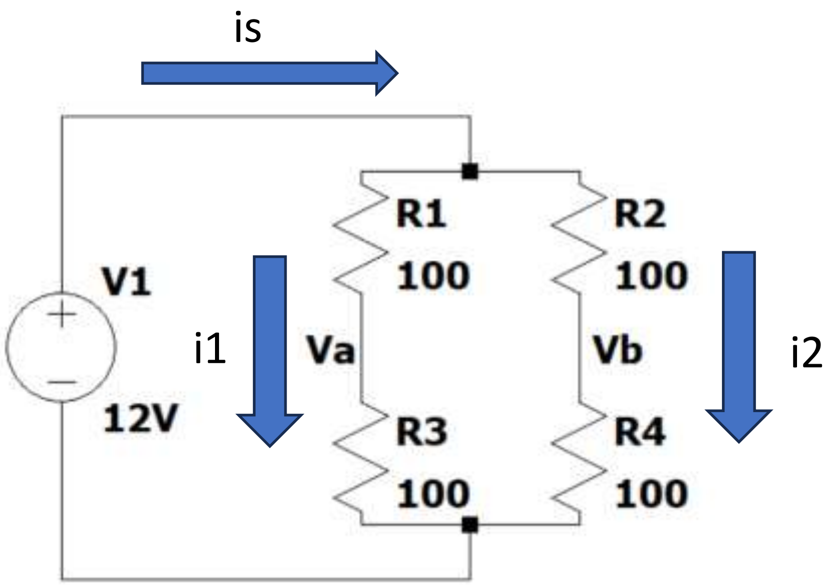
Va=6V

Vb=0.057 x 110= 6.3V

Vab=-0.3V

Strain Gauge Resistors (voltage divider)





E=12V, R1=R2=R3=Rs=100 ohm

a) What is V ?

b) if Rs=110 ohm what is V

a) Va= E. R2/(R1+R2)

Va=12.100/200=6V

Vb=6V

Vab=0V

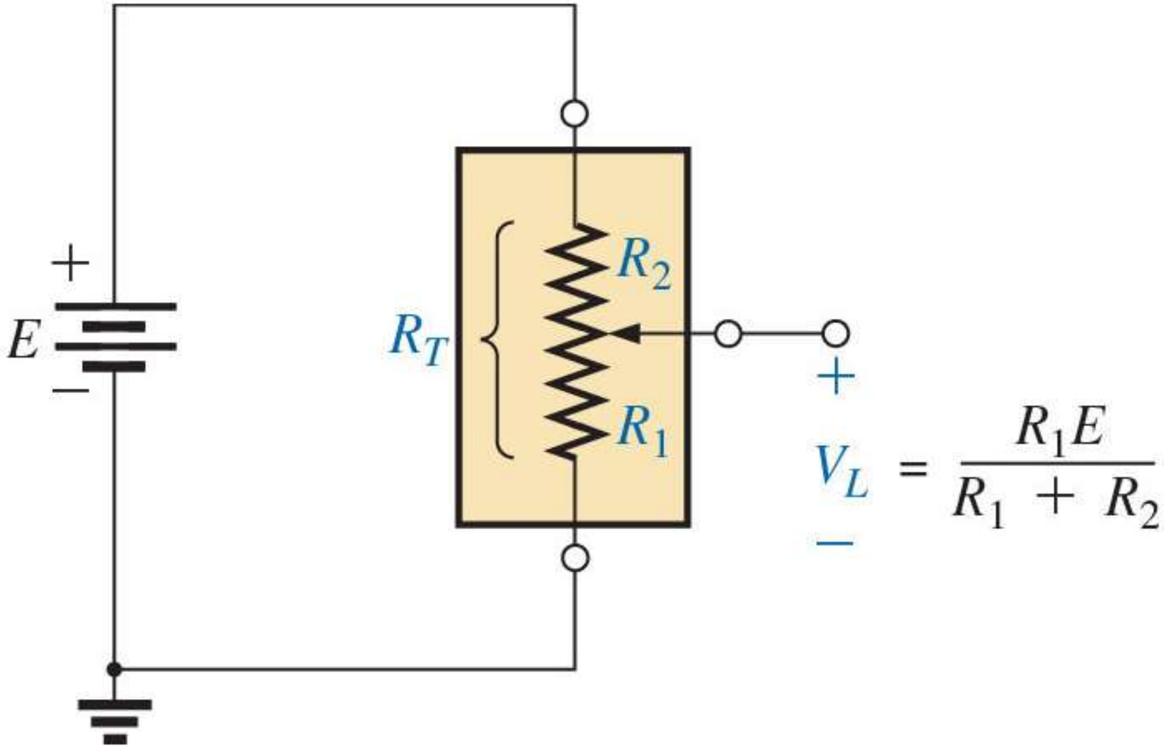
b) Va=6V

Vb=12.110/210=6.3

Vab=-0.3V

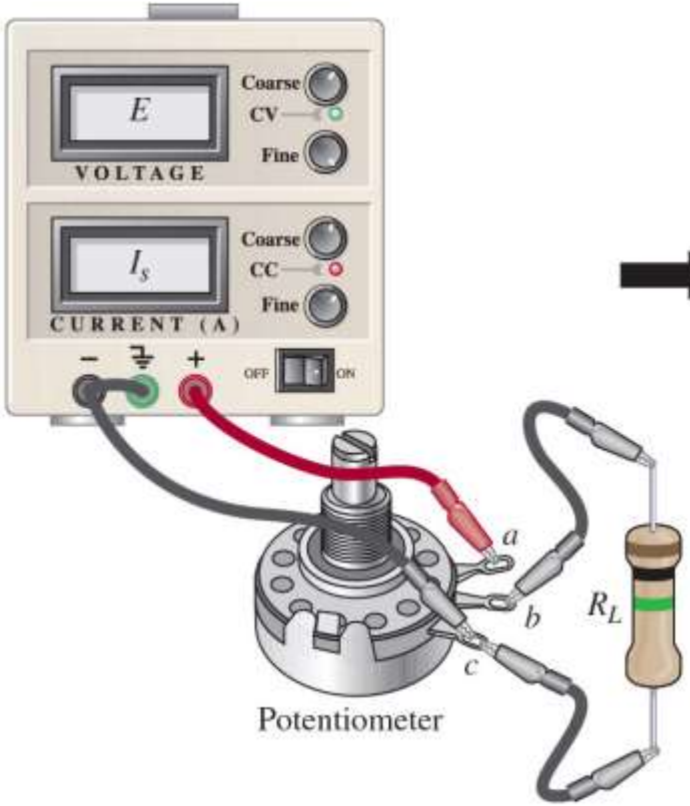
Potentiometer Loading (1 of 10)

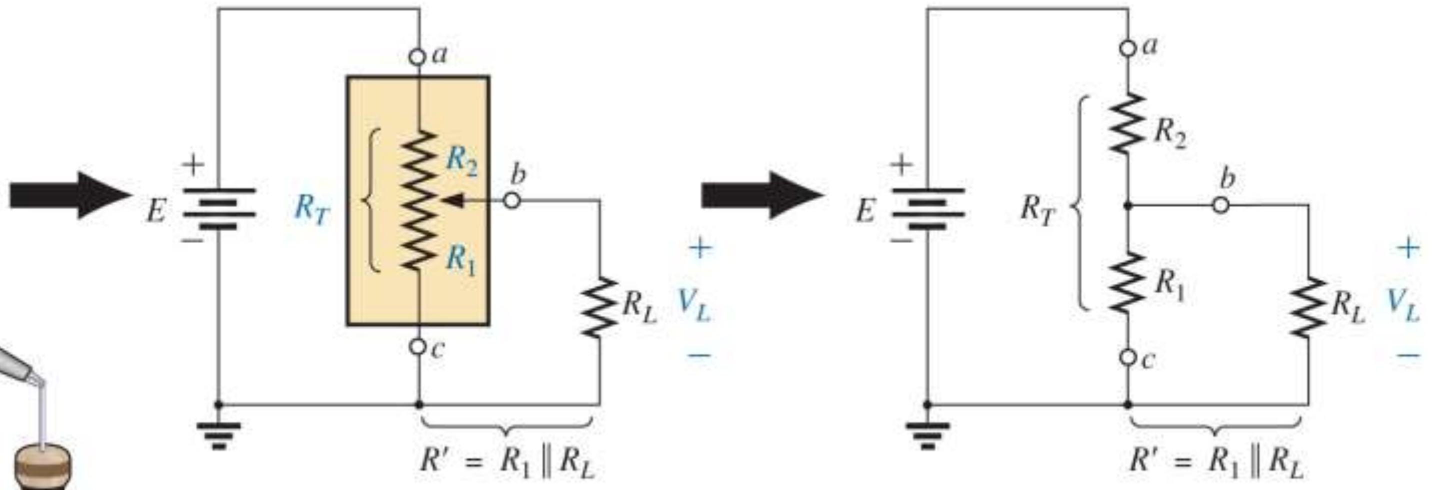
Fig. 7.44 *Unloaded potentiometer.*



Potentiometer Loading (2 of 10)

Fig. 7.45 *Loaded potentiometer.*

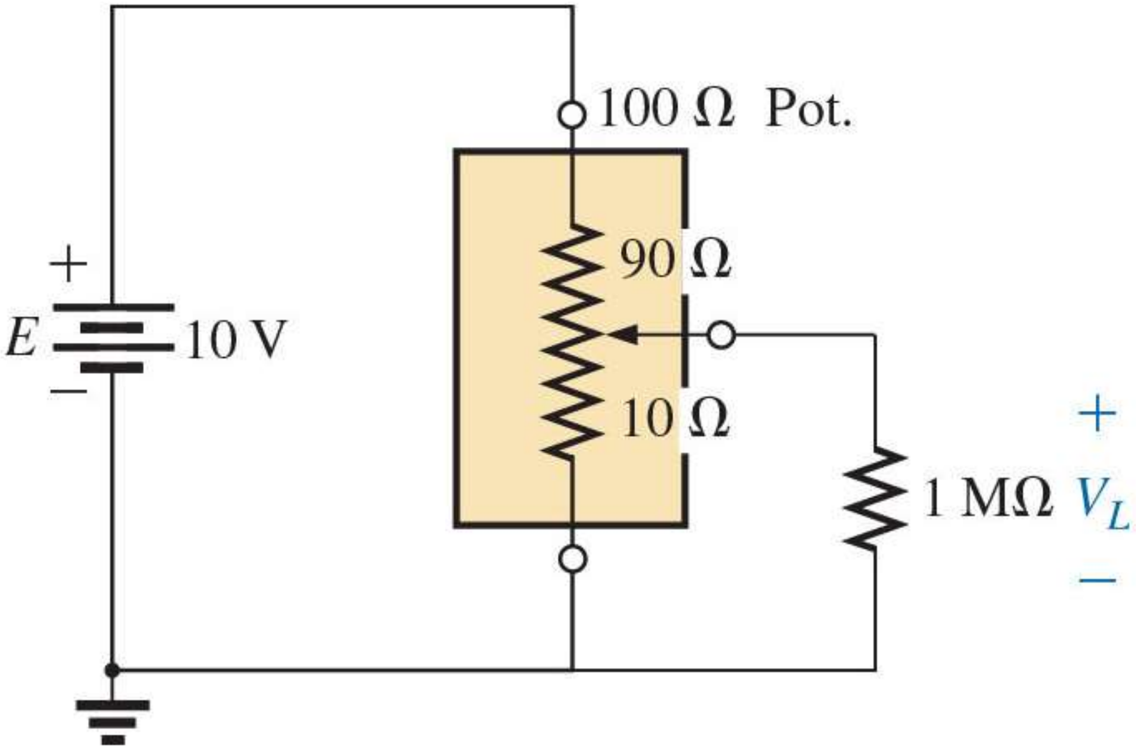




$$\boxed{R_L \geq R_T} \qquad (7.2)$$

Potentiometer Loading (5 of 10)

Fig. 7.47 *Loaded potentiometer with* $R_L >> R_T$.



Using the reverse situation of $R_T = 100\ \Omega$ and $R_L = 1\ \text{M}\Omega$ and the wiper arm at the 1/10 position, as in Fig. 7.40, we find

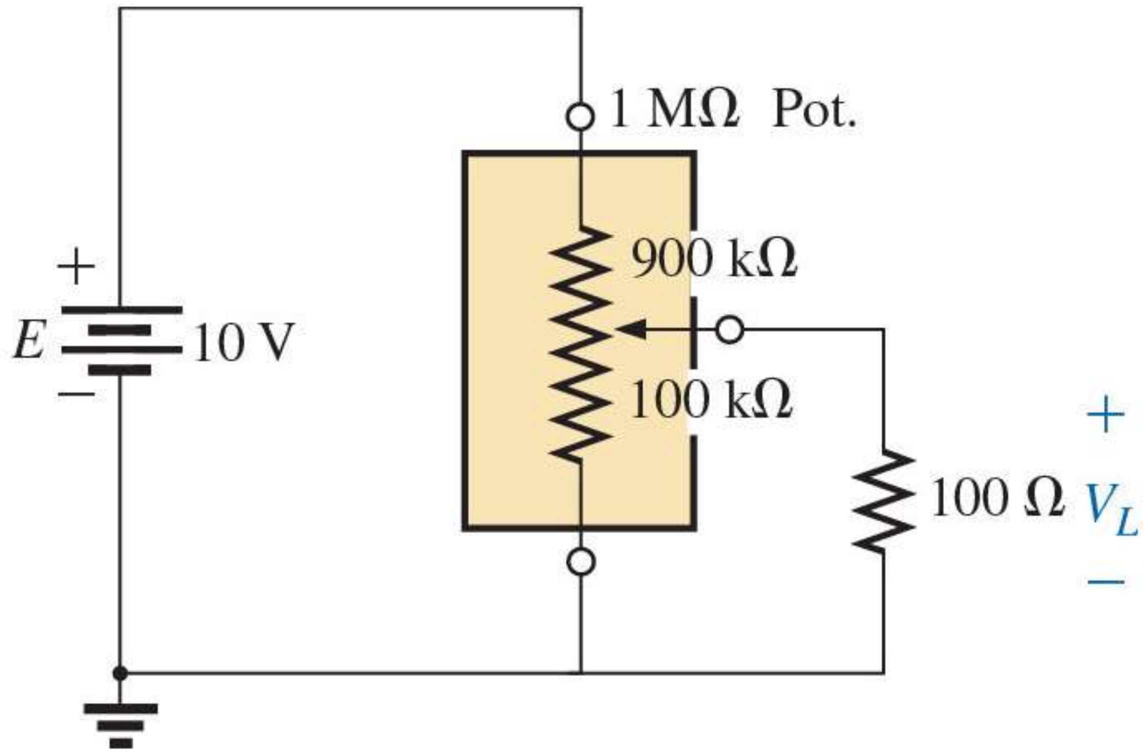
$$R' = 10\ \Omega \parallel 1\ \text{M}\Omega \cong 10\ \Omega$$

and

$$V_L = \frac{10\ \Omega(10\ \text{V})}{10\ \Omega + 90\ \Omega} = 1\ \text{V}$$

Potentiometer Loading (4 of 10)

Fig. 7.46 *Loaded potentiometer with* $R_L << R_T$.



For example, if we disregard Eq. (7.2) and choose a 1-MΩ potentiometer with a 100-Ω load and set the wiper arm to 1/10 the total resistance, as shown in Fig. 7.39, then

$$R' = 100\ \text{k}\Omega \parallel 100\ \Omega = 99.9\ \Omega$$

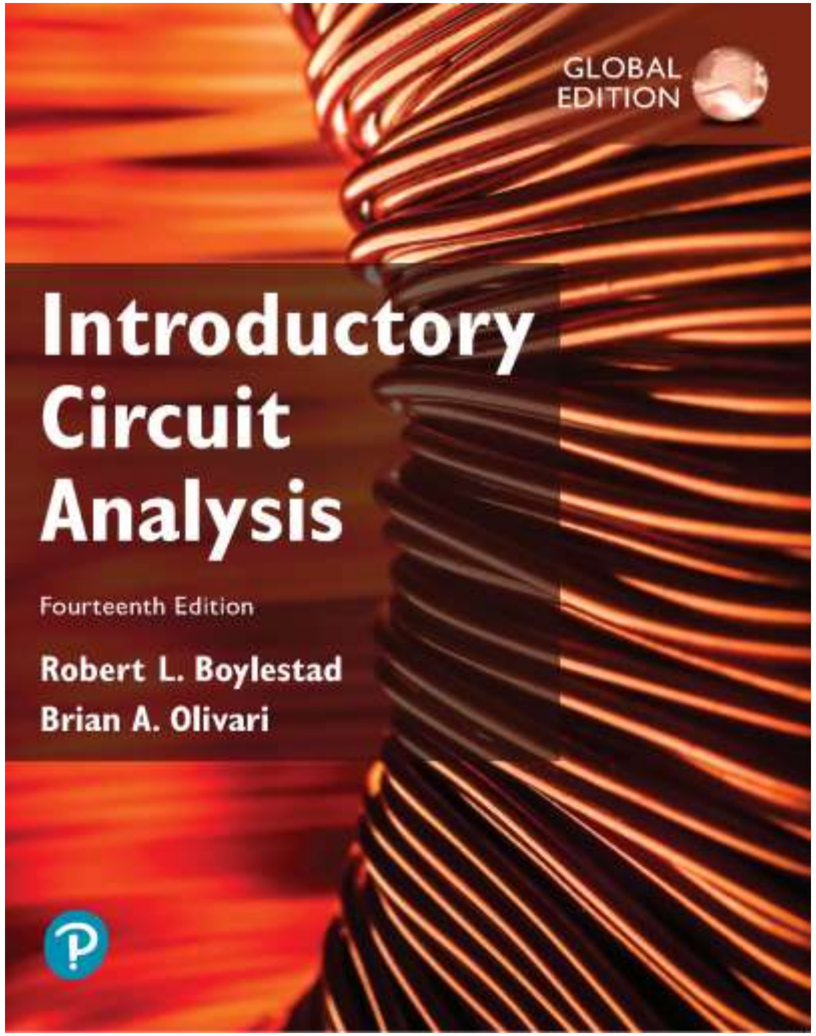
and

$$V_L = \frac{99.9\ \Omega(10\ \text{V})}{99.9\ \Omega + 900\ \text{k}\Omega} \cong 0.001\ \text{V} = 1\ \text{mV}$$

which is extremely small compared to the expected level of 1 V.

Introductory Circuit Analysis

Fourteenth Edition, Global Edition



Chapter 8

Methods of Analysis and Selected Topics (dc)

Pearson

Current Sources

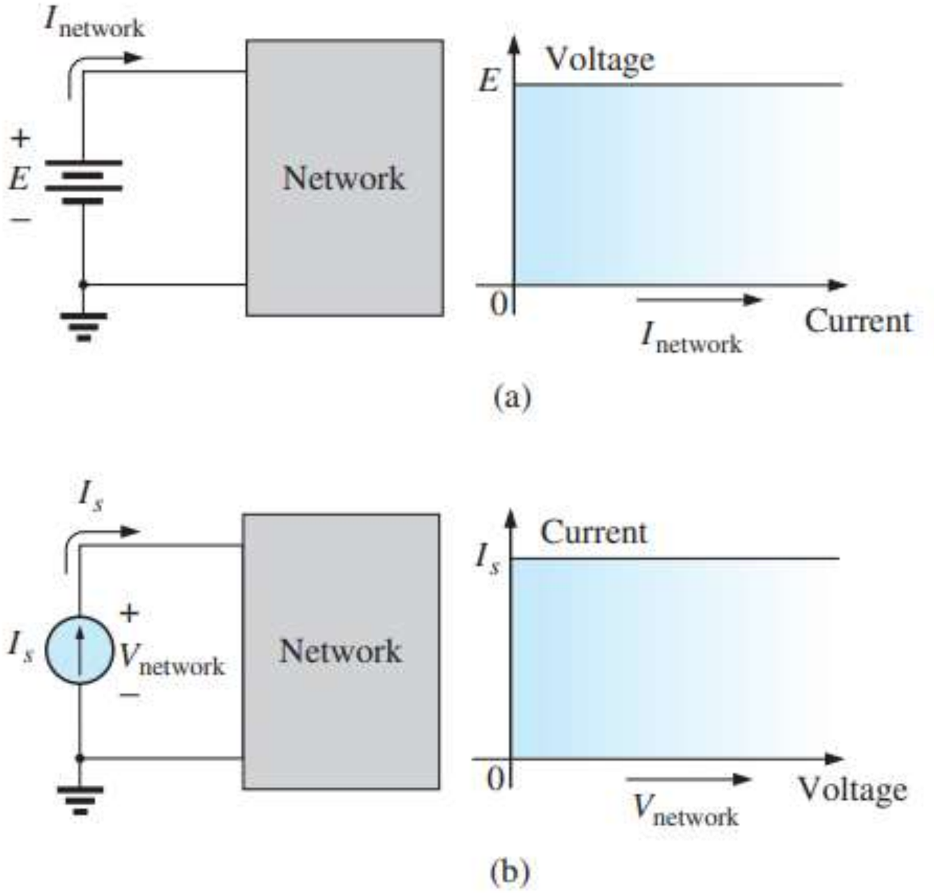


FIG. 8.1
Terminal characteristics of an (a) ideal voltage source and (b) ideal current source.

Current Sources

EXAMPLE 8.1 Find the source voltage, the voltage V_1, and current I_1 for the circuit in Fig. 8.3.

Solution: Since the current source establishes the current in the branch in which it is located, the current I_1 must equal I, and

$$I_1 = I = \mathbf{10\ mA}$$

The voltage across R_1 is then determined by Ohm's law:

$$V_1 = I_1R_1 = (10\ \text{mA})(20\ \text{k}\Omega) = \mathbf{200\ V}$$

Since resistor R_1 and the current source are in parallel, the voltage across each must be the same, and

$$V_s = V_1 = \mathbf{200\ V}$$

with the polarity shown.

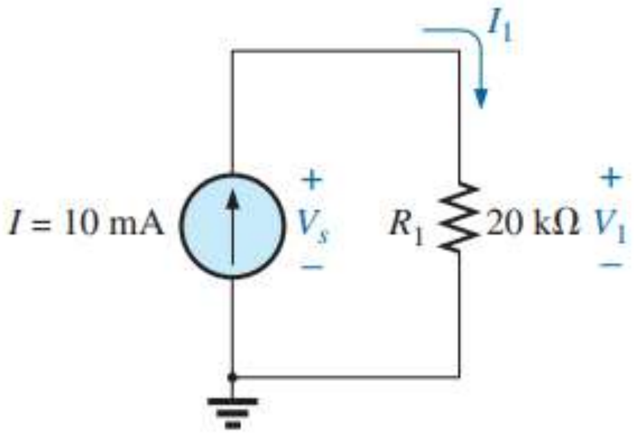


FIG. 8.3
Circuit for Example 8.1.

Current Sources

EXAMPLE 8.2 Find the voltage V_s and currents I_1 and I_2 for the network in Fig. 8.4.

Solution: This is an interesting problem because it has both a current source and a voltage source. For each source, the dependent (a function of something else) variable will be determined. That is, for the current source, V_s must be determined, and for the voltage source, I_s must be determined.

Since the current source and voltage source are in parallel,

$$V_s = E = \mathbf{12\ V}$$

Further, since the voltage source and resistor R are in parallel,

$$V_R = E = 12\ \text{V}$$

and
$$I_2 = \frac{V_R}{R} = \frac{12\ \text{V}}{4\ \Omega} = \mathbf{3\ A}$$

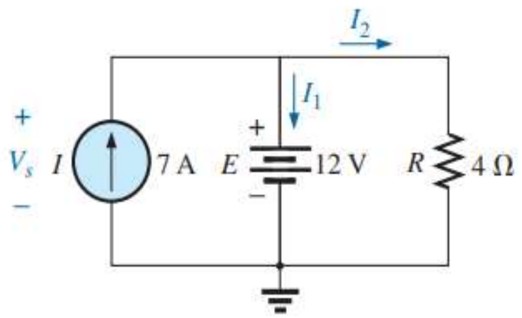


FIG. 8.4
Network for Example 8.2.

The current I_1 of the voltage source can then be determined by applying Kirchhoff's current law at the top of the network as follows:

$$\Sigma I_i = \Sigma I_o$$
$$I = I_1 + I_2$$

and
$$I_1 = I - I_2 = 7\ \text{A} - 3\ \text{A} = \mathbf{4\ A}$$

Current Sources

current sources of different values cannot be placed in series due to a violation of Kirchhoff's current law.

However, current sources can be placed in parallel just as voltage sources can be placed in series. In general,

two or more current sources in parallel can be replaced by a single current source having a magnitude determined by the difference of the sum of the currents in one direction and the sum in the opposite direction. The new parallel internal resistance is the total resistance of the resulting parallel resistive elements.

General Solution for DC Resistor Circuits

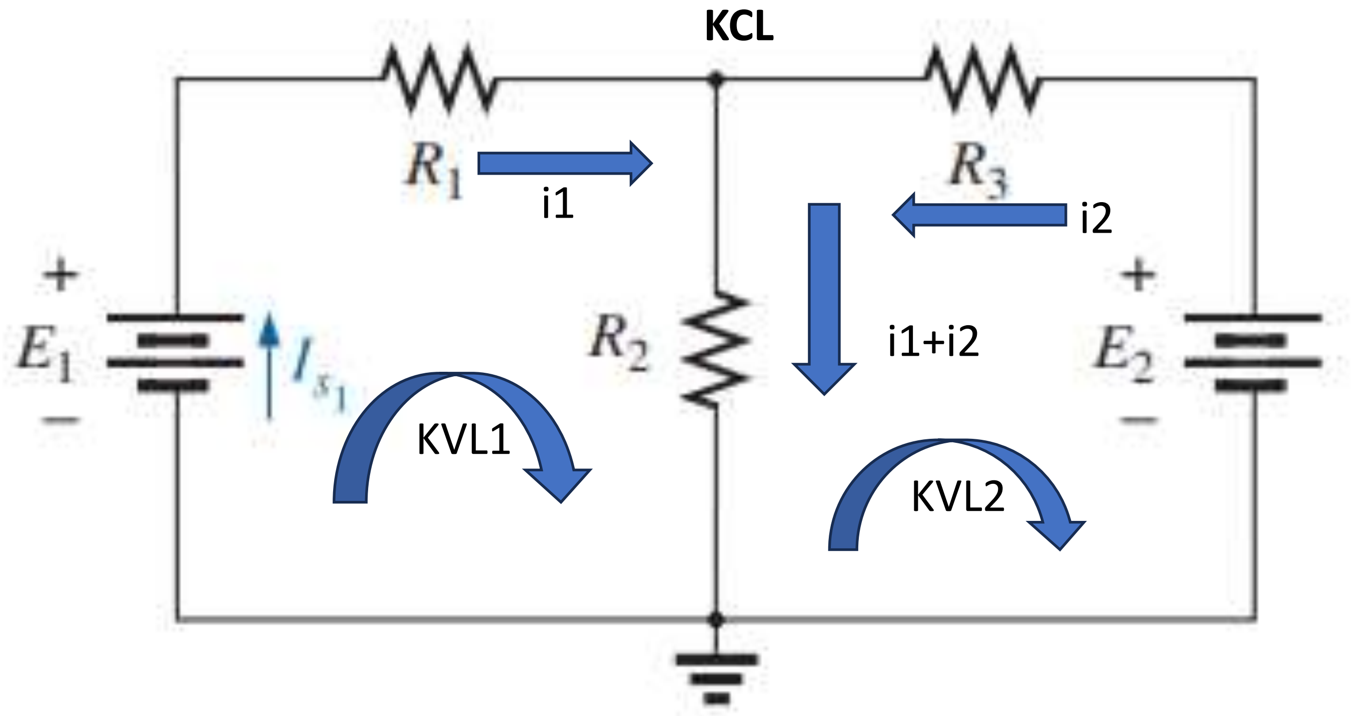


FIG. 8.22

Write all possible

- KVL for loops
- KCL for nodes

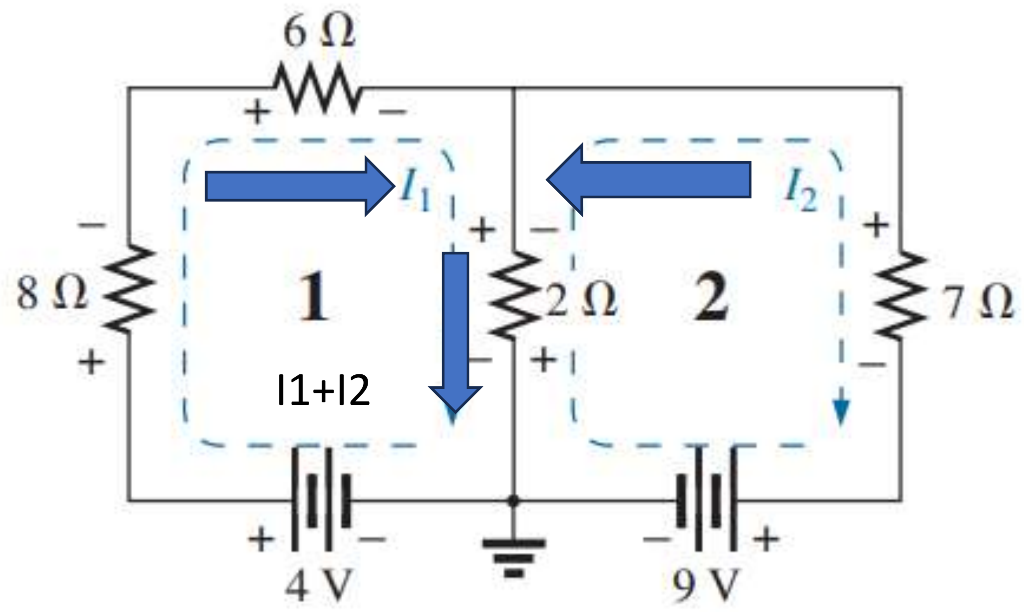
KVL1:

$-E1 + i1.R1 + (i1+i2).R2 = 0$

KVL2:

$-(i1+i2).R2 - i2.R3 + E2 = 0$

MESH ANALYSIS (FORMAT APPROACH)



KVL1:

-4 + 14.I1 + 2.(I1 + I2)=0

-2.(I1 + I2) –I2.7 +9 =0

16.I1 + 2.I2 = 4

-2.I1 - 9.I2 = -9 (x8))

-70.I2 =4-72

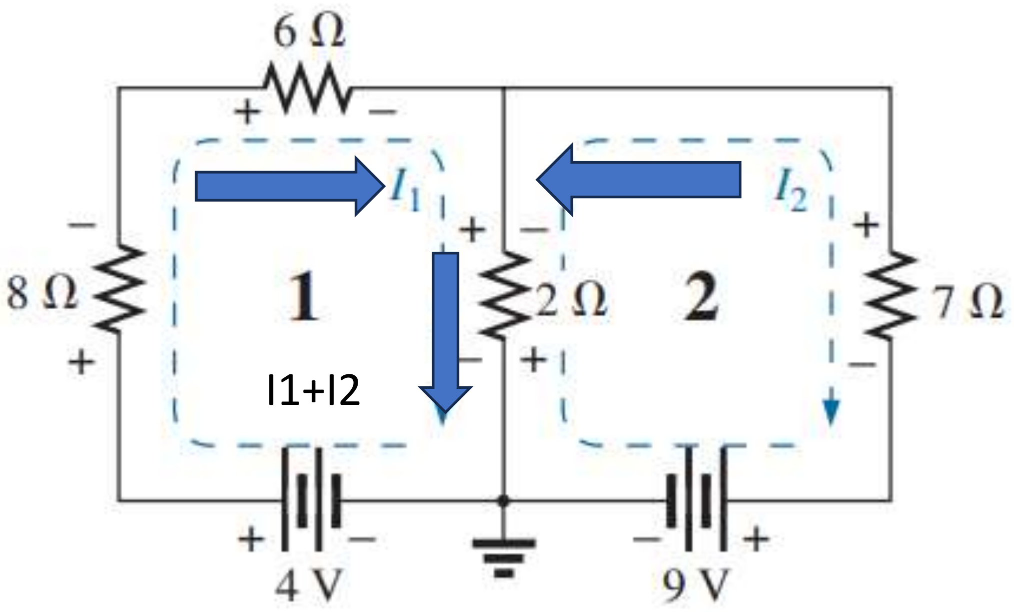
-70.I2 = -68

I2=-68/70= 0.97A

16.I1 + 2x0.97 = 4

I1=0.128A

NODAL ANALYSIS (GENERAL APPROACH)



KVL1:

-4 + 14.I1 + 2.(I1 + I2)=0

-2.(I1 + I2) –I2.7 +9 =0

16.I1 + 2.I2 = 4

-2.I1 - 9.I2 = -9 (x8))

-70.I2 =4-72

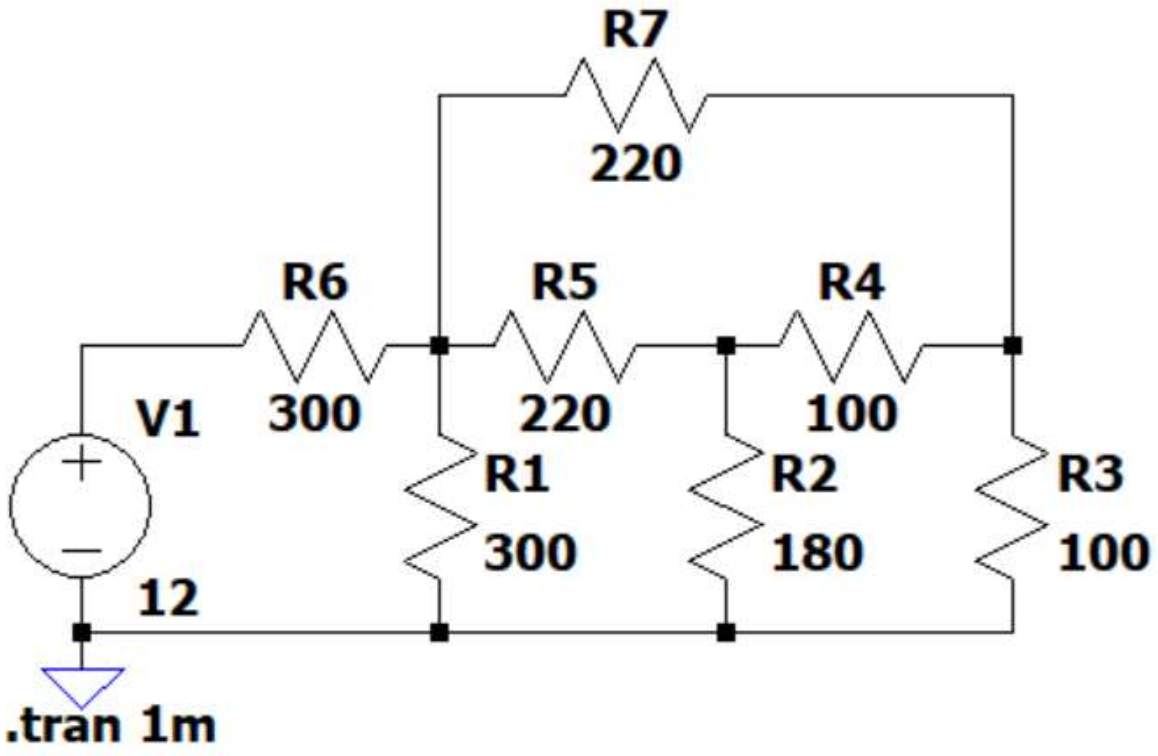
-70.I2 = -68

I2=-68/70= 0.97A

16.I1 + 2x0.97 = 4

I1=0.128A

SOLUTION USING LTSPICE



using LTSpice

V1=3.2V
V2=1.3V
V3=1.1V

Boosting a Car Battery

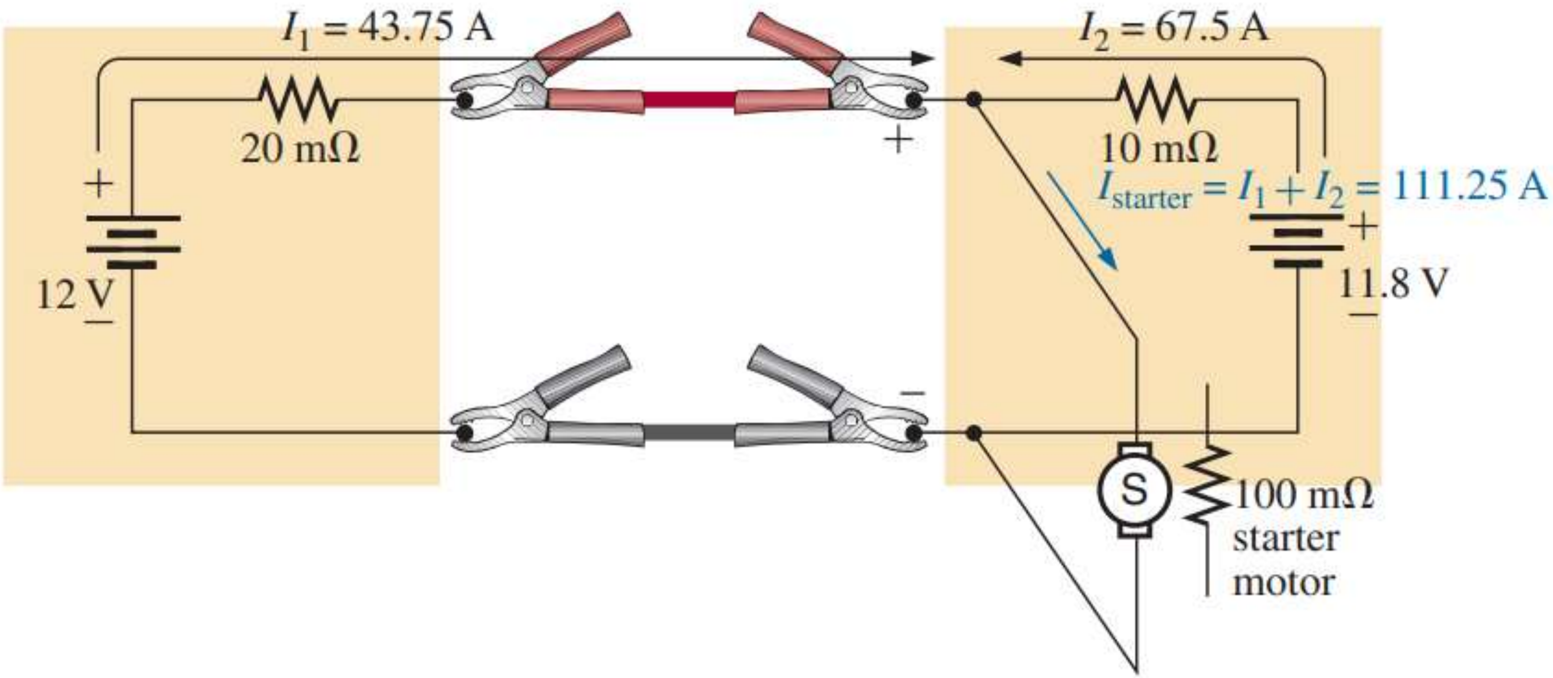


FIG. 7.64
Current levels at starting.

KVL1, KVL2:
-12+I1.20+(I1+I2).100=0
-(I1+I2).100-I2.10+11.8=0

120.I1 + 100.I2 = 12
100.I1 + 110.I2 = 11.8

120.I1 + 100.I2 = 12 (-1)
120.I1 + 132.I2 = 14.16 (1.2)

32. I2 = 2.16V

I2=67.5A
I1=43.75A
I1+I2=111.25A

KVL, KCL Solutions

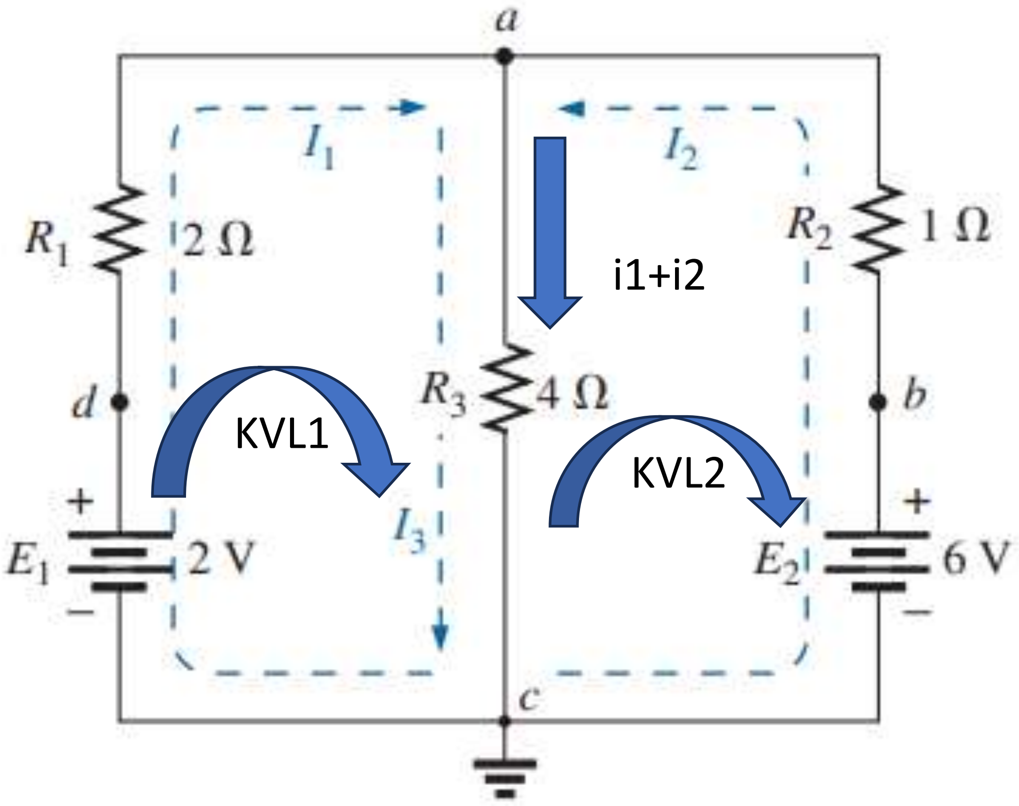


FIG. 8.25
Example 8.10.

KVL1, KVL2:

-2 + i1.2 + (i1+i2)4 = 0

-4.(i1+i2) –i2.1 +6 = 0

6.i1 + 4.i2 = 2 (x2)

4.i1 + 5.i2 = 6 (-3)

12.i1 + 8.i2 = 4

-12.i1 -15.i2=-18

-7.i2 = -14

i2=2A

6.i1 + 4.2 = 2

i1=-1A

LTSpice

if the circuit is complex we need to use a circuit simulator, example LTSpice

1. DC operating point: text output
2. Transient Analysis

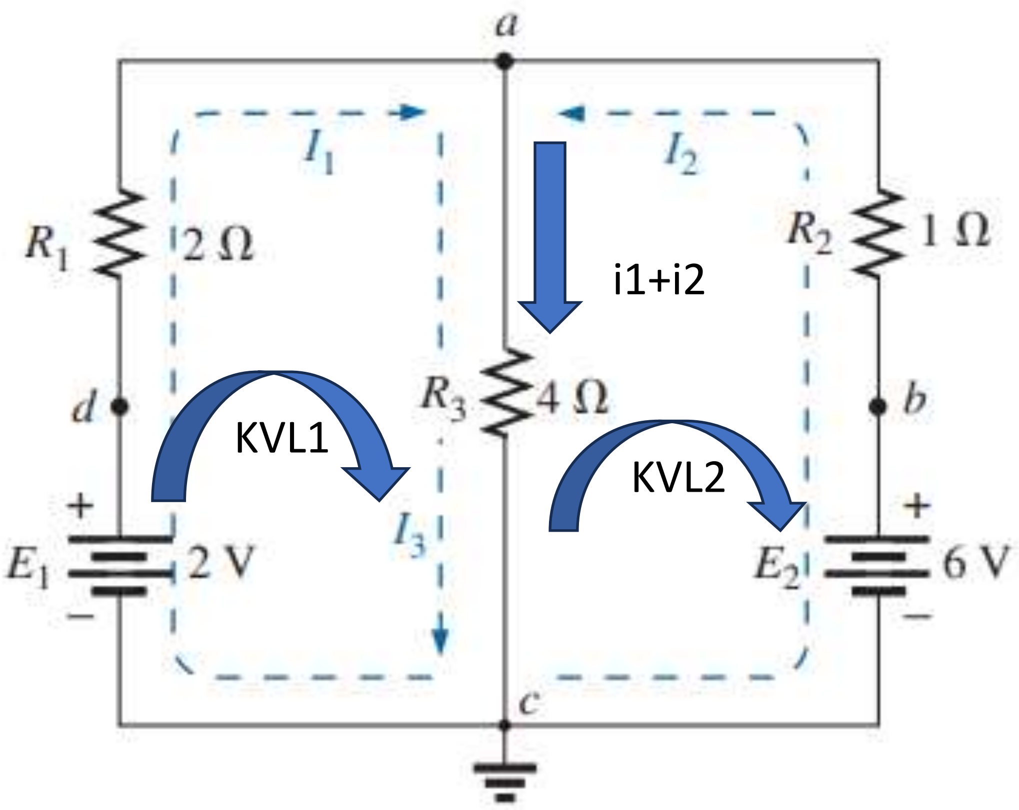
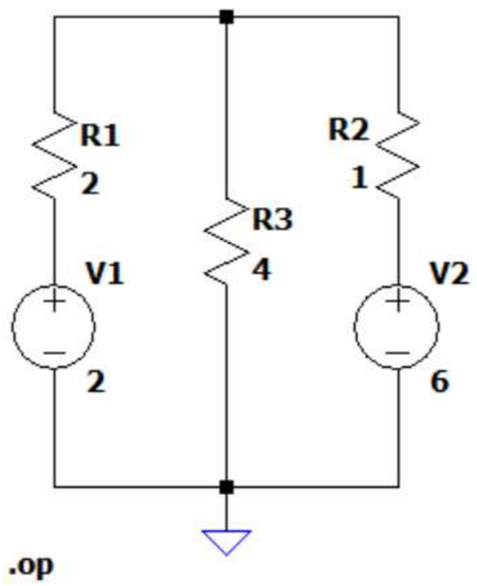


FIG. 8.25
Example 8.10.

```
--- Operating Point ---

V(n002):     2     voltage
V(n003):     6     voltage
V(n001):     4     voltage
I(R1):       1     device_current
I(R2):       2     device_current
I(R3):       1     device_current
I(V1):       1     device_current
I(V2):       -2    device_current
```



LTSpice

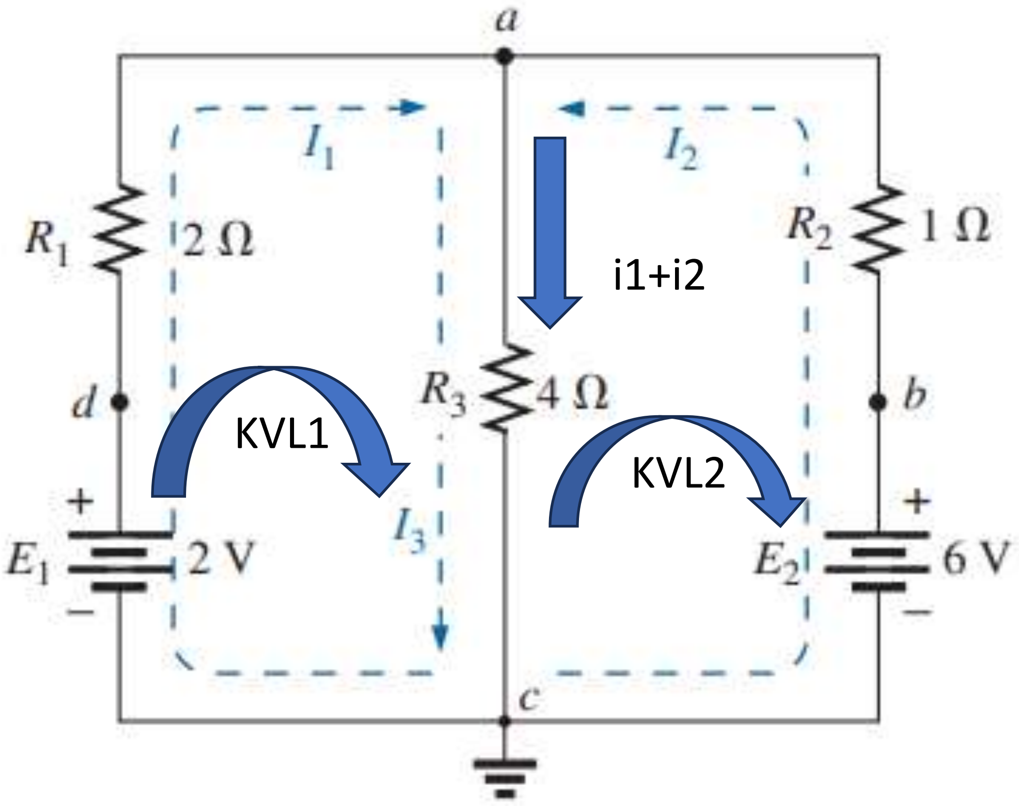
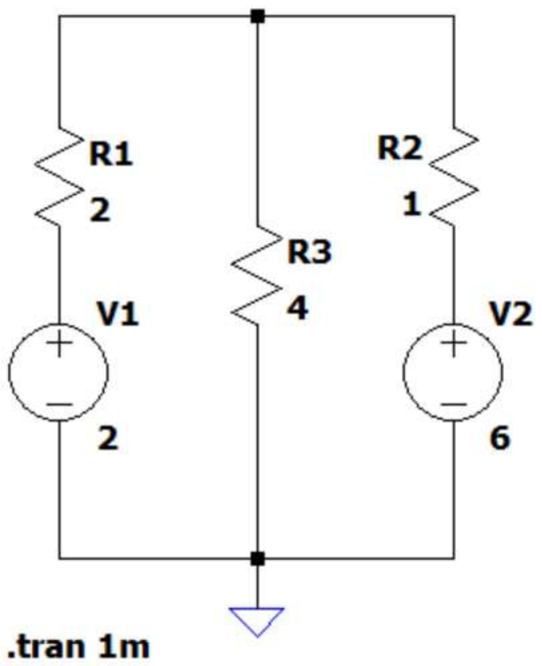


FIG. 8.25
Example 8.10.

if the circuit is complex we need to use a circuit simulator, example LTSpice

1. DC operating point
2. Transient Analysis : will show the current direction and value



LTSpice

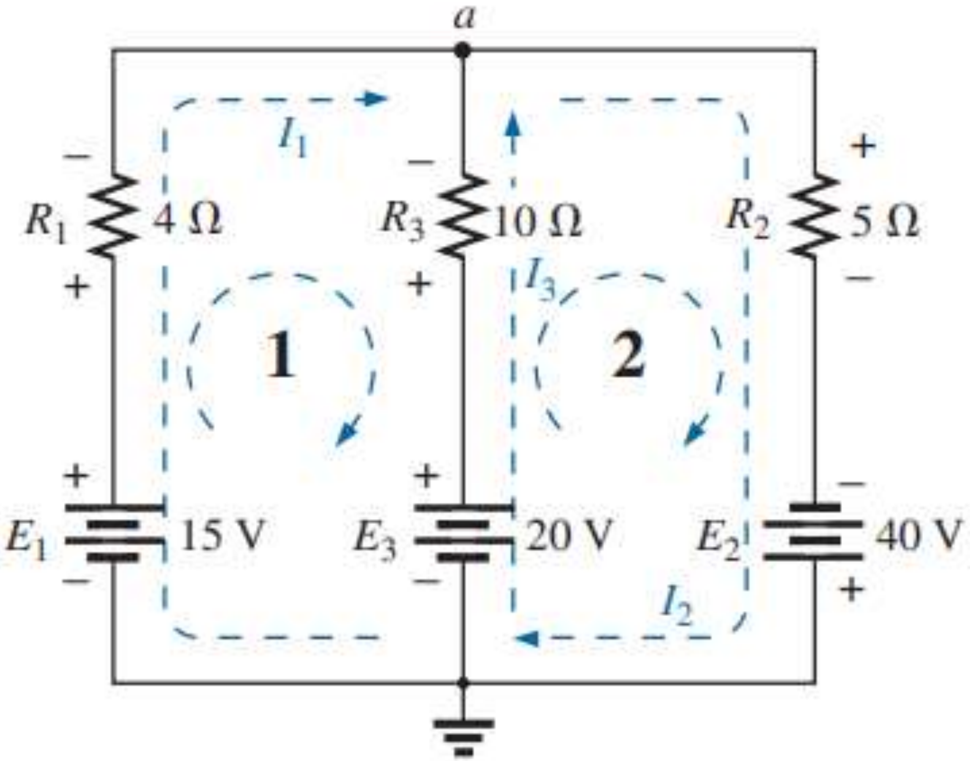
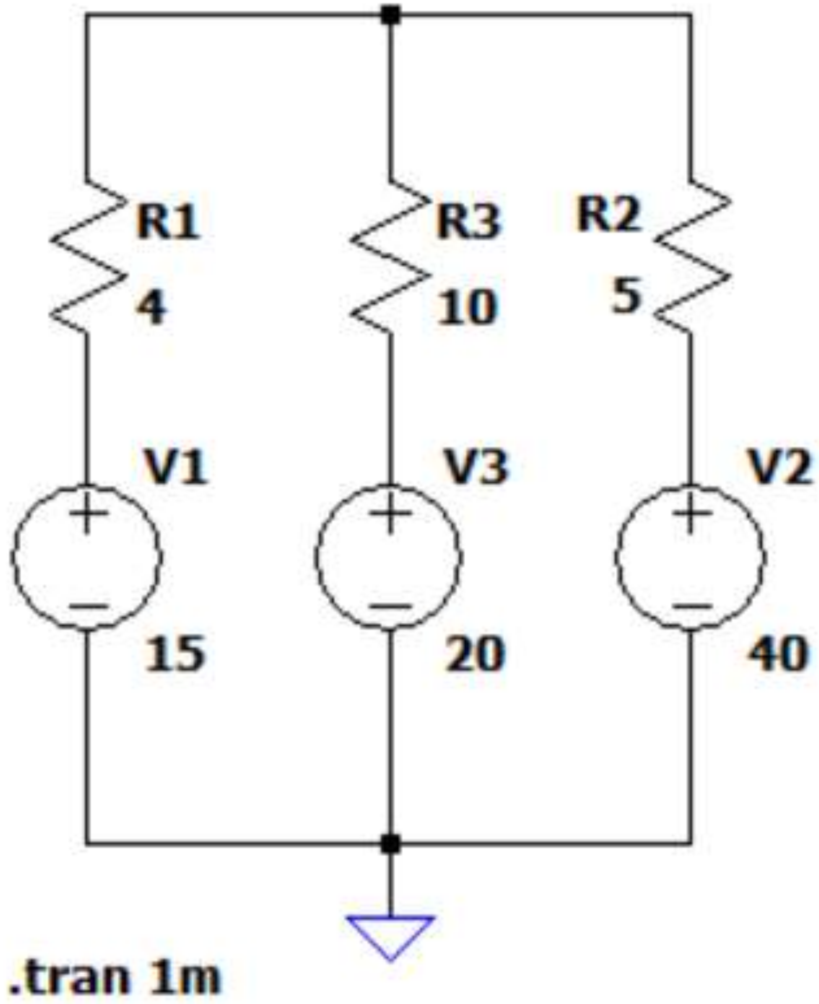
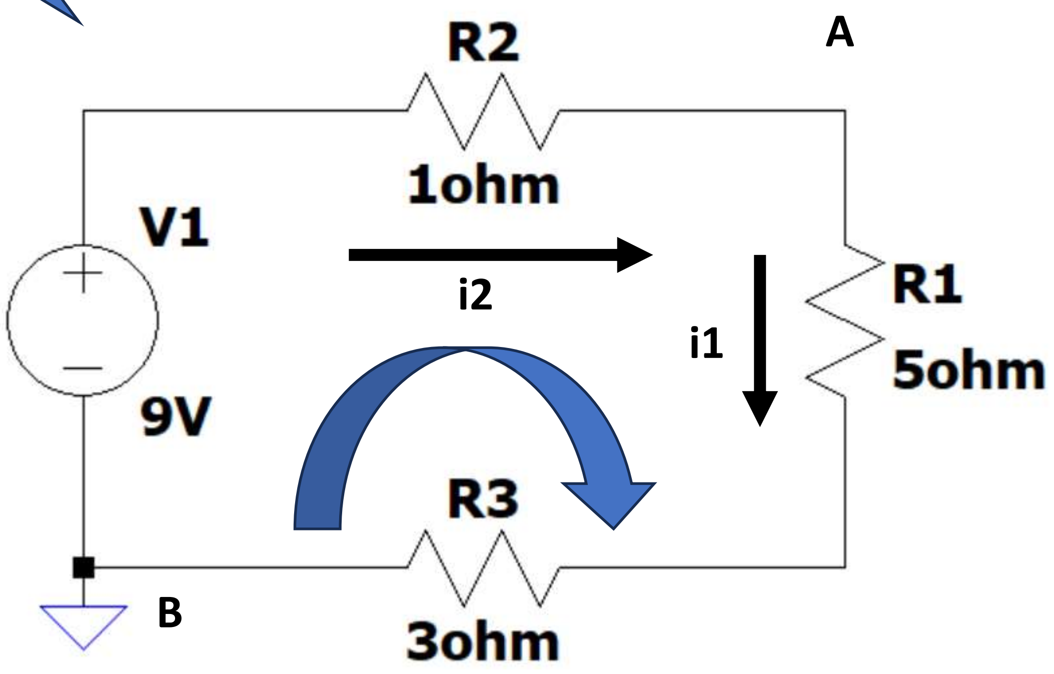


FIG. 8.31
Example 8.11.



EXERCIZES



V1=i1*R1
V1=1A * 5ohm = 5V

VAB = i1*R1 + i1*R3 = 1A*5ohm + 1A*3ohm = 8V

What i1 and i2 currents ?

RT= 1+5+3 = 9 ohm (Serial Resistances, ADD)

V=I*R

i1=V/R=9V/9ohm=1A (Volt, Ampere, Ohm)

i2=i1=i3 Single Closed Loop

Second Solution

KVL: left buttom, CW

-9V + i2*R2 + i1*R1 + i3*R3 =0

from geometry of the circuit

i1=i2=i3

-9 + i1*R2 + i1*R1 + i1*R3 = 0

-9 + i1*(R1+R2+R3) = 0

-9 + i1*9 = 0

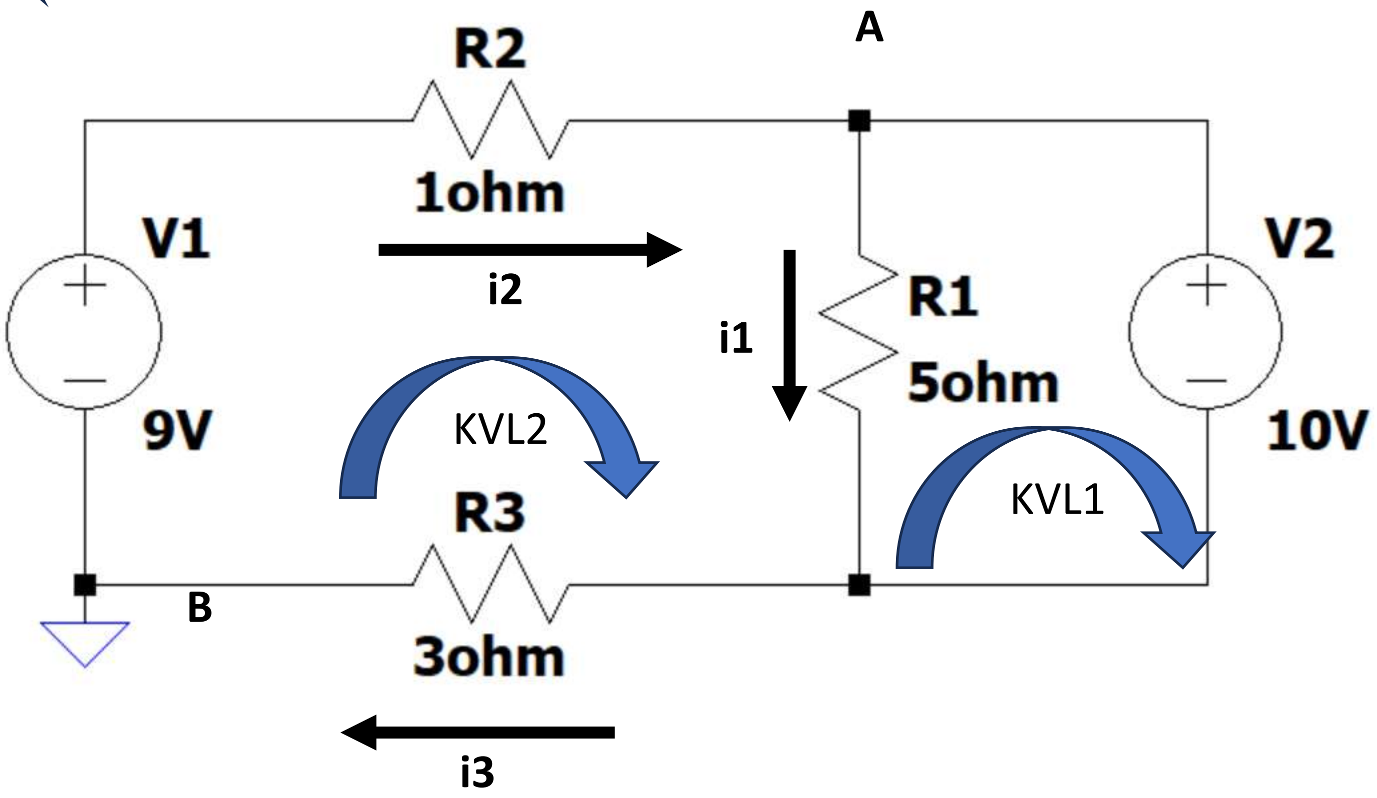
i1*9 = 9

i1=9/9 = 1A

V1 = i1 * R1

V1 = 1 * 5 = 5V (VOLT, AMPER, OHM

EXERCIZES



current i1 ?

Write KVL1:

-i1*R1 + 10V = 0

-i1*5 + 10 = 0

i1 = -10/-5=2A

current i2=?

KVL2:

-9 + i2*R2 + i1*R1 +i3*R3 = 0

-9 + i2*1 + 2*5 +i3*3 = 0

-9 + i2 + 10 + 3*i3 = 0

i2 = i3 by using KCL on 9V supply

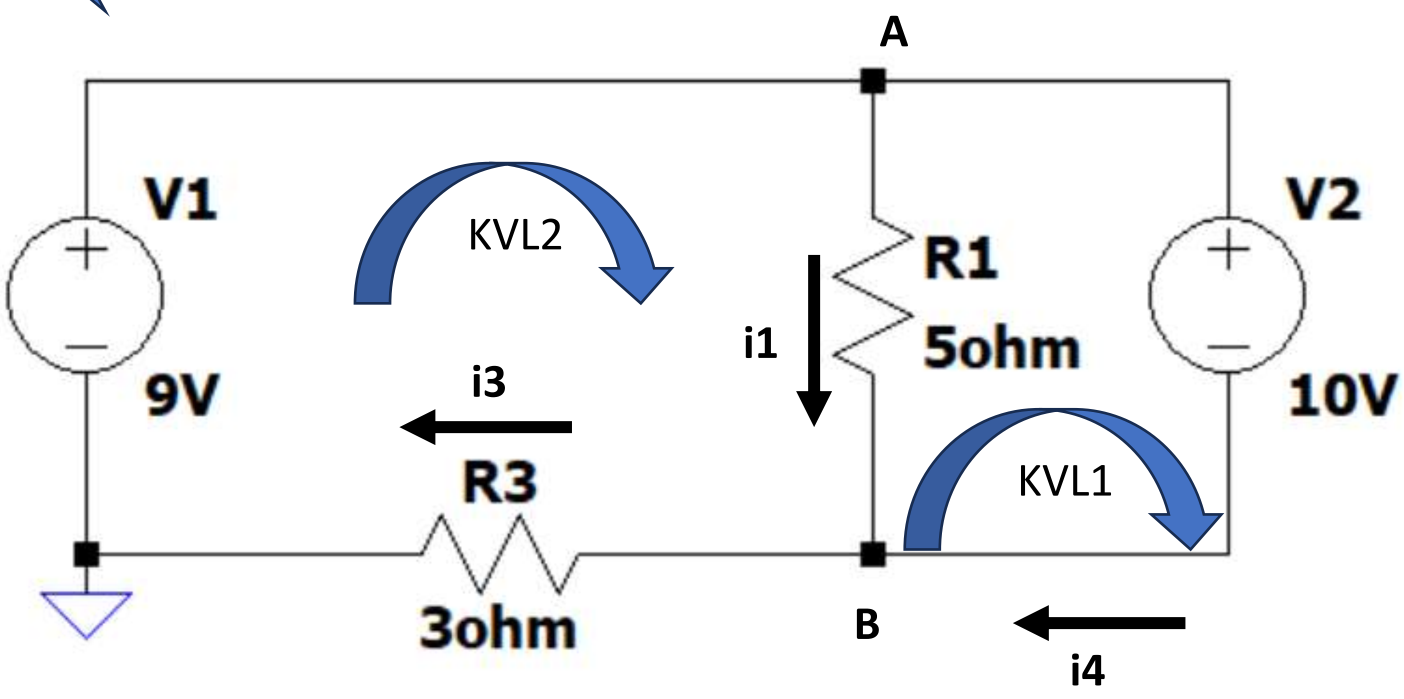
current coming IN = OUT

-9 + i2 + 10 + 3*i2 = 0

4*i2 = -1

i2 = -1/4 = -0.25A

EXERCIZES

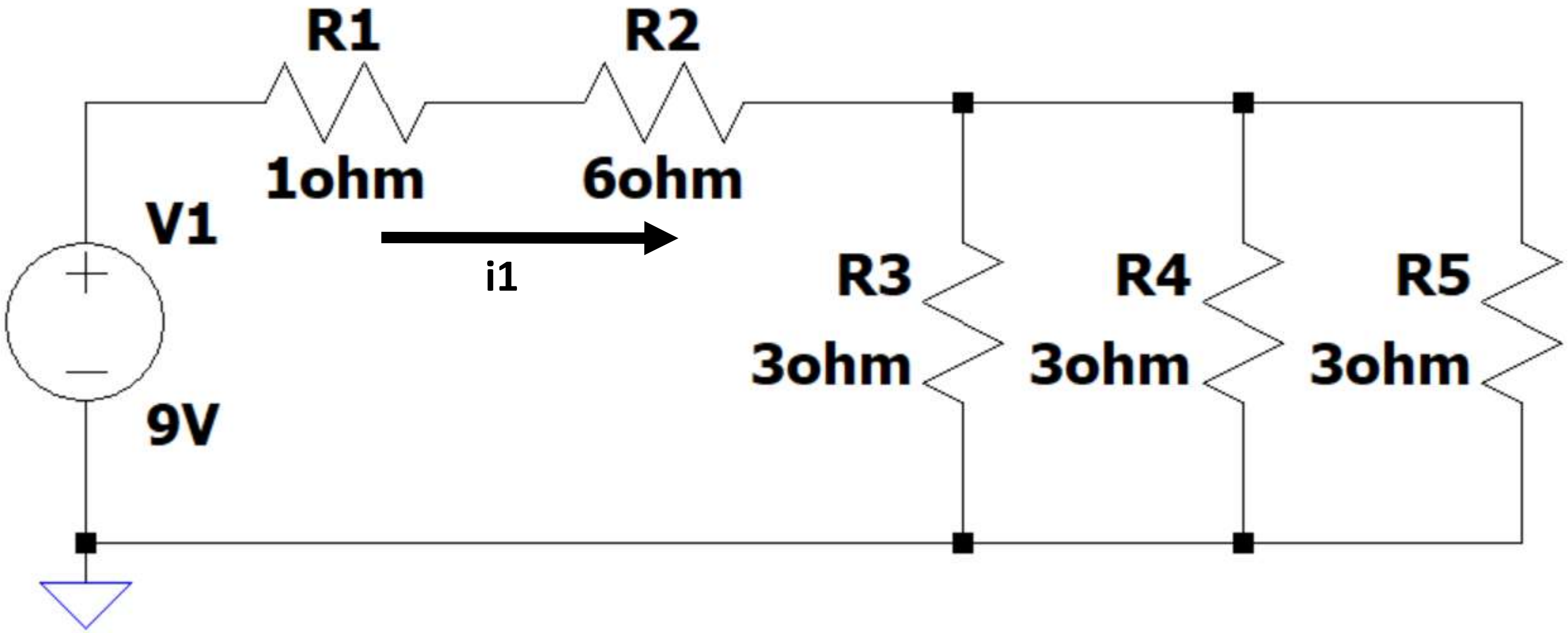


current i1 ?
KVL
-i1*R1 + 10 = 0
-i1*5 + 10 = 0
i1 = -10/-5 = 2A

current i3=?
KVL
-9 + i1*R1 + i3*R3 = 0
-9 + 2*5 +i3*3 = 0
i3*3 = -1 /3 = -0.333A
negative means it in REVERSE direction to your initial guess

i4=?
KCL at node B
i4 + i1 = i3
i4 + 2 = -0.33
i4 = -2.33A

EXERCIZES



Total resistance od the circuit

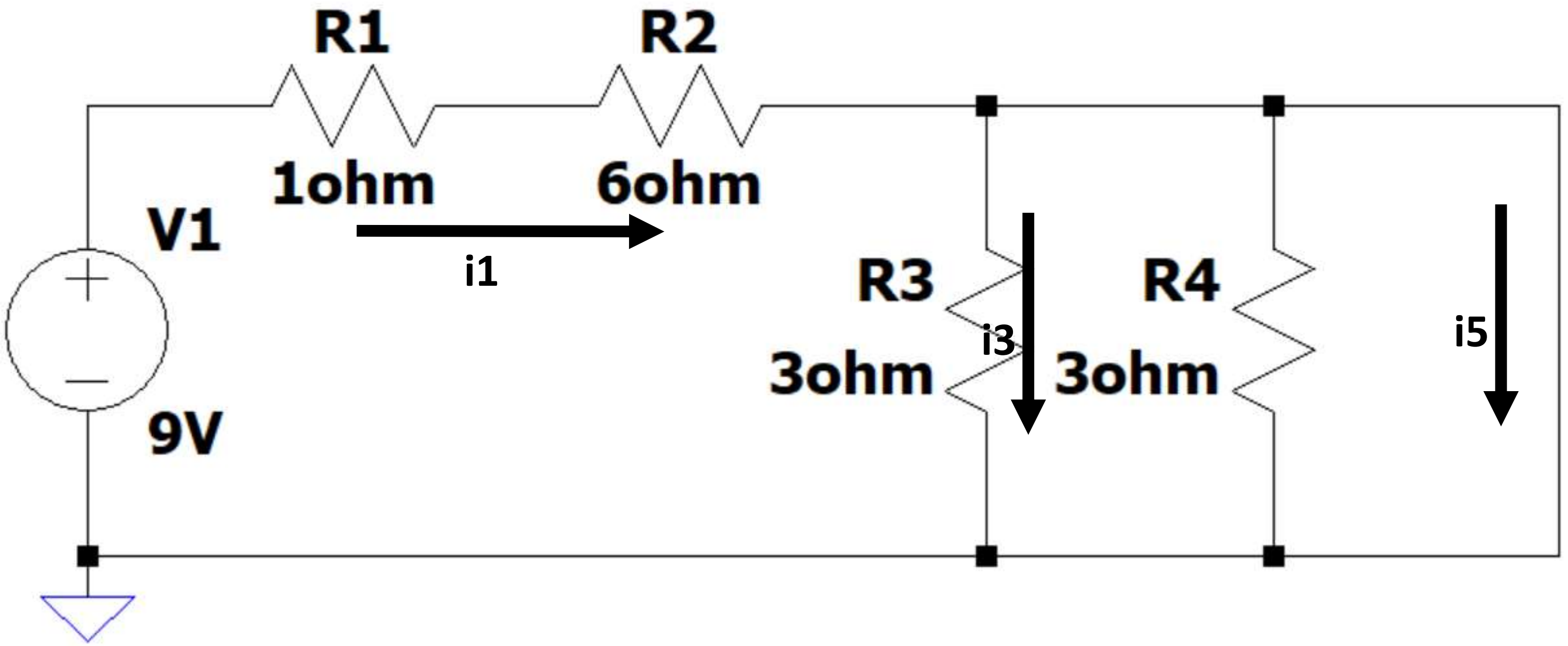
start with paralllel resistors

1/Rp = 1/R1 + 1/R2 + 1/R3
1/Rp = 1/3 + 1/3 +1/3
1/Rp = 1
Rp = 1ohm

RT = R1 + R2 + Rp
RT = 1 + 6 + 1
RT = 8 ohm

V=I*R
9 = i1 * RT
9 = i1*8ohm
i1=9/8=1.125A

EXERCIZES



Total resistance od the circuit

calculate i1=?

RT = R1 + R2 + short =7ohm
short=0

V=i1 * RT
9 = i1 * 7
i1=9/7=1.28A

i5=1.28A

i3=0

EXERCIZES

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.

Colors are:
BROWN-RED-ORANGE-GOLD

what is the resistor

1-2 resistor values
3rd color is how many ZEROS

R = 1 2 000   GOLD 5% tolerance
R = 12Kohm

what the colors of 370 ohm , 5% tolerance

ORANGE – VIOLET - BROWN – GOLD

EXERCIZES

AWG Size	Diameter (mm)	Max Current Capacity (A)*
0	8.25 mm	125 A
1	7.35 mm	110 A
2	6.54 mm	95 A
3	5.83 mm	80 A
4	5.19 mm	70 A
5	4.62 mm	55 A
6	4.12 mm	45 A
7	3.67 mm	40 A
8	3.26 mm	35 A
9	2.91 mm	30 A
10	2.59 mm	25 A
11	2.30 mm	20 A
12	2.05 mm	20 A
13	1.83 mm	15 A
14	1.63 mm	15 A
15	1.45 mm	10 A
16	1.29 mm	10 A
17	1.15 mm	7 A
18	1.02 mm	7 A
19	0.91 mm	5 A
20	0.81 mm	5 A
21	0.72 mm	3 A
22	0.64 mm	3 A
23	0.57 mm	2 A
24	0.51 mm	2 A

Calculate resistance of 2 meter 4AWG cable

R= p * L / A

R = p*L*4*10^6 / (pi*D^2)

L is in meter, D is in mm

p=1.68 e-8

R=0.002 ohm = 2 mohm

Material	Resistivity, ρ, at 20 °C (Ω·m)
Silver[d]	1.59×10^{-8}
Copper[e]	1.68×10^{-8}
Annealed copper[f]	1.72×10^{-8}
Gold[g]	2.44×10^{-8}
Aluminium[h]	2.65×10^{-8}

EXERCIZES

Calculate max current of 1/2W, 68ohm resistor ?

P = V * I, V = I * R

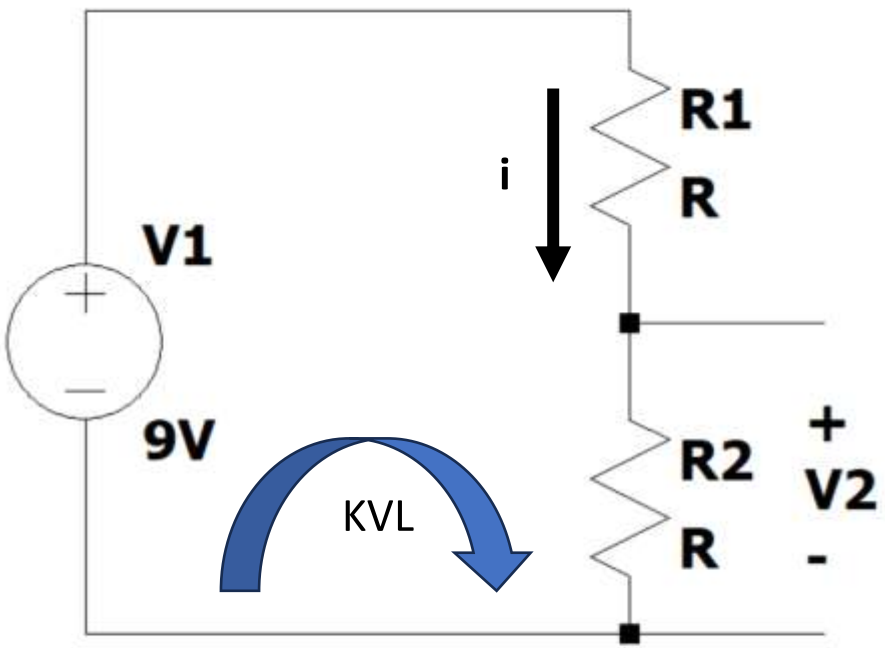
P = I^2 * R, P=V^2/R

0.5 = I^2 * 68

I^2 = 0.5/68

I = sqrt (0.5/68) = 0.085 A = 85 mA

EXERCIZES



KVL:

$-9V + i*R1 + i*R2 = 0$

$i=9V / (R1+R2)$

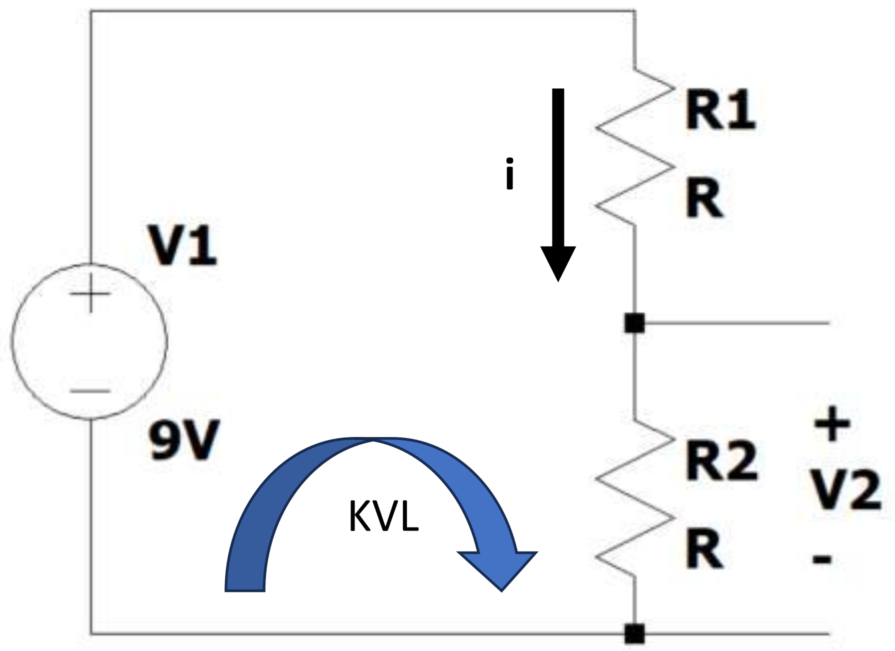
$V2 = i*R2$

$V2=9V * R2 / (R2+R1)$

$V2=5V$, $R1=4Kohm$, $R2=?$
$5V = 9V * R2/(R2+4K)$

$R2=5K$

EXERCIZES



V2=9V * R2 / (R2+R1)

V2=5V, R1=?, R2=?

R2 = 5ohm

5=9*5/(5+R1)
25+5*R1 = 45
R1=20/5=4 ohm

R2=10ohm
5=9*10/(10+R1)
50+5*R1 = 90
R1=40/5 = 8ohm

Network Theorems

9

Objectives

- *Become familiar with the superposition theorem and its unique ability to separate the impact of each source on the quantity of interest.*
- *Be able to apply Thévenin's theorem to reduce any two-terminal, series-parallel network with any number of sources to an equivalent circuit consisting of a single voltage source and a series resistor.*
- *Become familiar with Norton's theorem and how it can be used to reduce any two-terminal, series-parallel network with any number of sources to an equivalent circuit consisting of a single current source and a parallel resistor.*
- *Understand how to apply the maximum power transfer theorem to determine the maximum power to a load and to choose a load that will receive maximum power.*
- *Become aware of the reduction powers of Millman's theorem and the powerful implications of the substitution and reciprocity theorems.*

SUPERPOSITION THEOREM

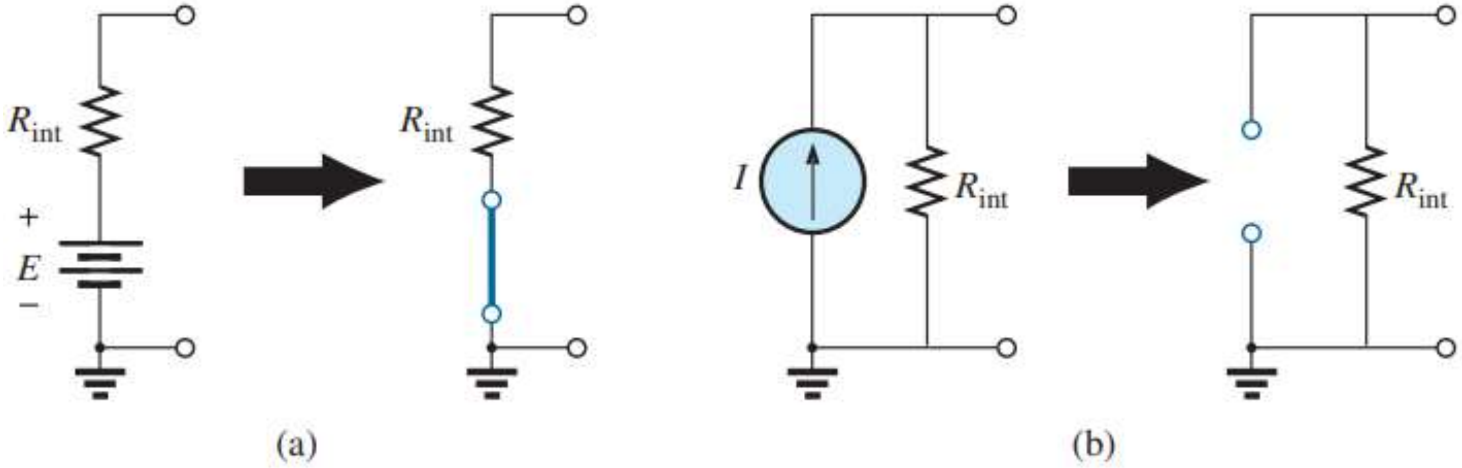
The superposition theorem states the following:

The current through, or voltage across, any element of a network is equal to the algebraic sum of the currents or voltages produced independently by each source.

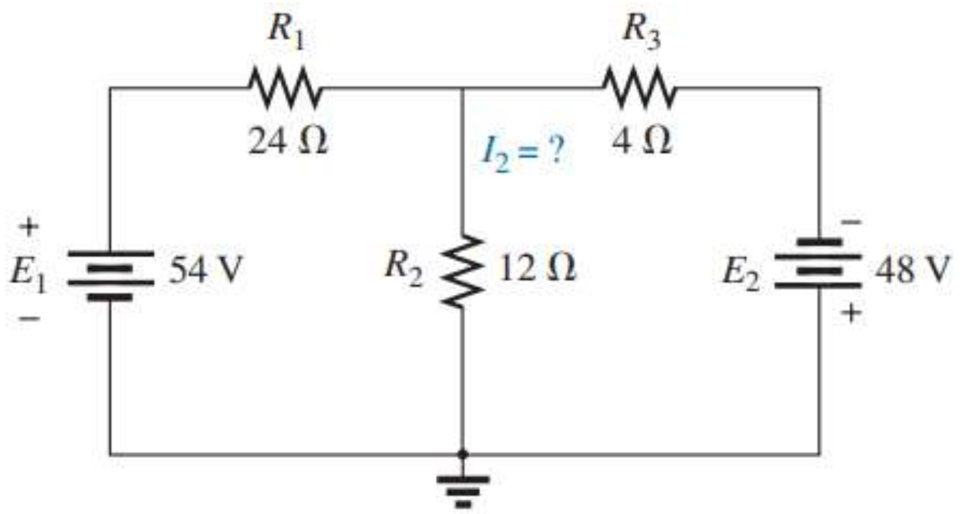
SUPERPOSITION THEOREM

In total, therefore, when removing a voltage source from a network schematic, replace it with a direct connection (short circuit) of zero ohms. Any internal resistance associated with the source must remain in the network.

In total, therefore, when removing a current source from a network schematic, replace it by an open circuit of infinite ohms. Any internal resistance associated with the source must remain in the network.



SUPERPOSITION THEOREM



EXAMPLE 9.2 Using the superposition theorem, determine the current through the 12 Ω resistor in Fig. 9.8. Note that this is a two-source network of the type examined in the previous chapter when we applied branch-current analysis and mesh analysis.

Solution: Considering the effects of the 54 V source requires replacing the 48 V source by a short-circuit equivalent as shown in Fig. 9.9. The result is that the 12 Ω and 4 Ω resistors are in parallel.

The total resistance seen by the source is therefore

$$R_T = R_1 + R_2 \| R_3 = 24\ \Omega + 12\ \Omega \| 4\ \Omega = 24\ \Omega + 3\ \Omega = 27\ \Omega$$

and the source current is

$$I_s = \frac{E_1}{R_T} = \frac{54\ \text{V}}{27\ \Omega} = 2\ \text{A}$$

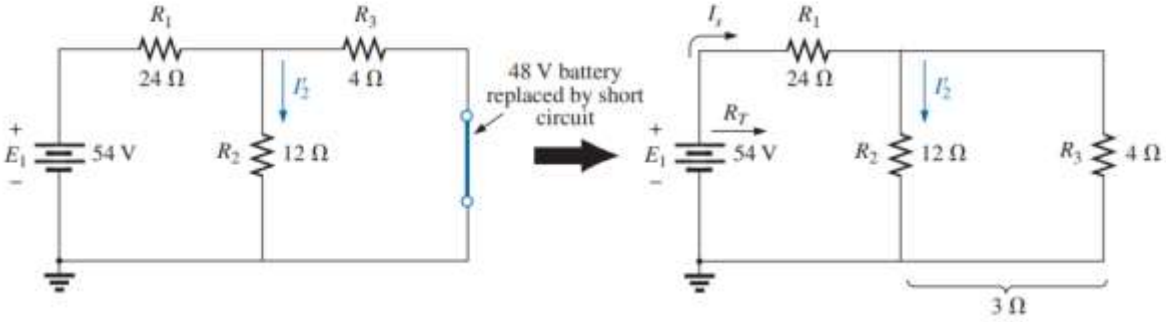


FIG. 9.9
Using the superposition theorem to determine the effect of the 54 V voltage source on current I_2 in Fig. 9.8.

Using the current divider rule results in the contribution to I_2 due to the 54 V source:

$$I_2' = \frac{R_3 I_s}{R_3 + R_2} = \frac{(4\ \Omega)(2\ \text{A})}{4\ \Omega + 12\ \Omega} = 0.5\ \text{A}$$

SUPERPOSITION THEOREM

If we now replace the 54 V source by a short-circuit equivalent, the network in Fig. 9.10 results. The result is a parallel connection for the 12 Ω and 24 Ω resistors.

Therefore, the total resistance seen by the 48 V source is

$$R_T = R_3 + R_2 \| R_1 = 4\ \Omega + 12\ \Omega \| 24\ \Omega = 4\ \Omega + 8\ \Omega = 12\ \Omega$$

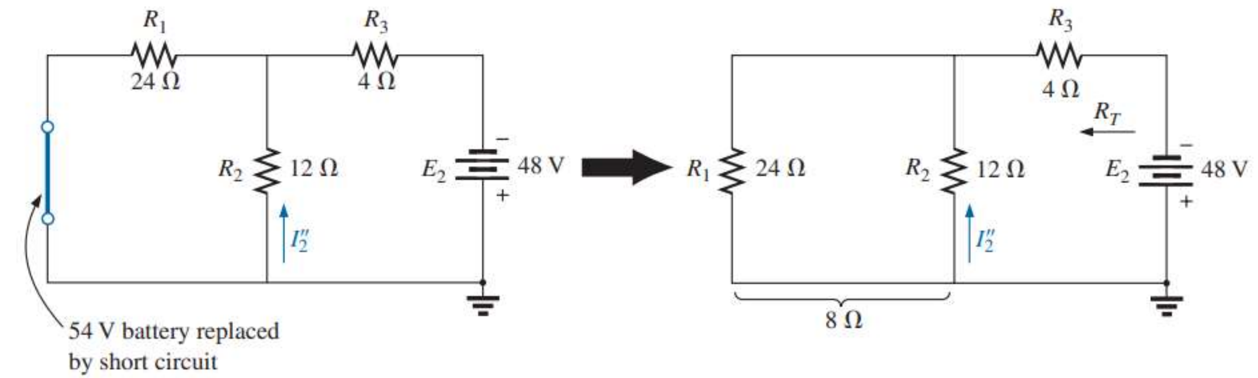


FIG. 9.10
Using the superposition theorem to determine the effect of the 48 V voltage source on current I_2 in Fig. 9.8.

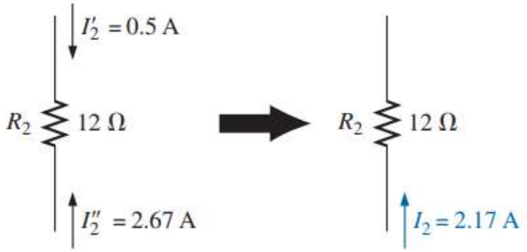


FIG. 9.11
Using the results of Figs. 9.9 and 9.10 to determine current I_2 for the network in Fig. 9.8.

and the source current is

$$I_s = \frac{E_2}{R_T} = \frac{48\ \text{V}}{12\ \Omega} = 4\ \text{A}$$

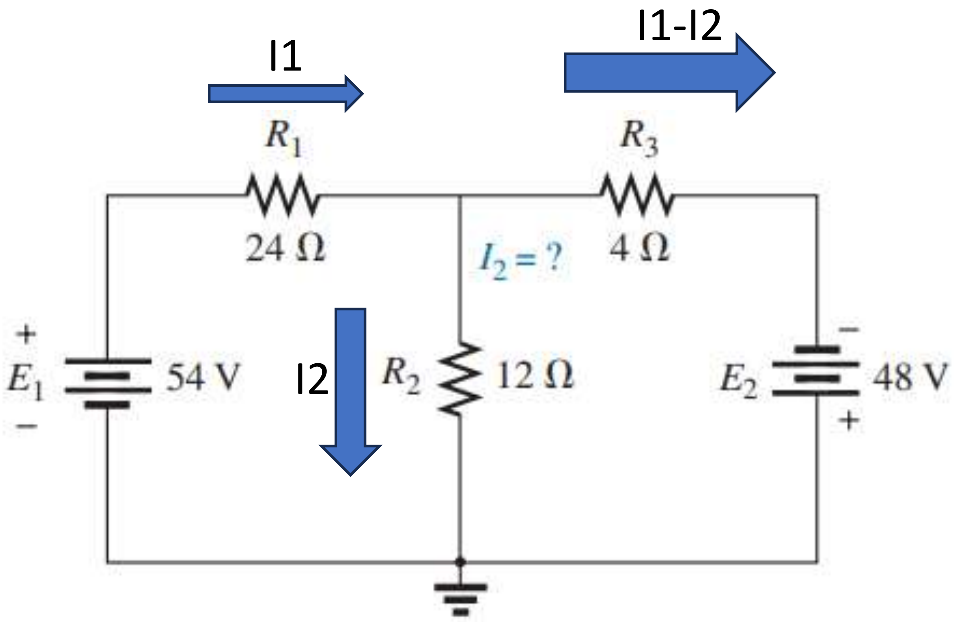
Applying the current divider rule results in

$$I_2'' = \frac{R_1(I_s)}{R_1 + R_2} = \frac{(24\ \Omega)(4\ \text{A})}{24\ \Omega + 12\ \Omega} = 2.67\ \text{A}$$

It is now important to realize that current I_2 due to each source has a different direction, as shown in Fig. 9.11. The net current therefore is the difference of the two and in the direction of the larger as follows:

$$I_2 = I_2'' - I_2' = 2.67\ \text{A} - 0.5\ \text{A} = \mathbf{2.17\ A}$$

SUPERPOSITION THEOREM vs KVL



KVL1, KVL2

-54 + I1.24 + I2.12 = 0

-I2.12 + (I1-I2).4 -48 = 0

24.I1 + 12.I2 = 54

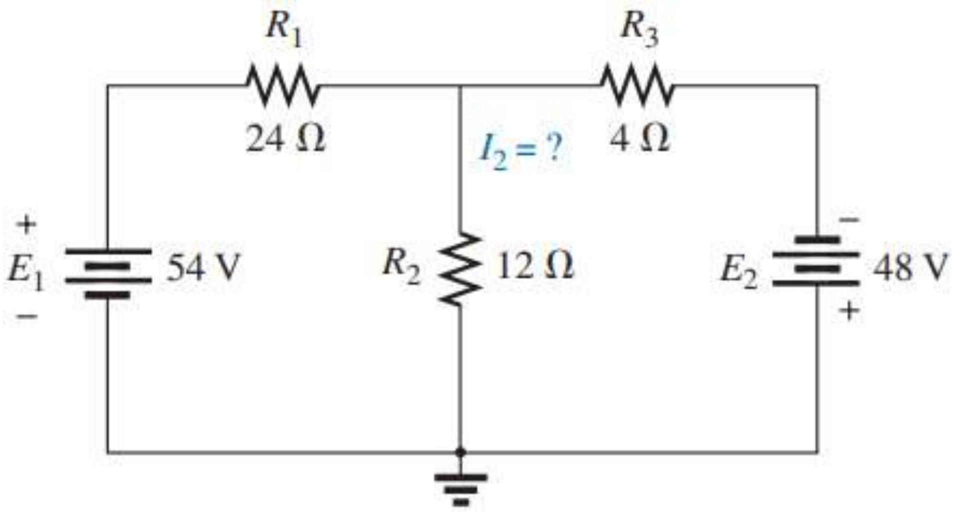
4.I1 – 16.I2 = 48 x(-6)

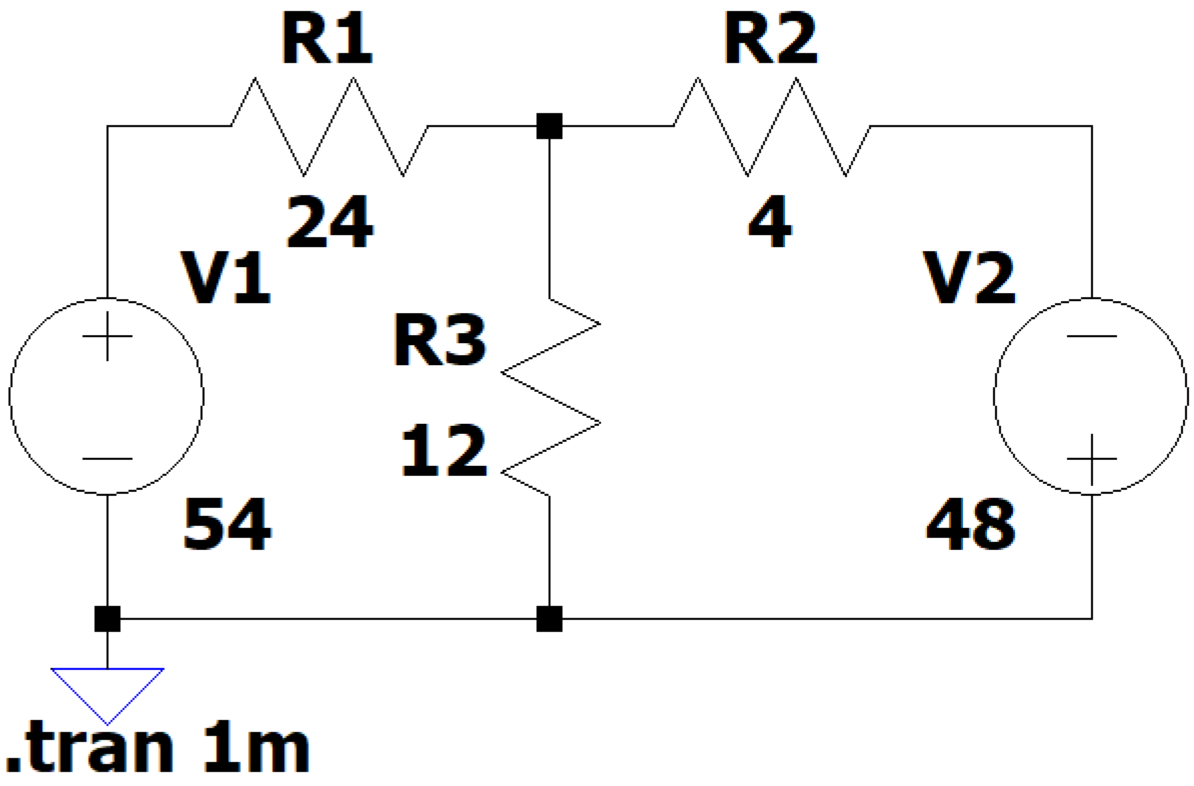
12.I2 + 96. I2 = 54 – 288

108.I2 = -234

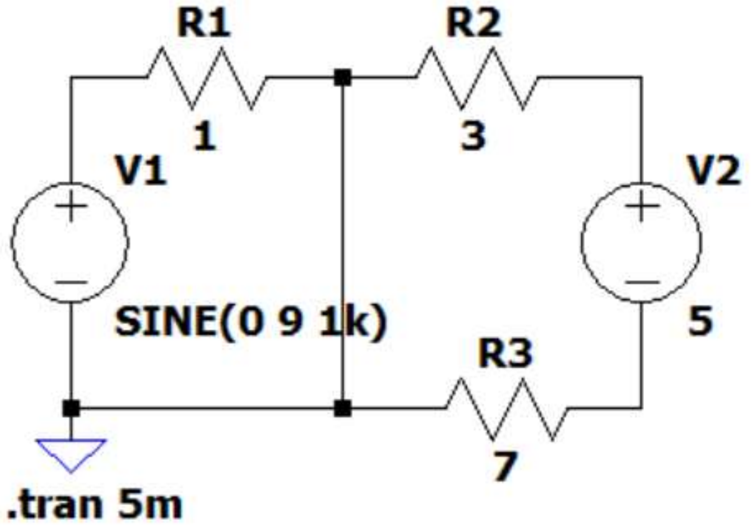
I2 = -234/108 = -2.17A (Aymen noticed that negative)

KVL vs LTspice





KVL vs Superposition



KVL1

-9sin(wt) +i1.1 = 0

i1= 9*sin(wt)

KVL2

- **i2*3 + 5 –i2*7 = 0**

i2 = 0.5A   DC

THÉVENIN'S THEOREM

Any two-terminal dc network can be replaced by an equivalent circuit consisting solely of a voltage source and a series resistor as shown in Fig. 9.23.

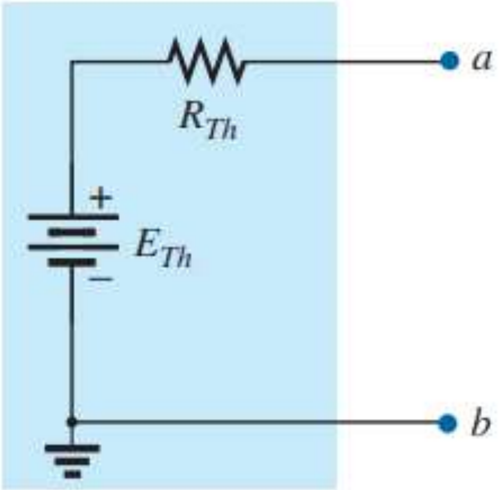


FIG. 9.23
Thévenin equivalent circuit.

THÉVENIN’S THEOREM

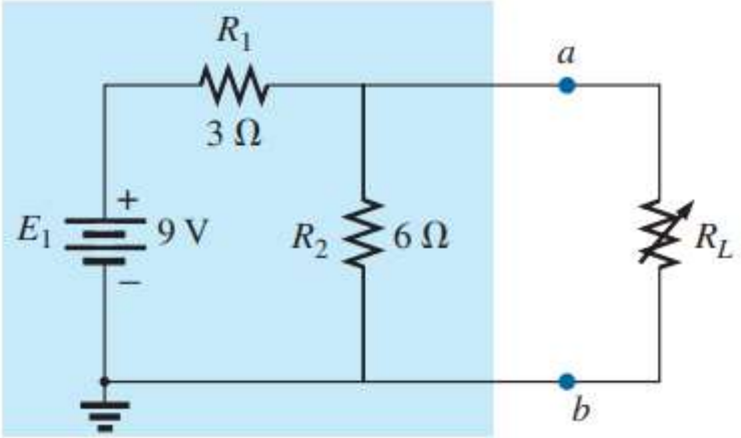
Thévenin’s Theorem Procedure

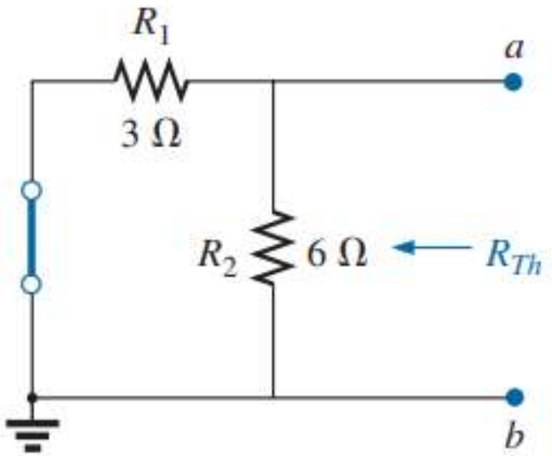
Preliminary:

1. *Remove that portion of the network where the Thévenin equivalent circuit is found. In Fig. 9.25(a), this requires that the load resistor R_L be temporarily removed from the network.*
2. *Mark the terminals of the remaining two-terminal network. (The importance of this step will become obvious as we progress through some complex networks.)*

R_{Th}:

3. *Calculate R_{Th} by first setting all sources to zero (voltage sources are replaced by short circuits and current sources by open circuits) and then finding the resultant resistance between the two marked terminals. (If the internal resistance of the voltage and/or current sources is included in the original network, it must remain when the sources are set to zero.)*





(a)

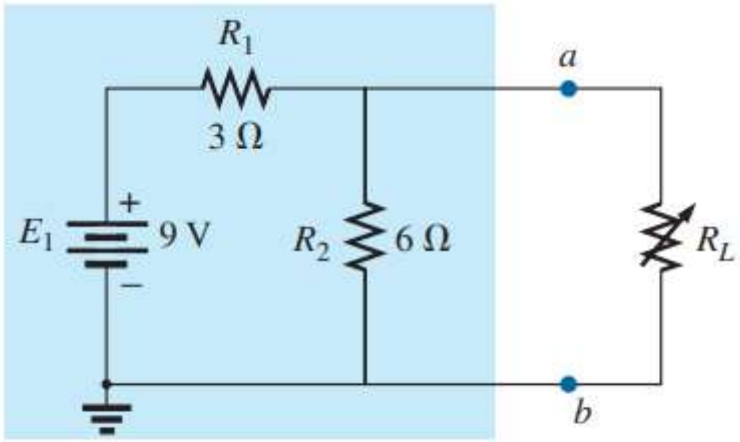
THÉVENIN'S THEOREM

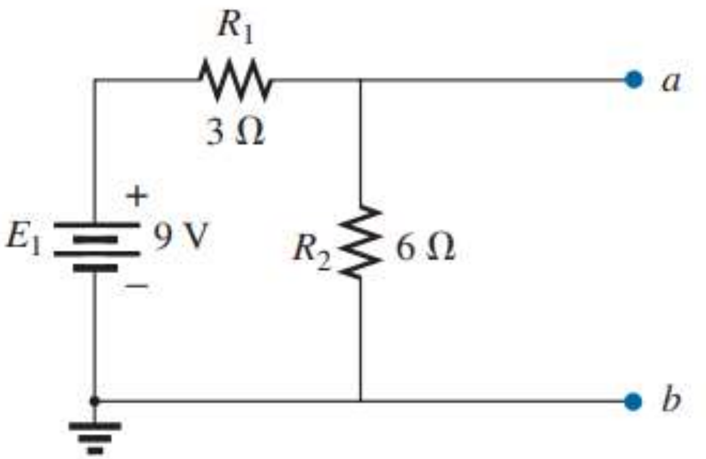
E_{Th}:

4. **Calculate E_{Th} by first returning all sources to their original position and finding the open-circuit voltage between the marked terminals. (This step is invariably the one that causes most confusion and errors. In all cases, keep in mind that it is the open-circuit potential between the two terminals marked in step 2.)**

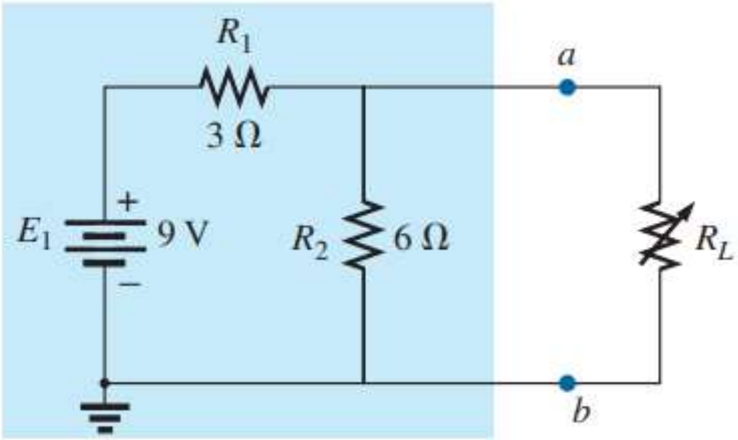
Final step:

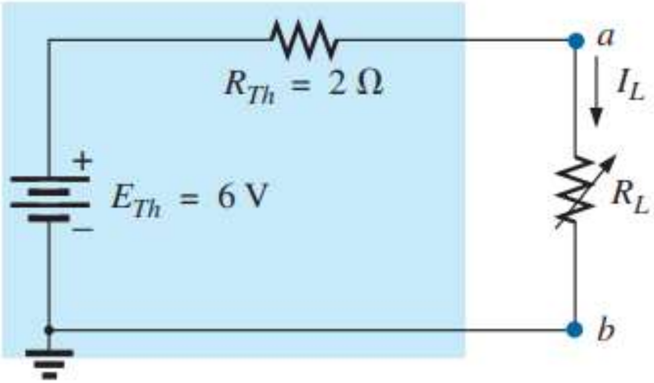
5. **Draw the Thévenin equivalent circuit with the portion of the circuit previously removed replaced between the terminals of the equivalent circuit. This step is indicated by the placement of the resistor R_L between the terminals of the Thévenin equivalent circuit as shown in Fig. 9.25(b).**

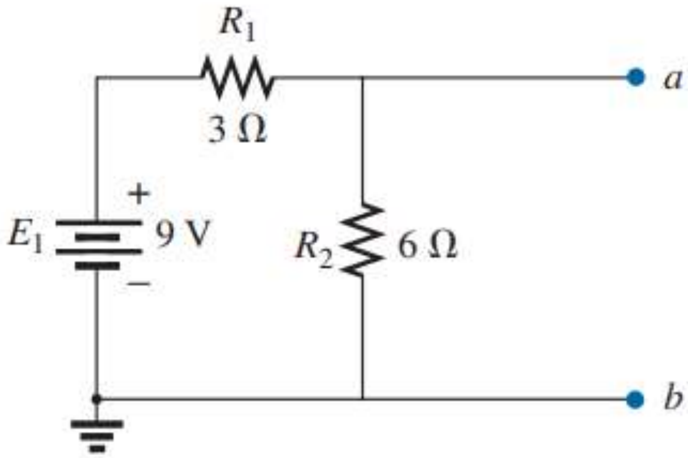


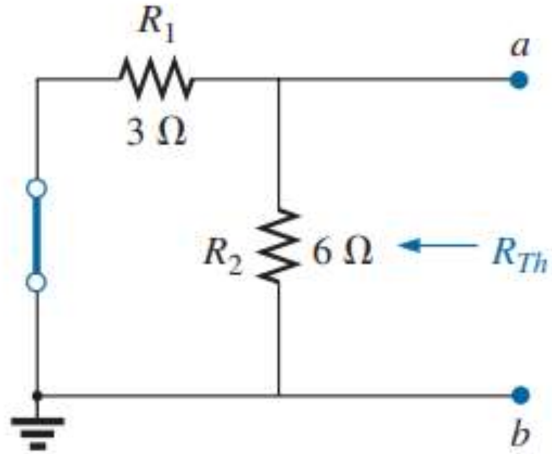


THÉVENIN'S THEOREM









(a)

THÉVENIN'S THEOREM

EXAMPLE 9.8 Find the Thévenin equivalent circuit for the network in the shaded area of the network in Fig. 9.37. Note in this example that there is no need for the section of the network to be preserved to be at the "end" of the configuration.

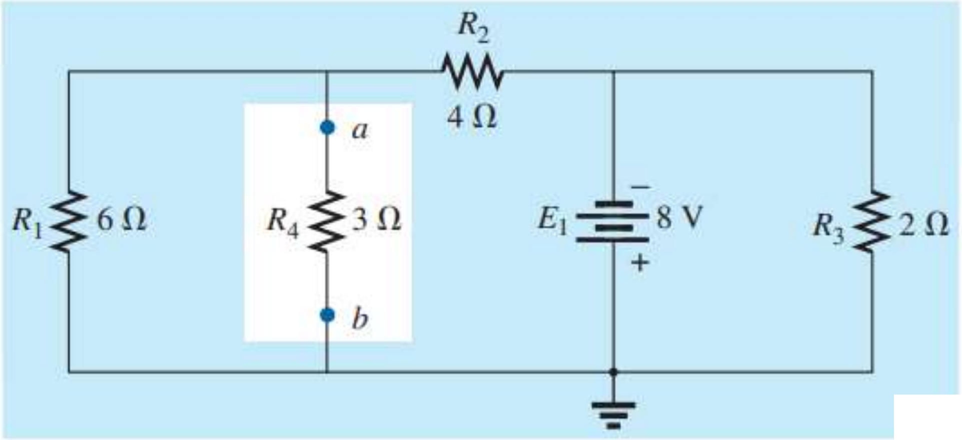


FIG. 9.37
Example 9.8.

$$R_{Th} = R_1 \| R_2 = \frac{(6\ \Omega)(4\ \Omega)}{6\ \Omega + 4\ \Omega} = \frac{24\ \Omega}{10} = \mathbf{2.4\ \Omega}$$

Solution:

Steps 1 and 2: See Fig. 9.38.

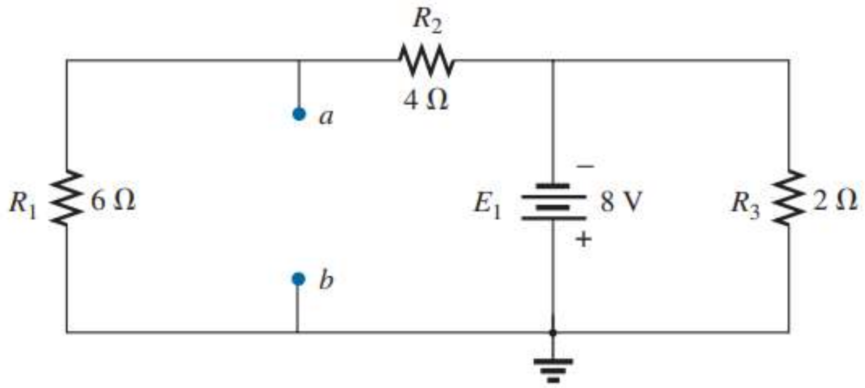
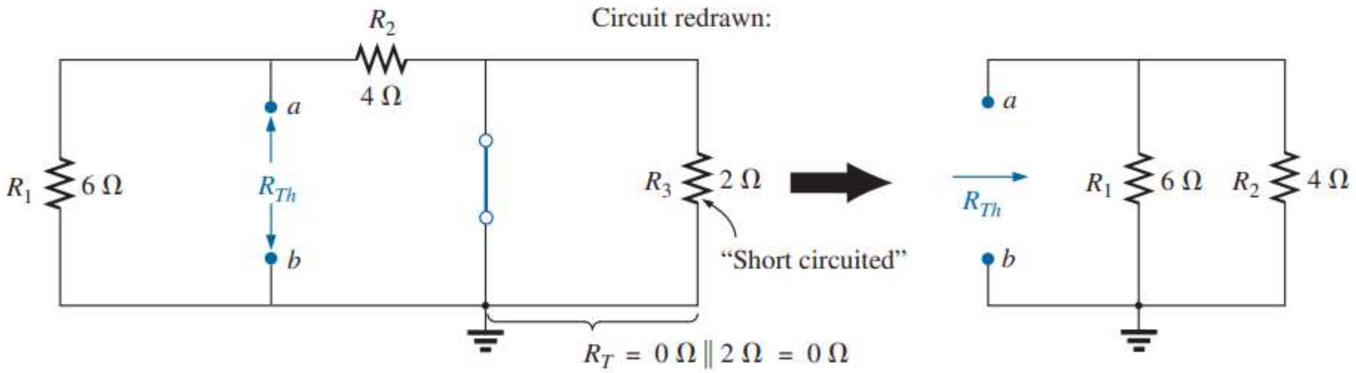


FIG. 9.38
Identifying the terminals of particular interest for the network in Fig. 9.37.



THÉVENIN’S THEOREM

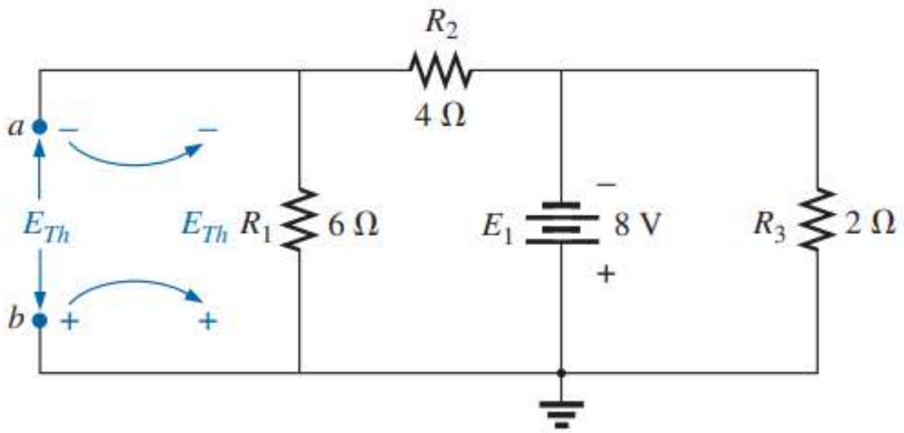
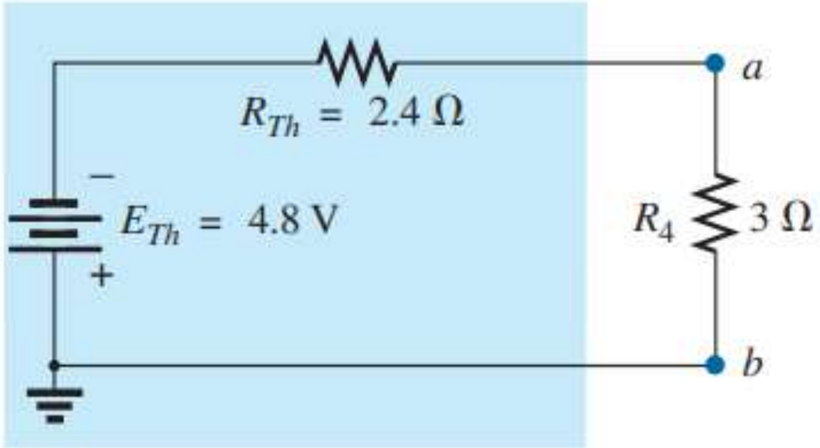
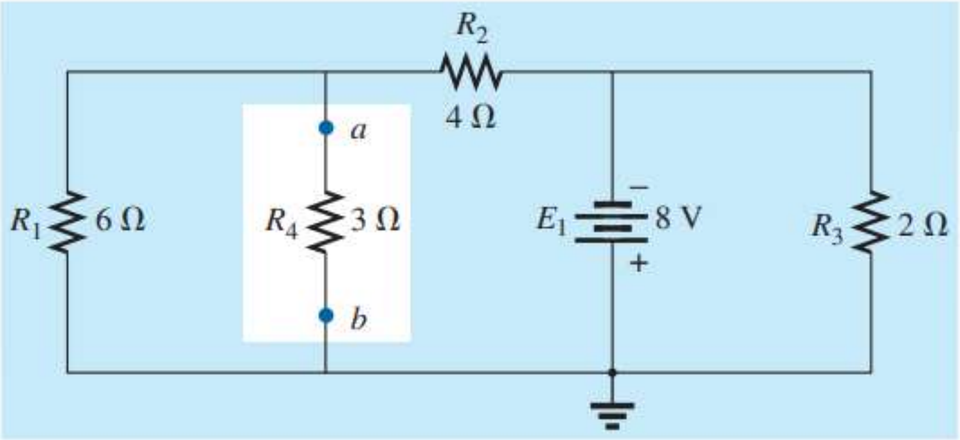


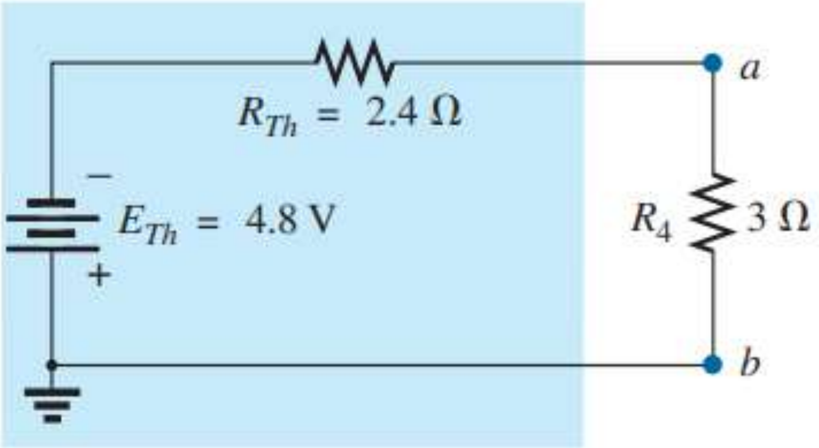
FIG. 9.40
Determining E_{Th} for the network in Fig. 9.38.



$$E_{Th} = \frac{R_1 E_1}{R_1 + R_2} = \frac{(6\ \Omega)(8\ \text{V})}{6\ \Omega + 4\ \Omega} = \frac{48\ \text{V}}{10} = \mathbf{4.8\ V}$$

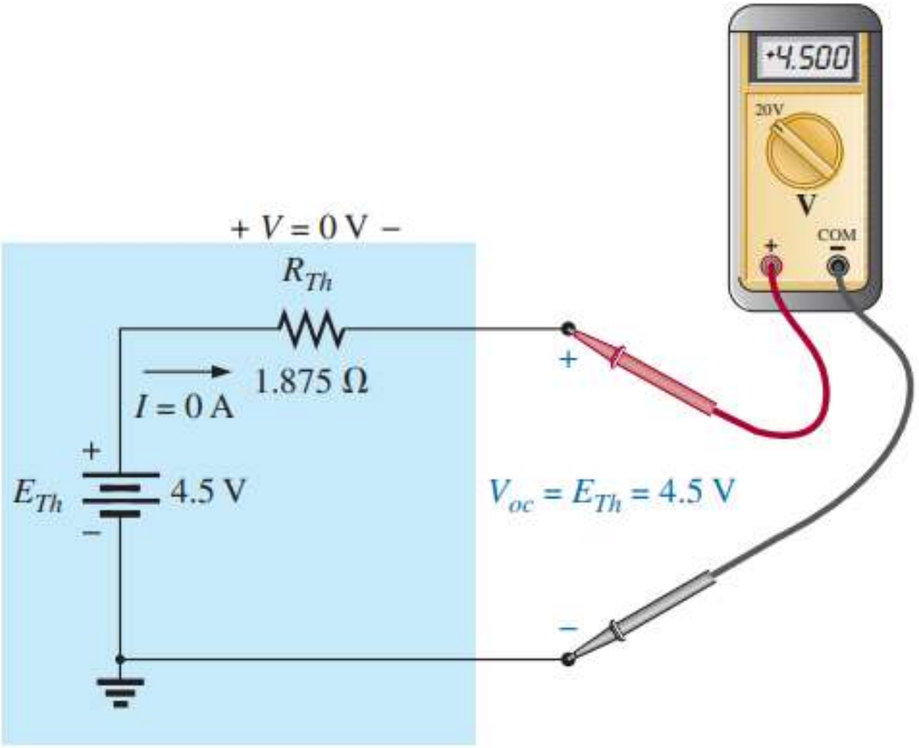
THÉVENIN'S THEOREM



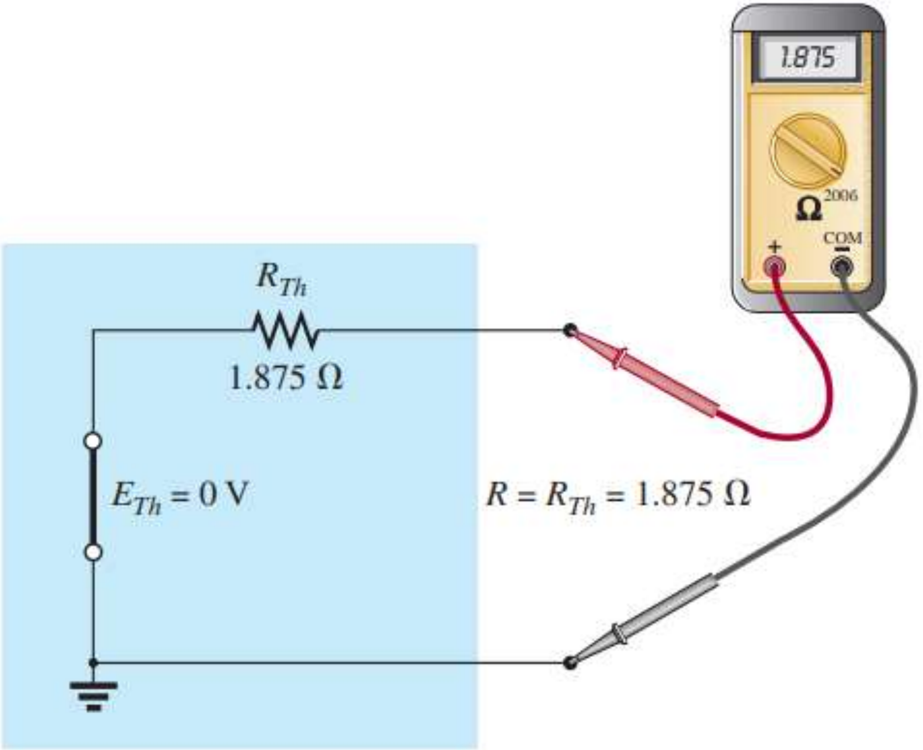


$$E_{Th} = \frac{R_1 E_1}{R_1 + R_2} = \frac{(6\ \Omega)(8\ \mathrm{V})}{6\ \Omega + 4\ \Omega} = \frac{48\ \mathrm{V}}{10} = \mathbf{4.8\ V}$$

THÉVENIN'S THEOREM-LAB



(b)



(b)

NORTON’S THEOREM

Any two-terminal linear bilateral dc network can be replaced by an equivalent circuit consisting of a current source and a parallel resistor, as shown in Fig. 9.65.

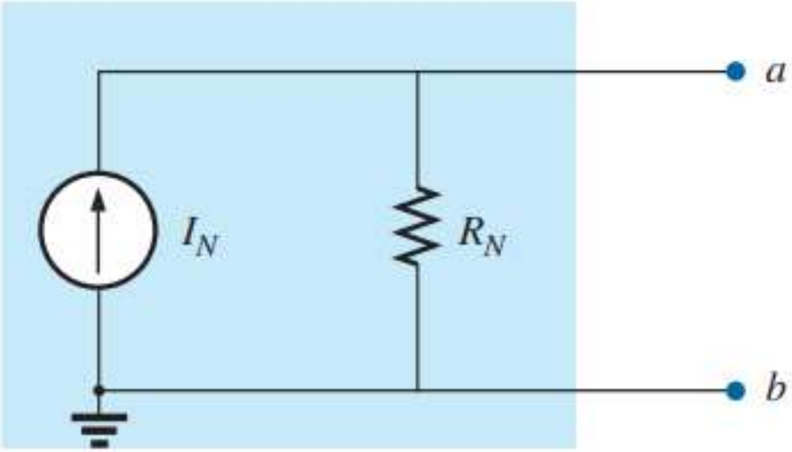


FIG. 9.65
Norton equivalent circuit.

MAXIMUM POWER TRANSFER THEOREM

A load will receive maximum power from a network when its resistance is equal to the Thévenin resistance of the network applied to the load. That is,

$$\boxed{R_L = R_{Th}} \qquad (9.2)$$

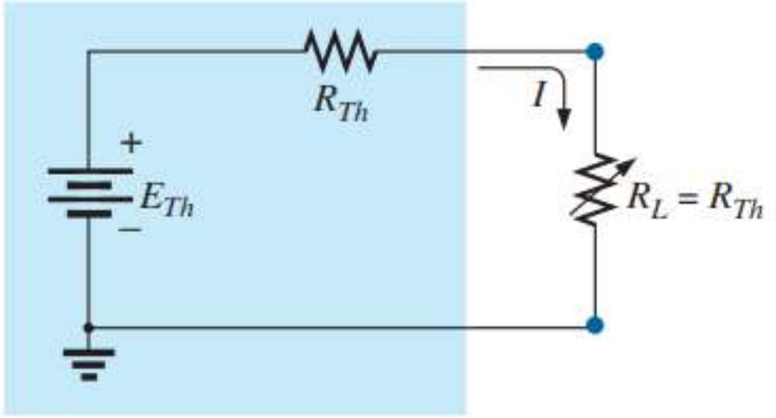
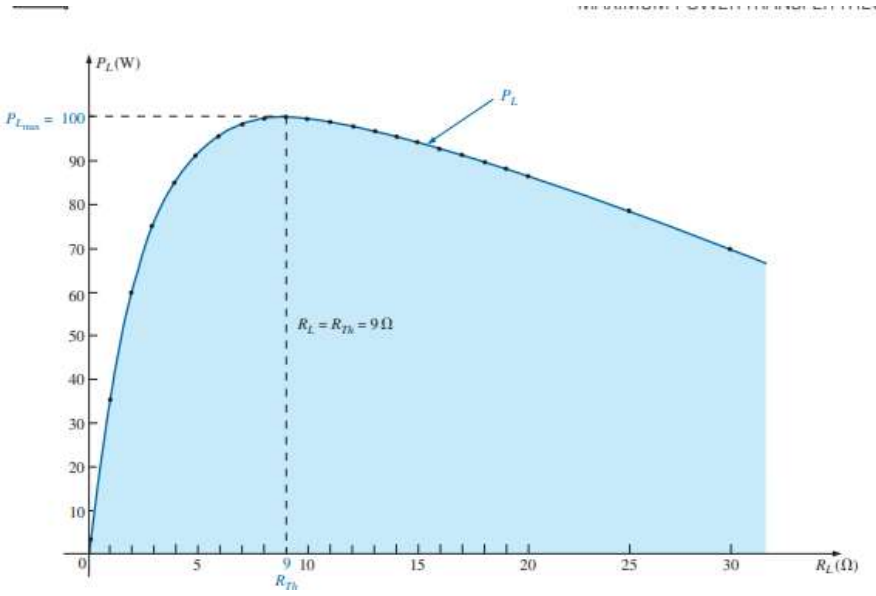


FIG. 9.84
Defining the conditions for maximum pow to a load using the Thévenin equivalent circuit.



PL = I^2 x RL
I=E/(RT+RL)
PL=E^2xRL / (RT + RL)^2

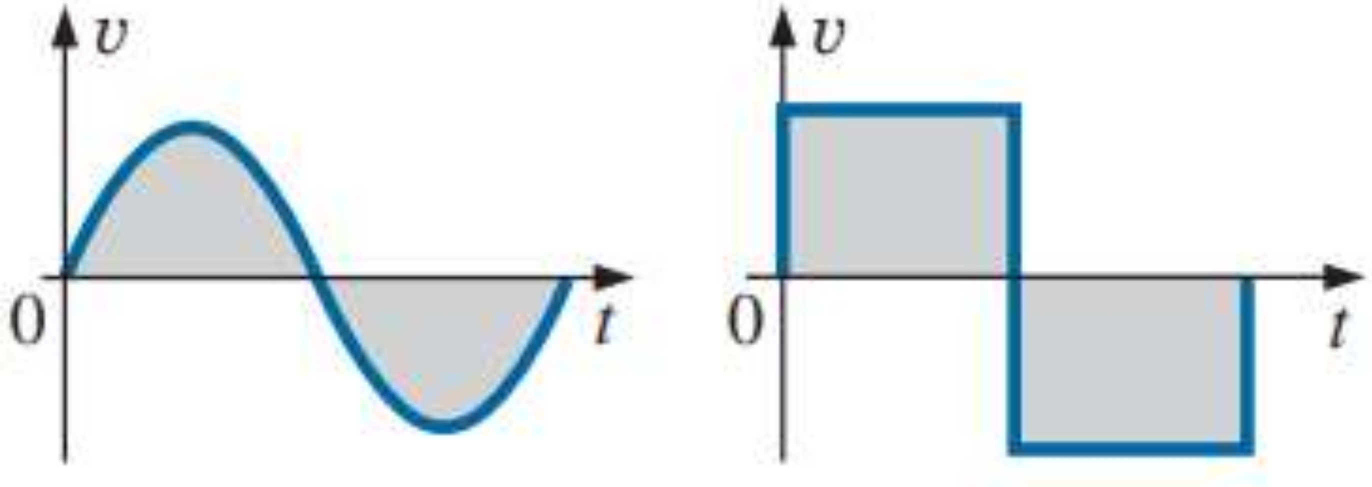
13

Sinusoidal Alternating Waveforms

Objectives

- *Become familiar with the characteristics of a sinusoidal waveform, including its general format, peak value, peak-to-peak value, period, and frequency.*
- *Be able to determine the phase relationship between two sinusoidal waveforms of the same frequency and which one leads or lags.*
- *Understand how to calculate the average and effective values of any waveform.*
- *Become familiar with the use of instruments designed to measure ac quantities.*

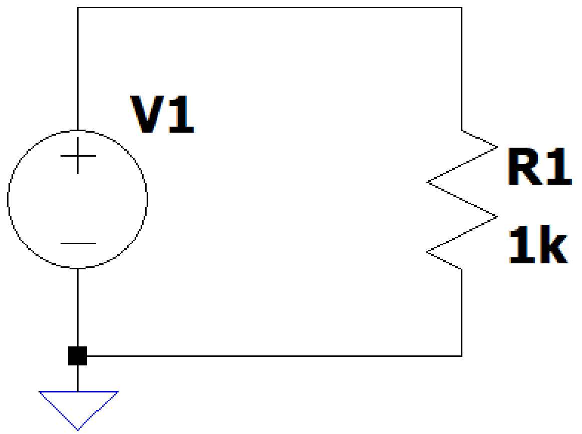
Alternating Waveforms



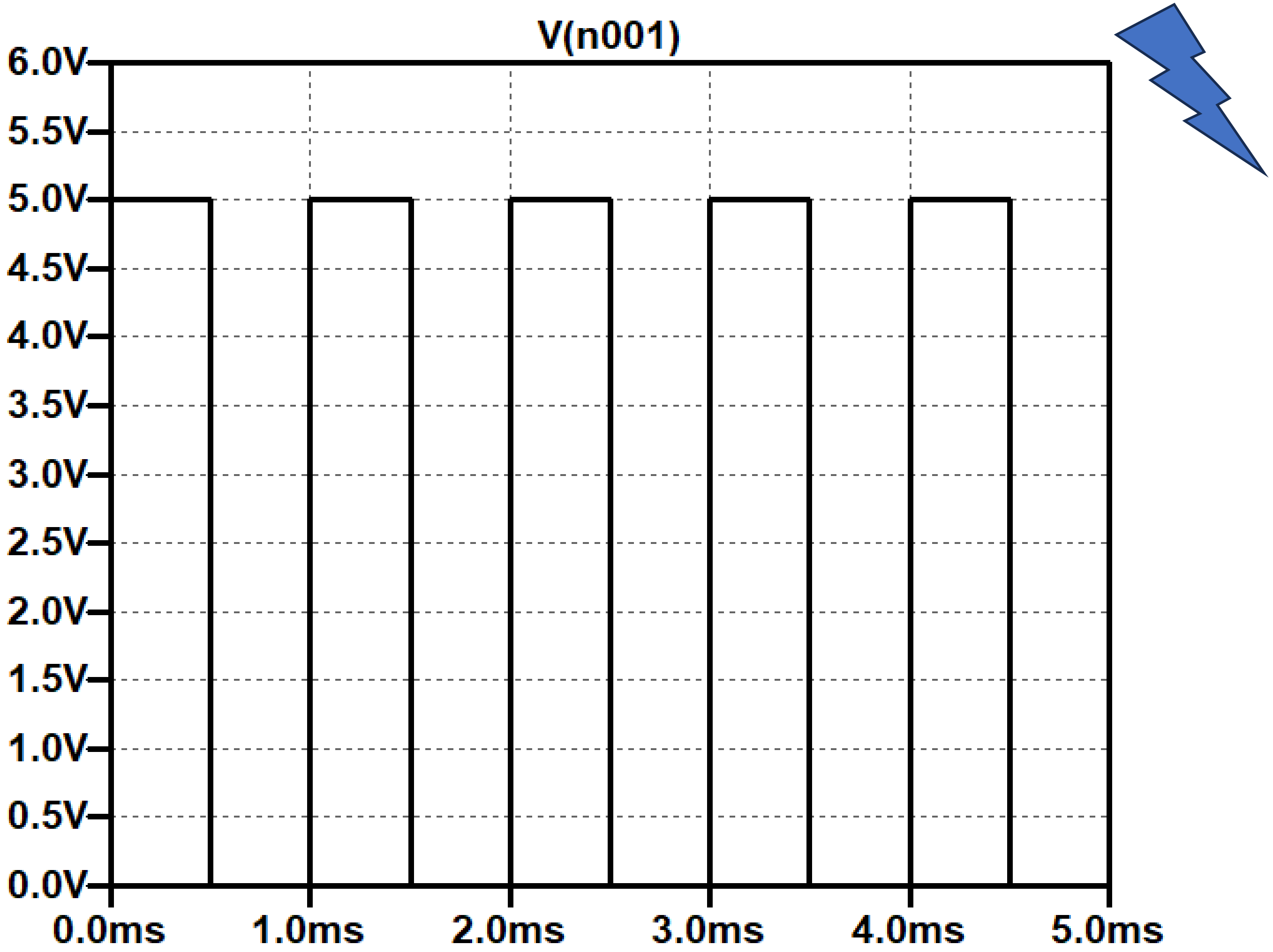
Sinusoidal Square wave

FIG. 13.1
Alternating waveforn

Square Wave

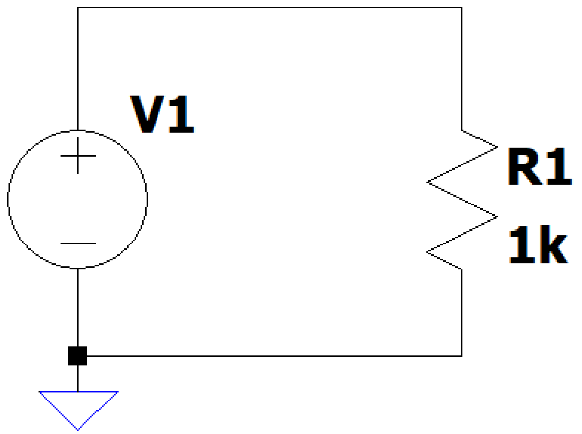


PULSE(0 5 0 1n 1n 0.5m 1m)
.tran 5m

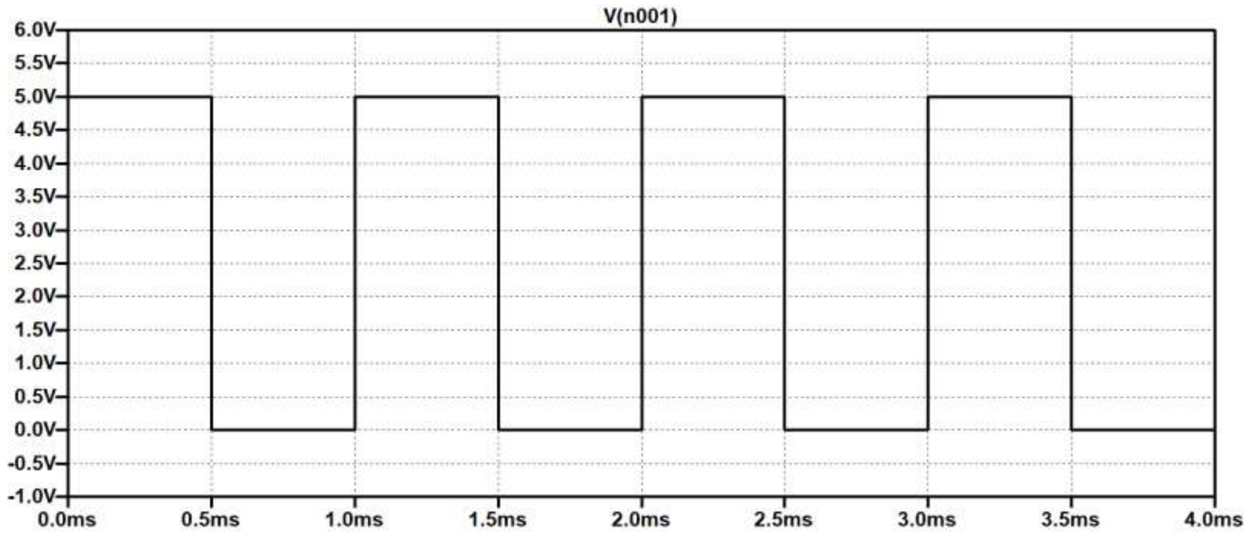


T=1/F, F=1/T, F : frequency T period
T=1ms, F=1/1ms=1KHz

DUTY CYCLE

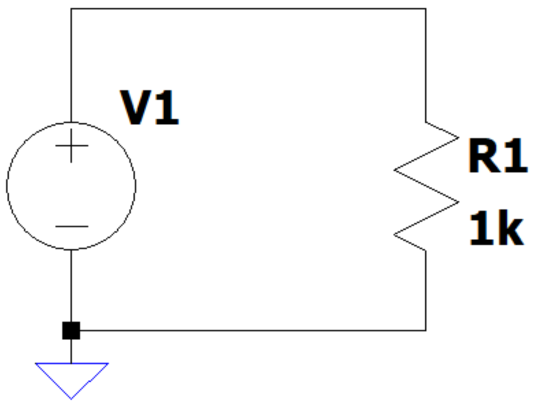


PULSE(0 5 0 1n 1n 0.5m 1m)
.tran 5m

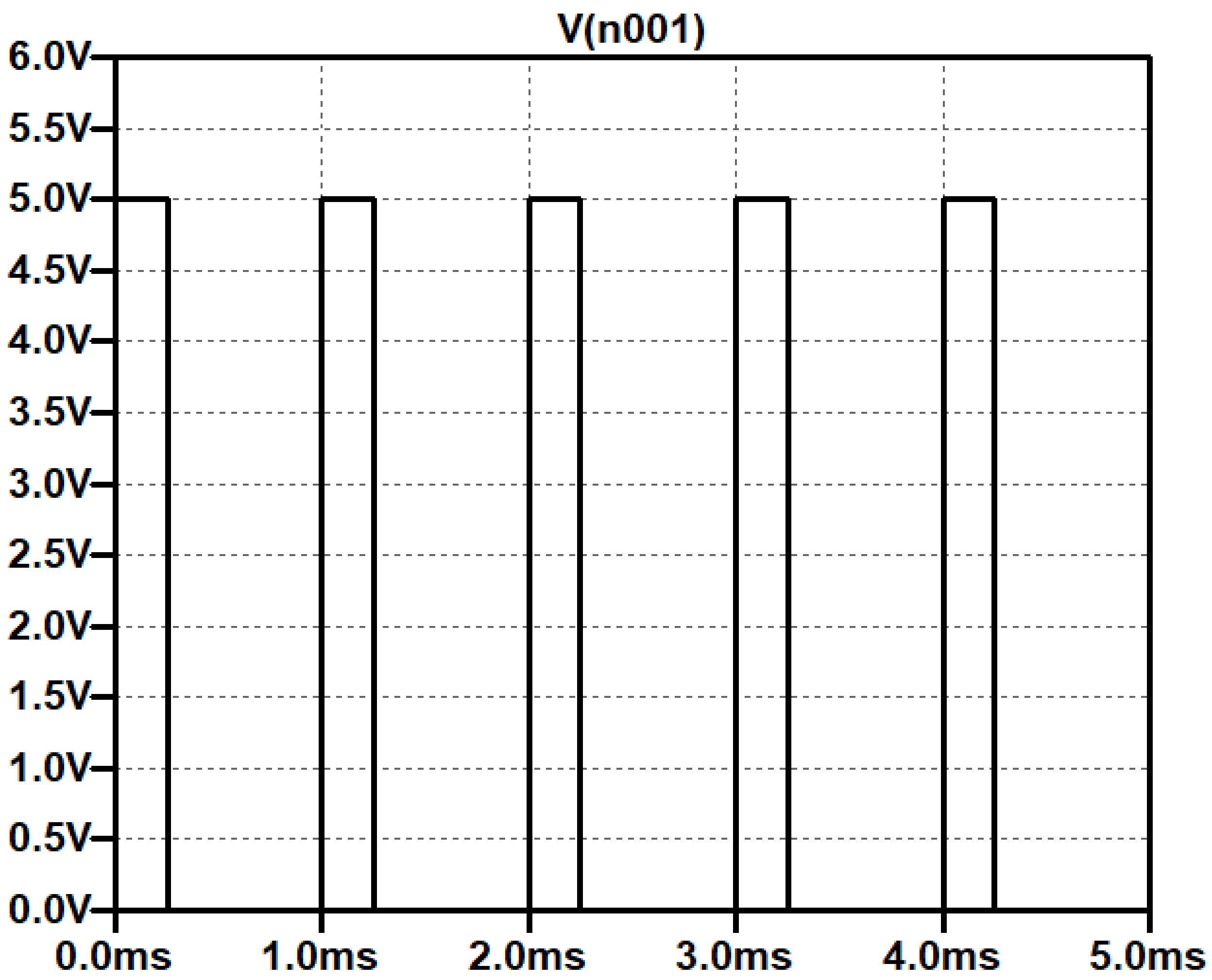


Duty Cycle = % Ontime/Period, D=0.5ms / 1ms = 0.5 in percentage 50%

DUTY CYCLE



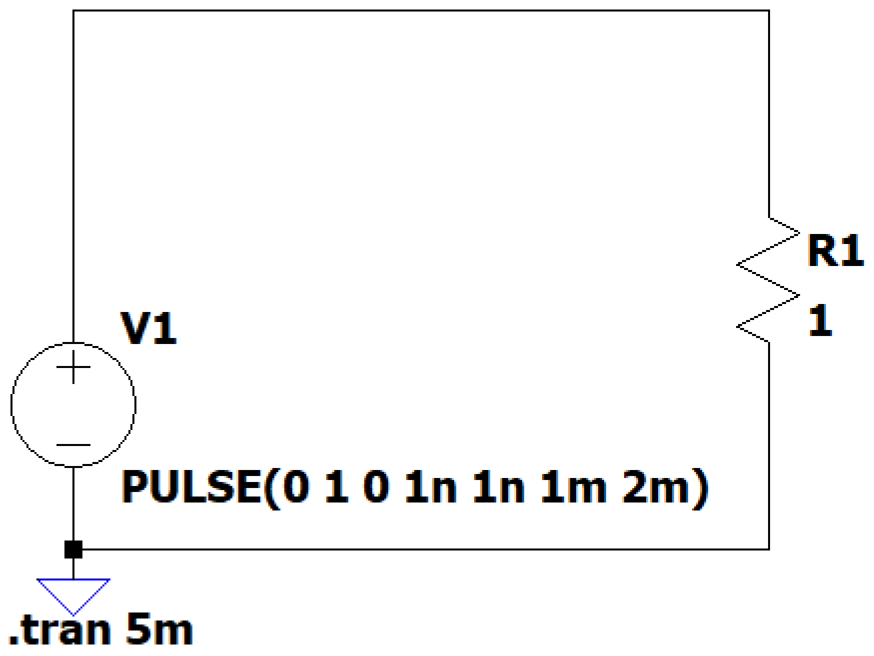
PULSE(0 5 0 1n 1n 0.25m 1m)
.tran 5m

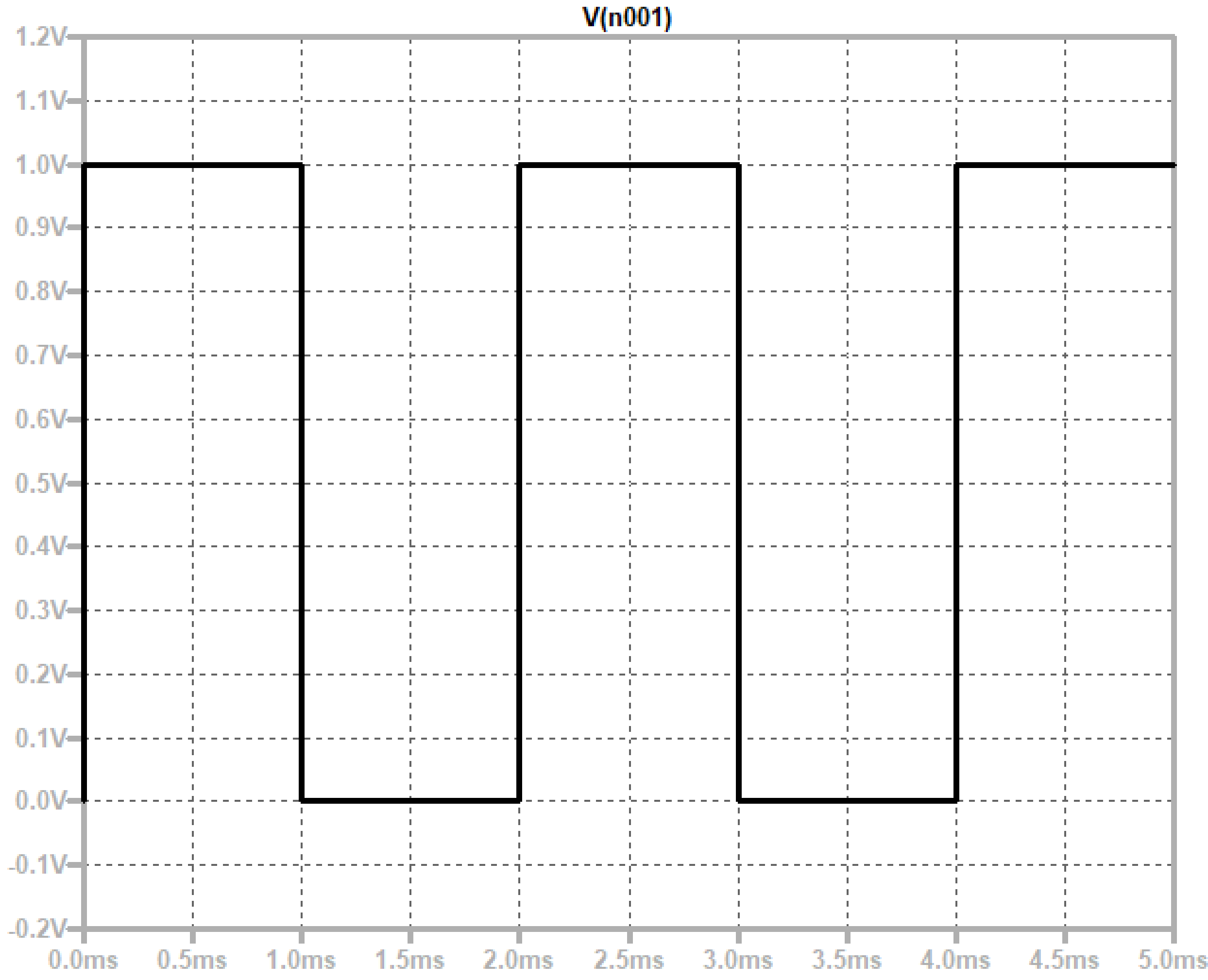


F = 1 /T = 1/1ms=1KHz

Duty Cycle = % Ontime/Period, D=0.25ms / 1ms = 0.25 = %25 in percentage
Thats why it is called as PWM, Pulse Width Modulation signal

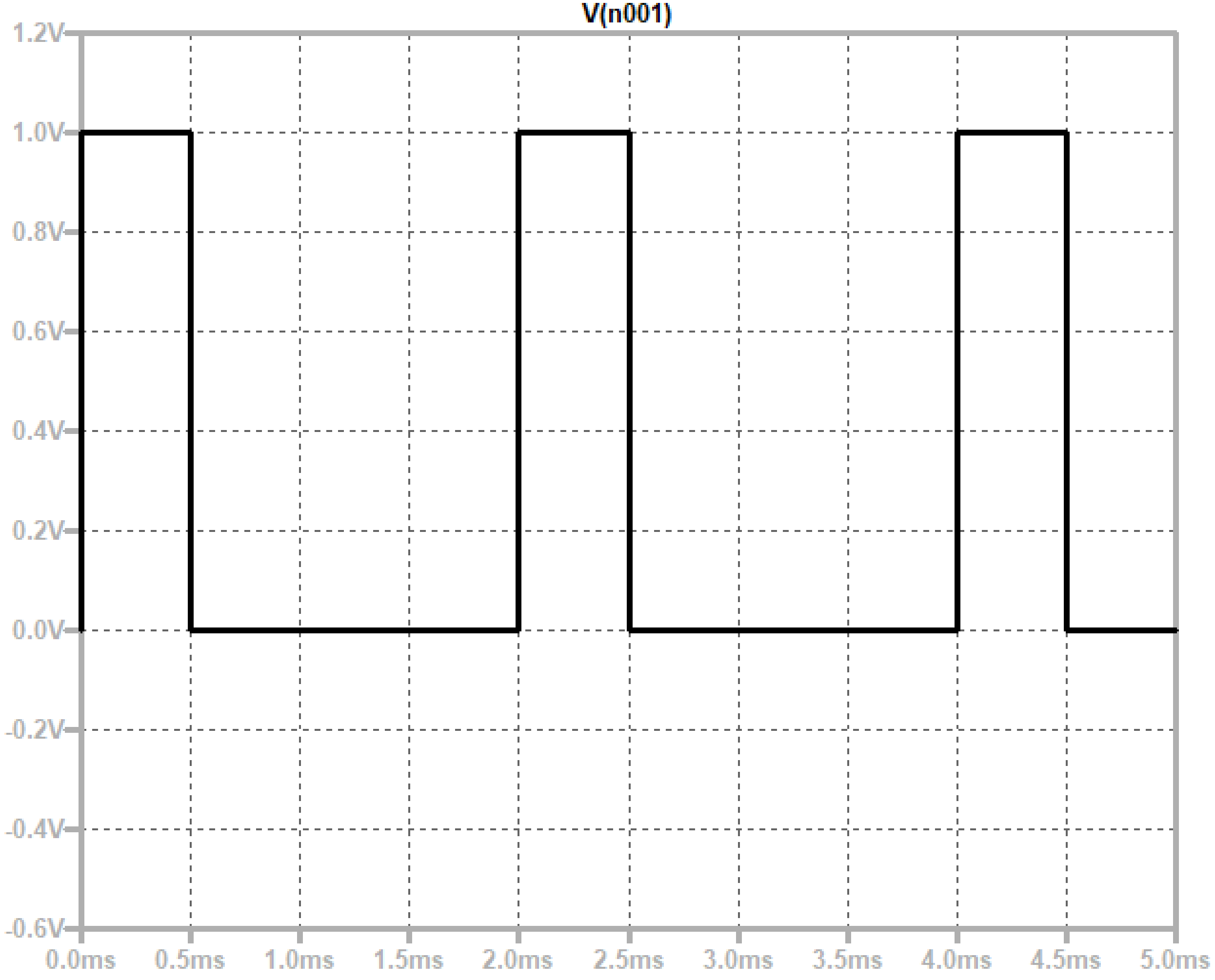
Square Wave

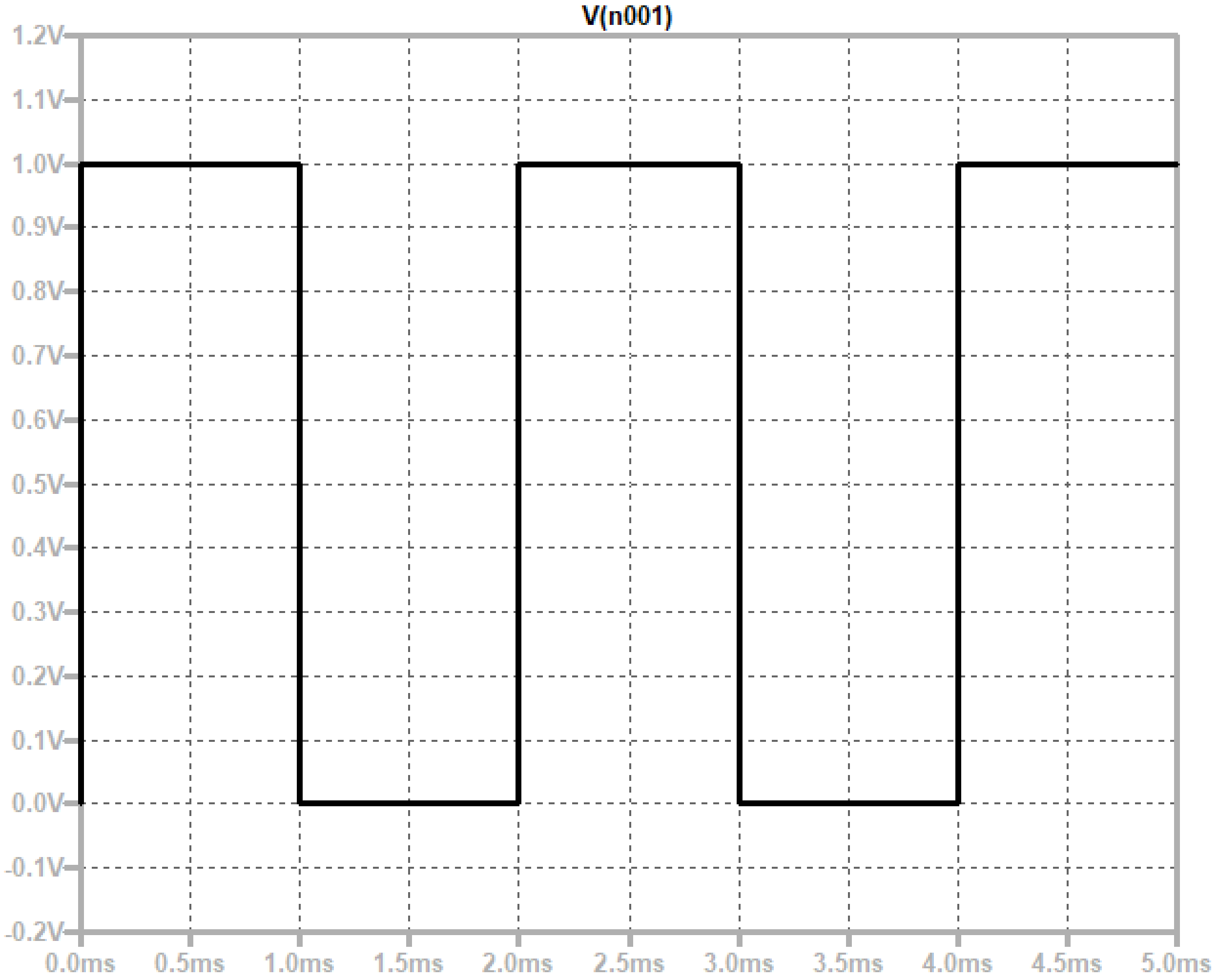




Frequency and duty cycle
duty = ontime/period
example 50%

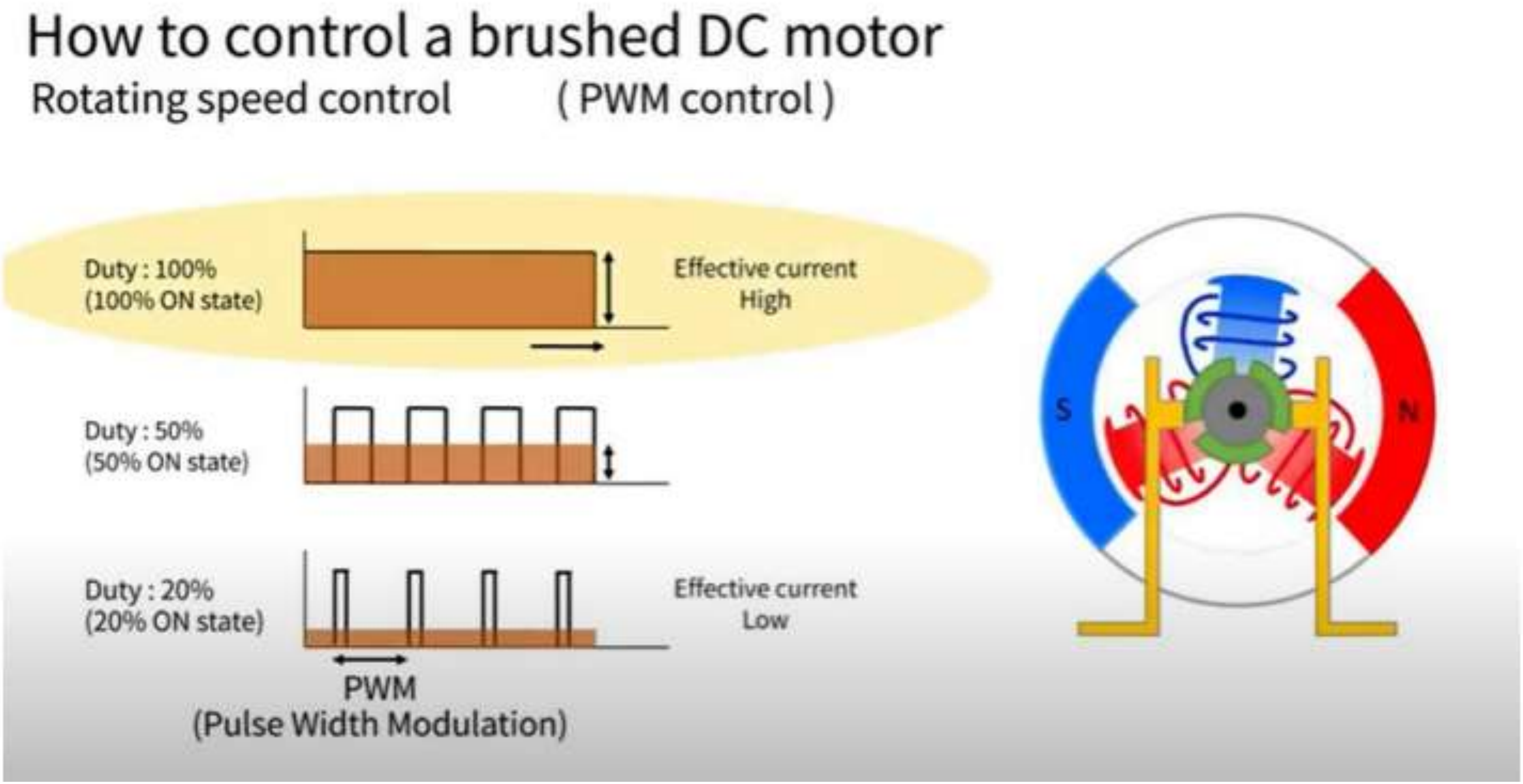
Square Wave





example 25% left - 50% right

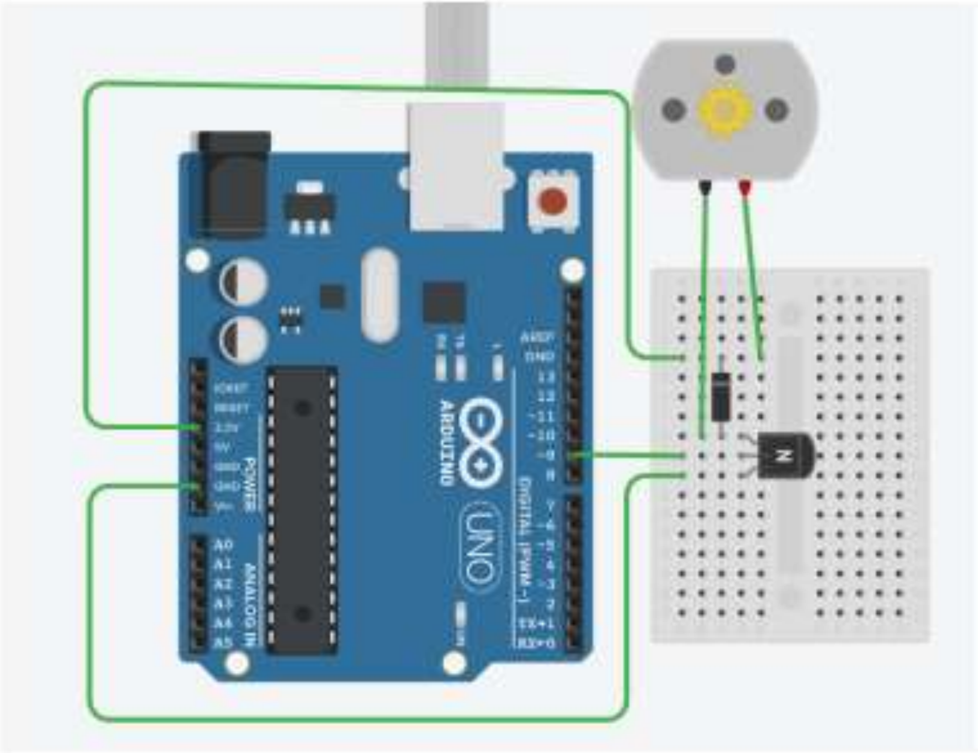
Square Wave



How to control a brushed DC motor
Rotating speed control
(PWM control)
Duty : 100%
(100% ON state)
Effective current
High
Duty : 50%
(50% ON state)
Duty : 20%
(20% ON state)
Effective current
Low
PWM
(Pulse Width Modulation)
S
N

Square Wave

DC MOTOR CONTROL

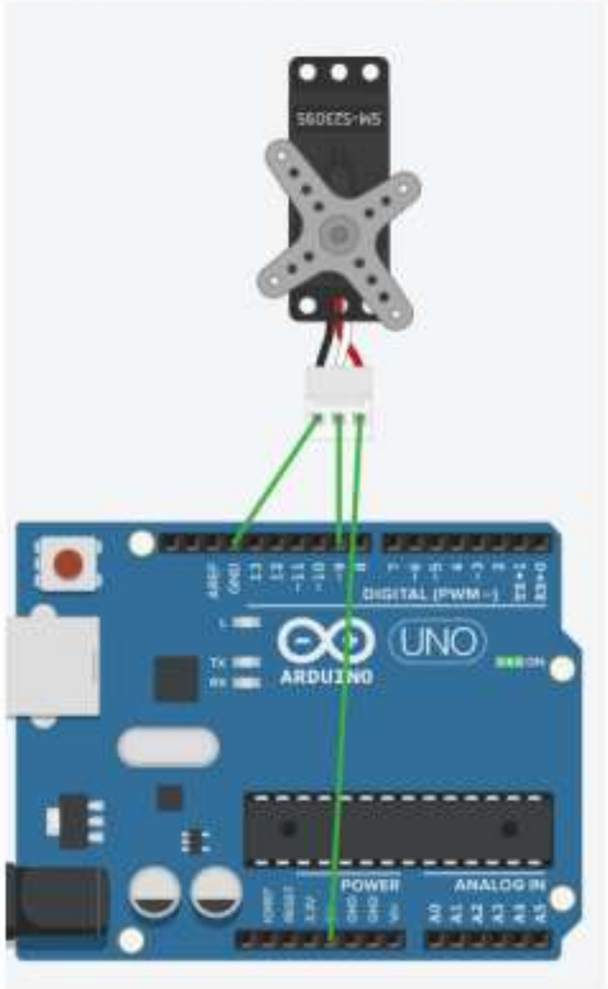


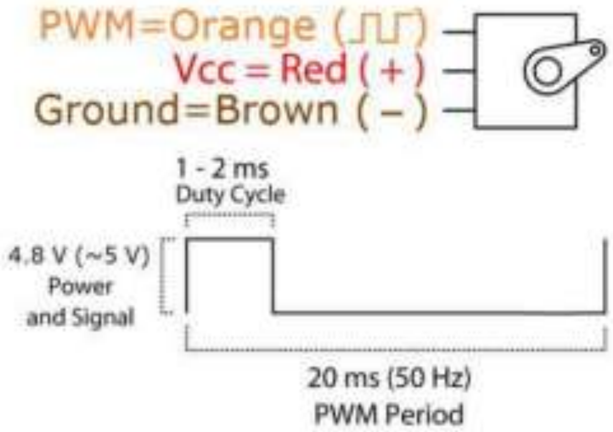

```
/*
Senol GUlgonul
Control of DC Motor with PWM
09.05.2023
*/


void setup()
{
  pinMode(10, OUTPUT);  // sets the pin as output
  Serial.begin(9600); // open the serial port at 9600 bps:
}

void loop()
{
 analogWrite(10, 1); // duty cycle is value/255*100
   Serial.println("MOTOR IS ON");
 delay(3000);

 analogWrite(10, 0); // duty cycle is value/255*100
   Serial.println("MOTOR IS OFF");
 delay(3000);
}
```

- A transistor used to drive the motor. A diode protect Arduino board from the back EMF current
- analogWrite() generates PWM signal, 255 is %100 duty

Square Wave

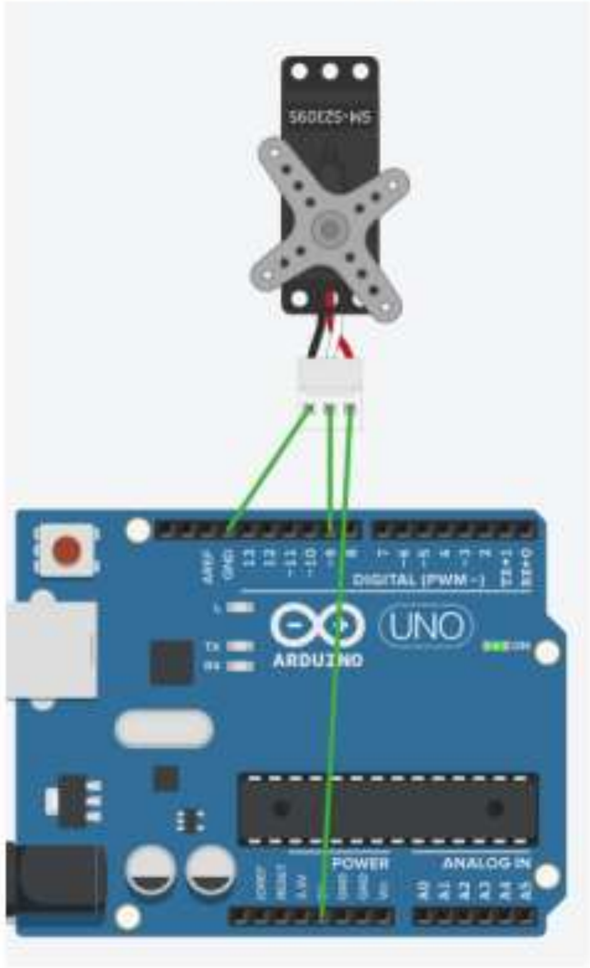
SERVO MOTOR CONTROL





Square Wave

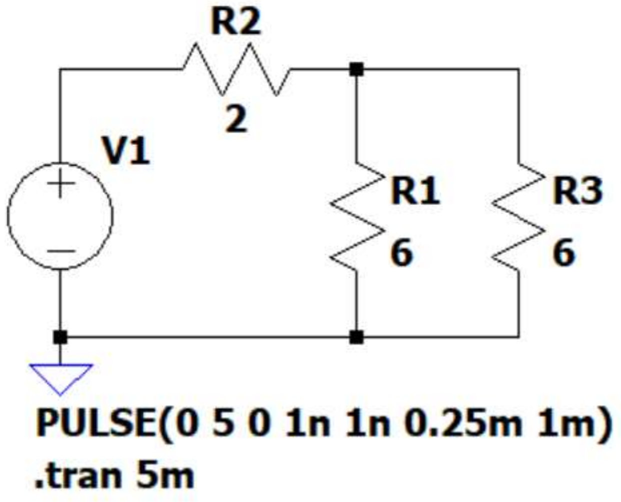
SERVO MOTOR CONTROL

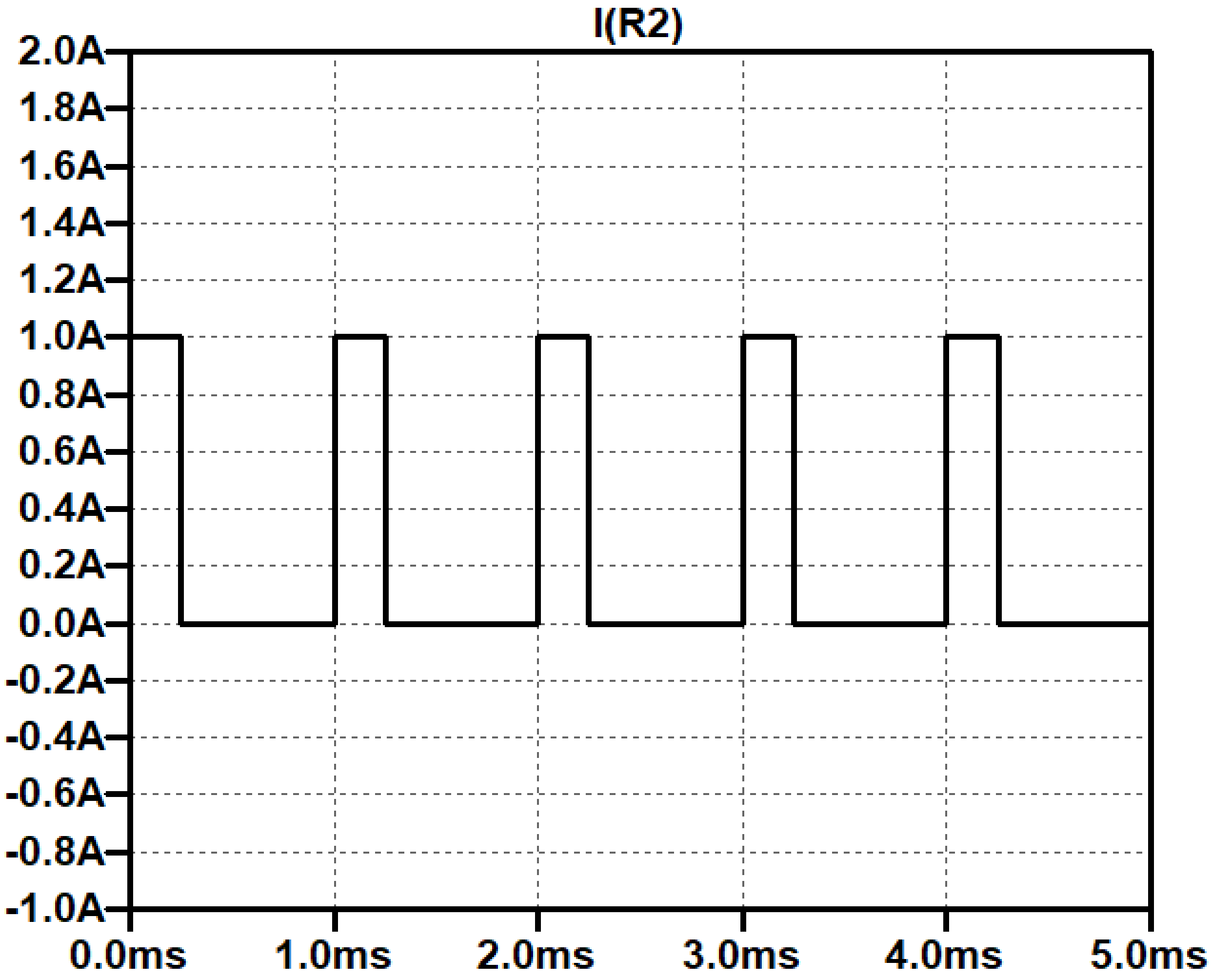



```
/*
Senol GUlgonul
Control of Servo Motor with PWM
09.05.2023
*/
#include <Servo.h>
Servo mymotor;


void setup()
{
  pinMode(10, OUTPUT);  // sets the pin as output
  Serial.begin(9600); // open the serial port at 9600 bps:

  mymotor.attach(10);

}

void loop()
{
 mymotor.write(0);
 Serial.println("MOTOR IS 0 degree");
 delay(3000);

 mymotor.write(90);
 Serial.println("MOTOR IS 90 degree");
 delay(3000);

   mymotor.write(180);
 Serial.println("MOTOR IS 180 degree");
 delay(3000);

}
```

Square Wave-R Circuits

- Ohm's Law, KVL,KCL is still valid for square waves
- Resistors does not change the frequency and shape of square wave signals





Sinusoidal

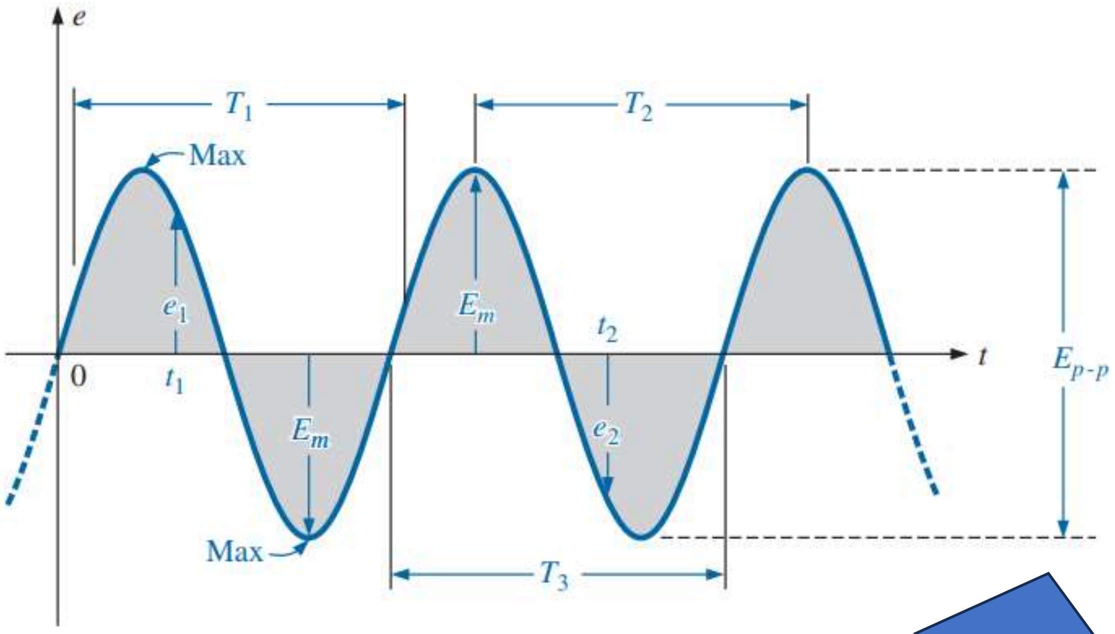


FIG. 13.3
Important parameters for a sinusoidal voltage.

$$\boxed{f = \frac{1}{T}} \quad \begin{aligned} f &= \text{Hz} \\ T &= \text{seconds (s)} \end{aligned} \qquad \textbf{(13.2)}$$

$$\boxed{T = \frac{1}{f}} \qquad \textbf{(13.3)}$$

Peak amplitude: The maximum value of a waveform as measured from its *average*, or *mean*, value, denoted by uppercase letters [such as E_m (Fig. 13.3) for sources of voltage and V_m for the voltage drop across a load]. For the waveform in Fig. 13.3, the average value is zero volts, and E_m is as defined by the figure.

Peak-to-peak value: Denoted by $E_{p\text{-}p}$ or $V_{p\text{-}p}$ (as shown in Fig. 13.3), the full voltage between positive and negative peaks of the waveform, that is, the sum of the magnitude of the positive and negative peaks.

Period (T): The time of a periodic waveform.

Frequency (f): The number of cycles that occur in 1 s. The frequency of the waveform in Fig. 13.5(a) is 1 cycle per second, and for Fig. 13.5(b), 2½ cycles per second. If a waveform of similar shape had a period of 0.5 s [Fig. 13.5(c)], the frequency would be 2 cycles per second.

Cycle: The portion of a waveform contained in one period of time. The cycles within T_1, T_2, and T_3 in Fig. 13.3 may appear differently in Fig. 13.4, but they are all bounded by one period of time and therefore satisfy the definition of a cycle.

Sinusoidal

EXAMPLE 13.1 For the sinusoidal waveform in Fig. 13.7:

a. What is the peak value?
b. What is the instantaneous value at 0.3 s and 0.6 s?
c. What is the peak-to-peak value of the waveform?
d. What is the period of the waveform?
e. How many cycles are shown?
f. What is the frequency of the waveform?

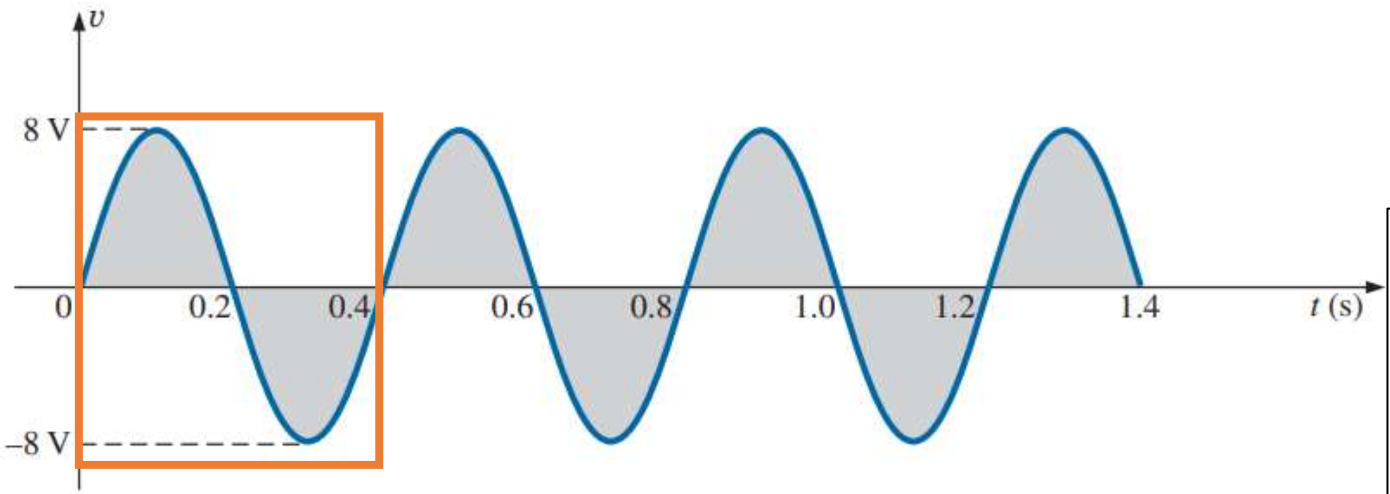


FIG. 13.7
Example 13.1.

Solutions:

a. **8 V.**
b. At 0.3 s, **−8 V**; at 0.6 s, **0 V.**
c. **16 V.**
d. **0.4 s.**
e. **3.5 cycles.**
f. **2.5 cps,** or **2.5 Hz.**

$$\boxed{f = \frac{1}{T}} \quad \begin{aligned} f &= \text{Hz} \\ T &= \text{seconds (s)} \end{aligned} \tag{13.2}$$

$$\boxed{T = \frac{1}{f}} \tag{13.3}$$

F=1/T

Hz =1/seconds

Khz = 1/milisecond

Sinusoidal

EXAMPLE 13.2 Find the period of periodic waveform with a frequency of

a. 60 Hz.
b. 1000 Hz.

Solutions:

a. $T = \frac{1}{f} = \frac{1}{60\text{ Hz}} \cong 0.01667\text{ s or } \mathbf{16.67\text{ ms}}$

(a recurring value since 60 Hz is so prevalent)

b. $T = \frac{1}{f} = \frac{1}{1000\text{ Hz}} = 10^{-3}\text{s} = \mathbf{1\text{ ms}}$

$$\boxed{f = \frac{1}{T}} \quad \begin{aligned} f &= \text{Hz} \\ T &= \text{seconds (s)} \end{aligned} \qquad \textbf{(13.2)}$$

$$\boxed{T = \frac{1}{f}} \qquad \textbf{(13.3)}$$

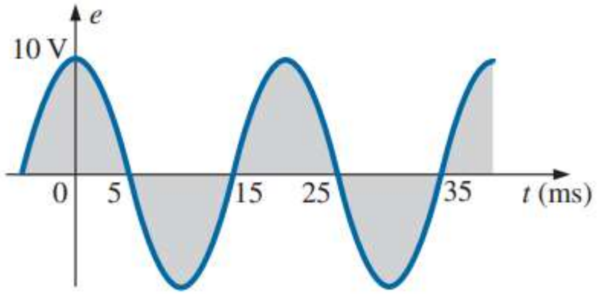


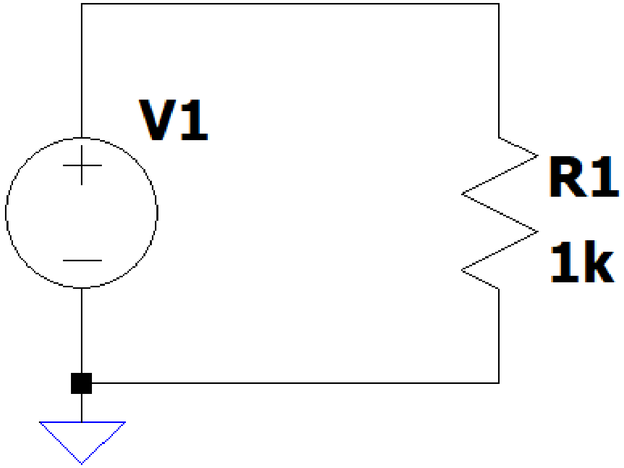
FIG. 13.9
Example 13.3.

EXAMPLE 13.3 Determine the frequency of the waveform in Fig. 13.9.

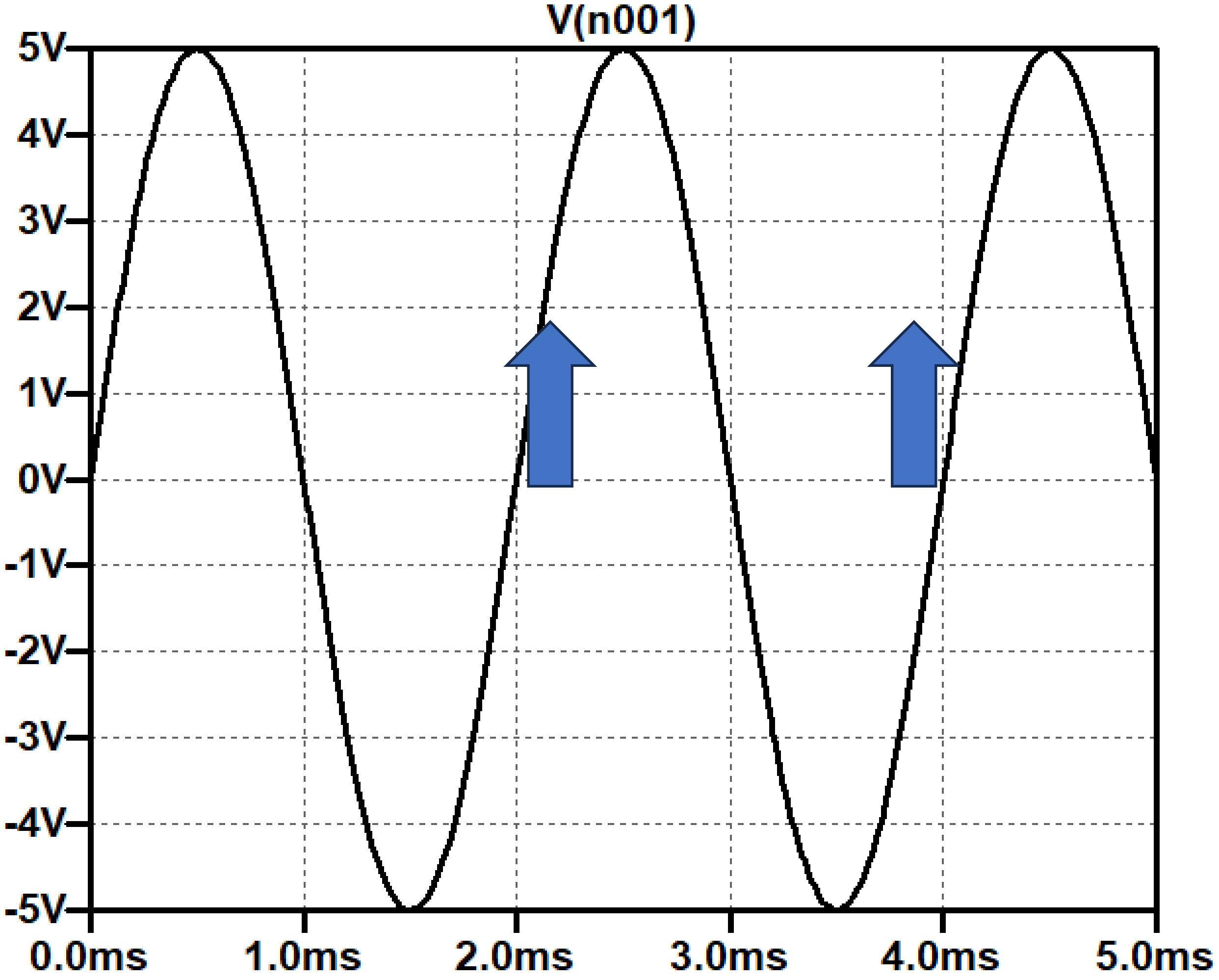
Solution: From the figure, $T = (25\text{ ms} - 5\text{ ms})$ or $(35\text{ ms} - 15\text{ ms}) = 20\text{ ms}$, and

$$f = \frac{1}{T} = \frac{1}{20 \times 10^{-3}\text{ s}} = \mathbf{50\text{ Hz}}$$

Sinusoidal

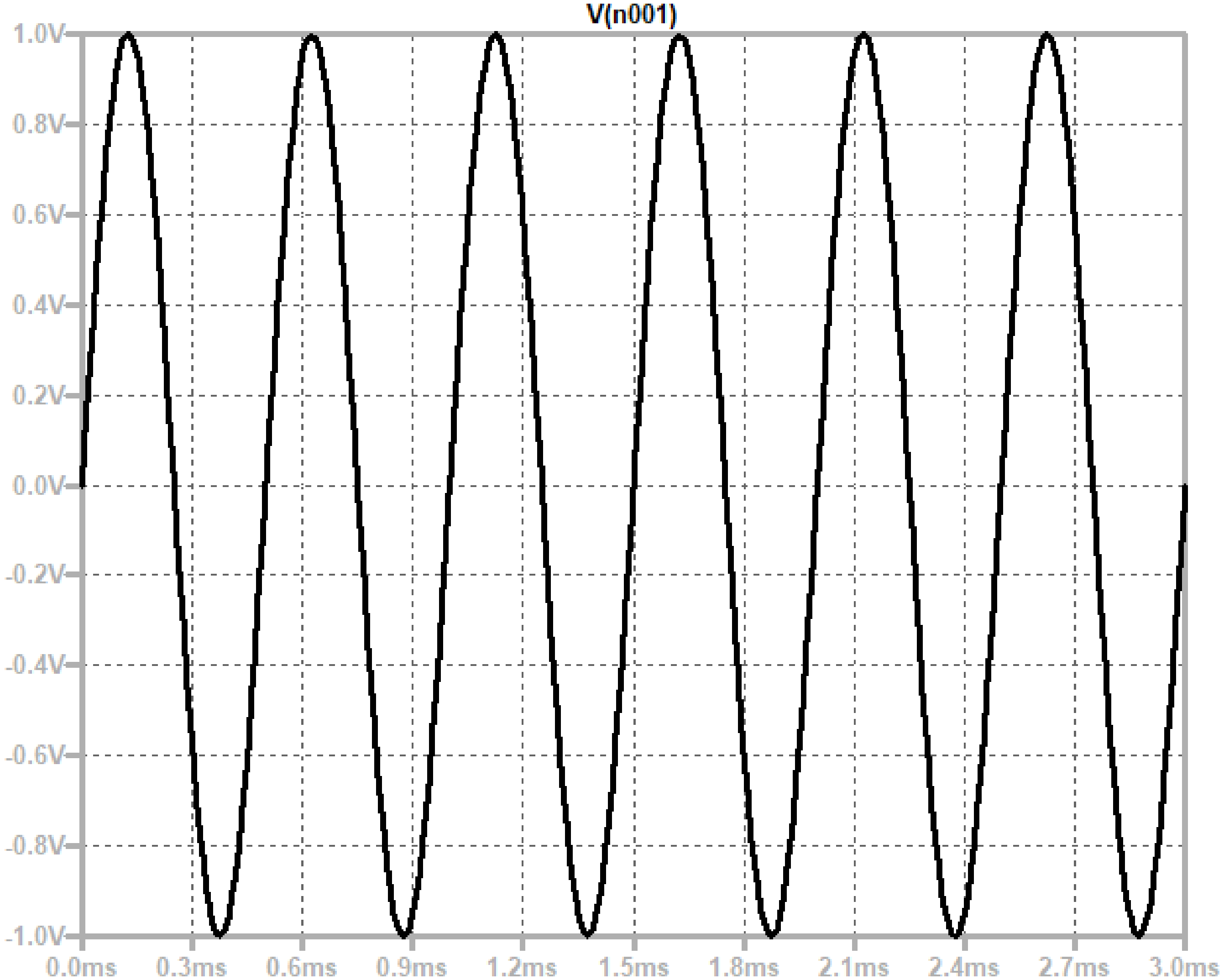


SINE(0 5 0.5k)
.tran 5m



T = 2ms, F = 1/2m = 0.5KHz
Amplitude, Peak 5V
Peak-to-Peak = 10V

Sinusoidal example



what is the frequency of the signal?
T=0.5ms
f=1/T=2kHz

what is the amplitude = 1V

peak to peak = 2V

Sinusoidal

The sinusoidal waveform is the only alternating waveform whose shape is unaffected by the response characteristics of R, L, and C elements.

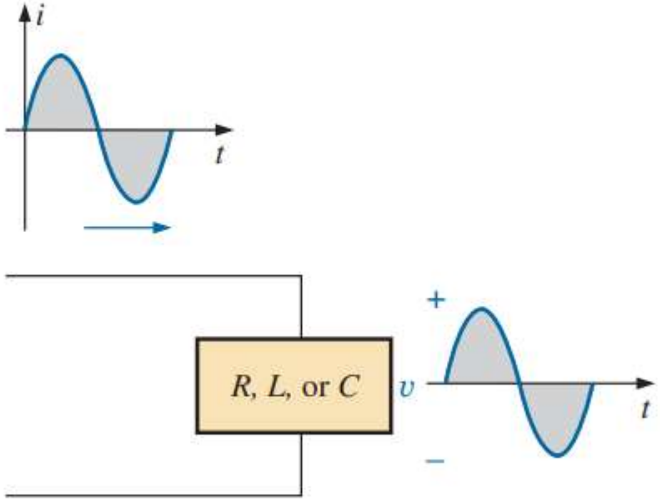


FIG. 13.12
The sine wave is the only alternating waveform whose shape is not altered by the response characteristics of a pure resistor, inductor, or capacitor.

Sinusoidal

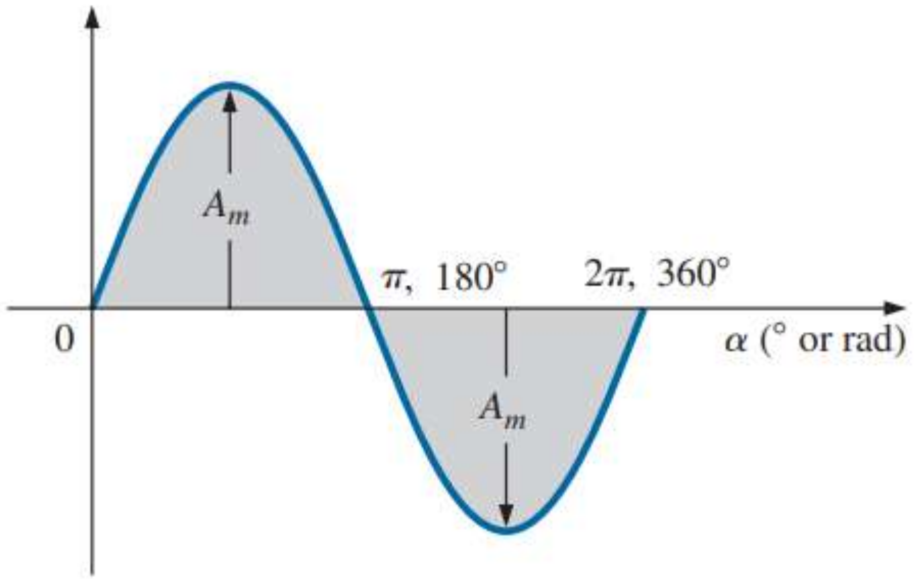


FIG. 13.18
Basic sinusoidal function.

$$\boxed{2\pi \text{ rad} = 360°} \tag{13.5}$$

$$\boxed{A_m \sin \omega t} \tag{13.14}$$

$$\boxed{\omega = 2\pi f} \quad \text{(rad/s)} \tag{13.12}$$

V=5*sin(2*pi*f* t)

V = 5*sin(w*t)
V = 5*sin(2*pi*f*t)

w=2*pi*f , w is in rad/s , f =Hz
w=2*pi/T

at t=T sine completes one cycle, w becomes 2pi

Sinusoidal

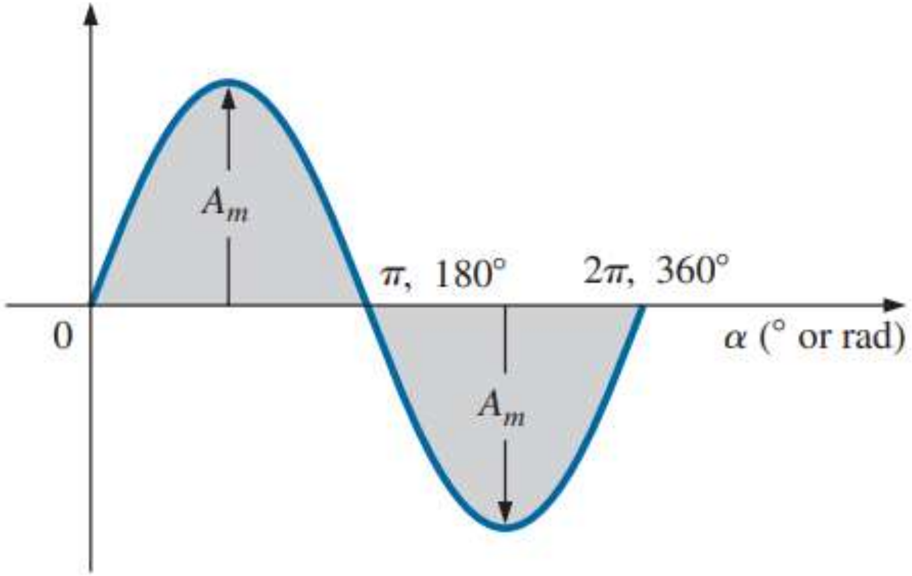


FIG. 13.18
Basic sinusoidal function.

$$\boxed{2\pi \text{ rad} = 360°} \qquad \textbf{(13.5)}$$

$$\boxed{A_m \sin \omega t} \qquad \textbf{(13.14)}$$

$$\boxed{\omega = 2\pi f} \quad \text{(rad/s)} \qquad \textbf{(13.12)}$$

at t=T sine completes one cycle, w becomes 2pi

Sinusoidal

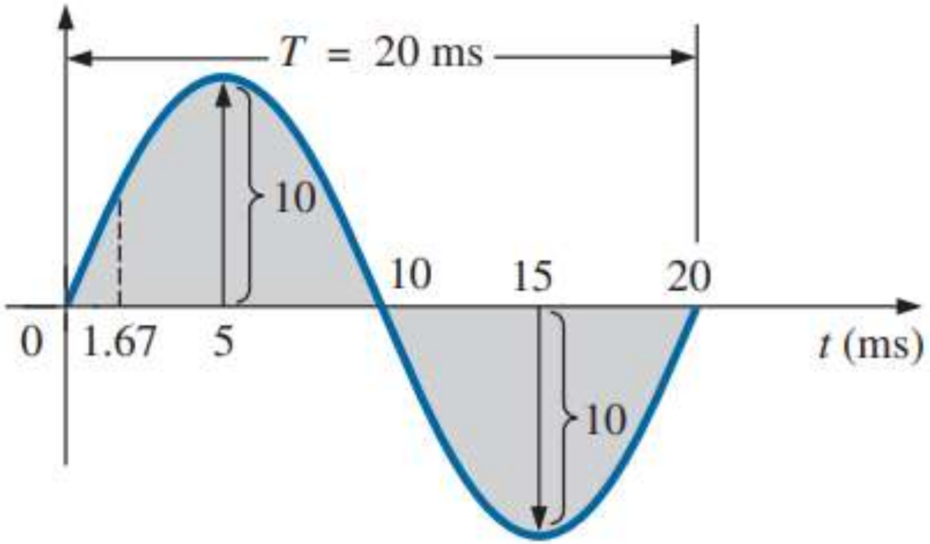


FIG. 13.26

Example 13.10, horizontal axis in milliseconds.

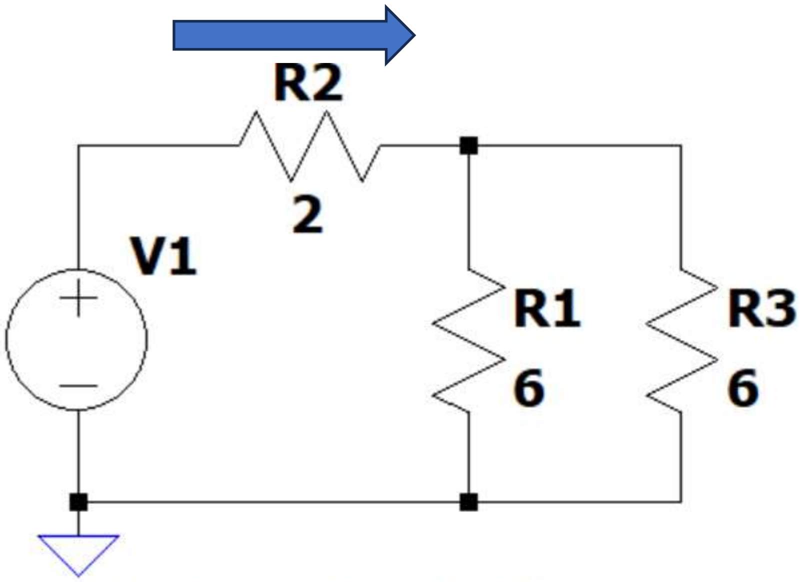
$$\boxed{2\pi \text{ rad} = 360°} \qquad \textbf{(13.5)}$$

$$\boxed{A_m \sin \omega t} \qquad \textbf{(13.14)}$$

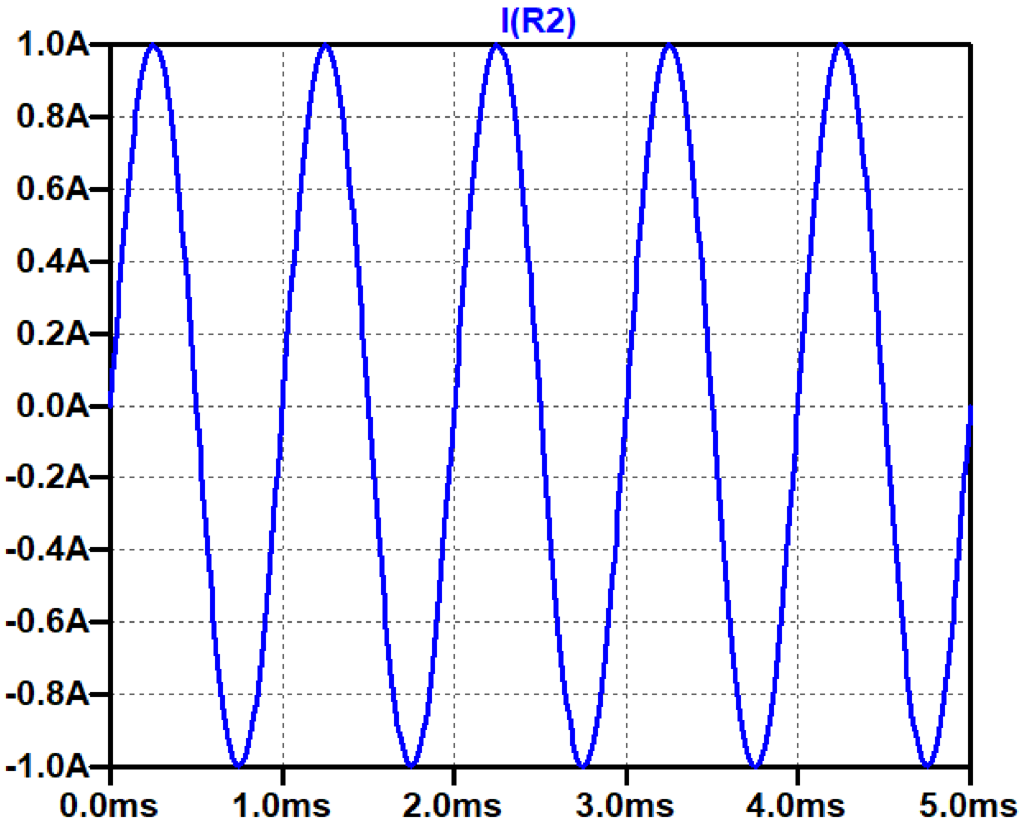
$$\boxed{\omega = 2\pi f} \quad \text{(rad/s)} \qquad \textbf{(13.12)}$$

at t=T sine completes one cycle, w becomes 2pi

Sinusoidal-LTspice



SINE(0 5 1k 0 0 0)
.tran 5m



what is the current i2 ? V1=5*sin(2*pi*f*t) f=1kHz

RT = 2 + 6//6 = 2 + 3 = 5 ohm
i2 = V1 /RT
i2=5* sin(2*pi*f*t) / 5 = sin(2*pi*f*t) A

Sinusoidal-Phase

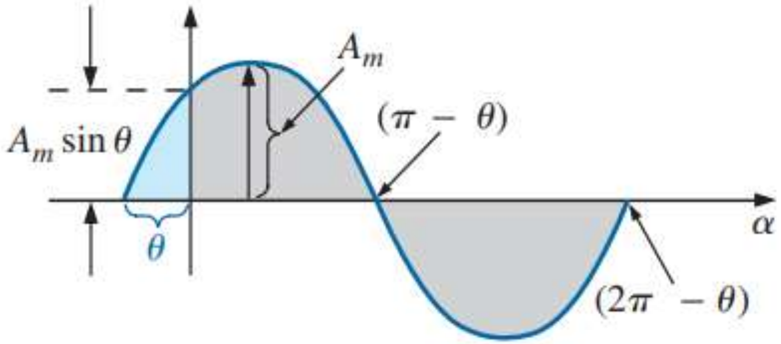


FIG. 13.27
Defining the phase shift for a sinusoidal function that crosses the horizontal axis with a positive slope before 0°.

$$\boxed{A_m \sin(\omega t + \theta)} \qquad \textbf{(13.18)}$$

Sinusoidal-Phase

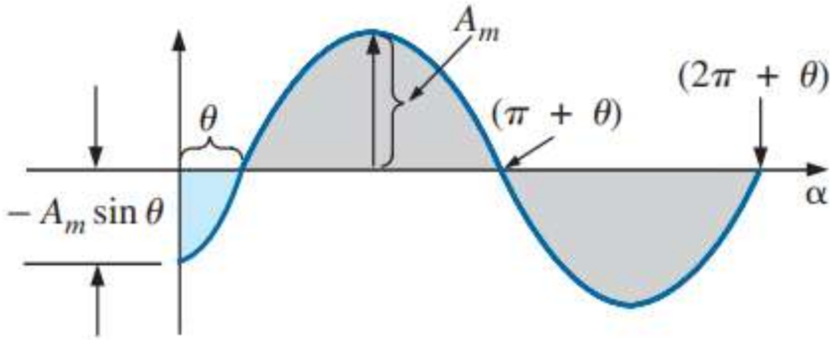


FIG. 13.28
Defining the phase shift for a sinusoidal function that crosses the horizontal axis with a positive slope after 0°.

$$\boxed{A_m \sin(\omega t - \theta)} \qquad \textbf{(13.19)}$$

Sinusoidal-Phase

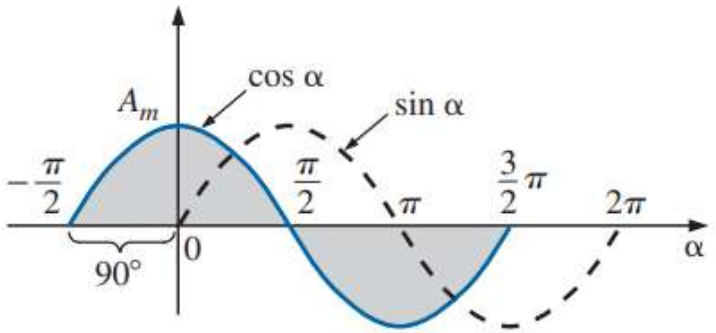


FIG. 13.29
Phase relationship between a sine wave and a cosine wave.

$$\sin(\omega t + 90°) = \sin\left(\omega t + \frac{\pi}{2}\right) = \cos \omega t \qquad (13.20)$$

$$\sin \omega t = \cos(\omega t - 90°) = \cos\left(\omega t - \frac{\pi}{2}\right) \qquad (13.21)$$

The terms leading and lagging are used to indicate the relationship between two sinusoidal waveforms of the same frequency plotted on the same set of axes.

In Fig. 13.29, the cosine curve is said to *lead* the sine curve by 90°, and the sine curve is said to *lag* the cosine curve by 90°. The 90° is referred to as the phase angle between the two waveforms. In language

Sinusoidal-Phase

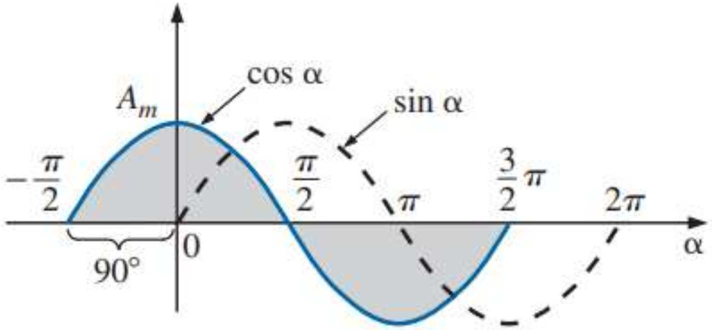


FIG. 13.29
Phase relationship between a sine wave and a cosine wave.

$$\begin{aligned}
\cos\alpha &= \sin(\alpha + 90^\circ) \\
\sin\alpha &= \cos(\alpha - 90^\circ) \\
-\sin\alpha &= \sin(\alpha \pm 180^\circ) \\
-\cos\alpha &= \sin(\alpha + 270^\circ) = \sin(\alpha - 90^\circ) \\
&\text{etc.}
\end{aligned} \tag{13.22}$$

In addition, note that

$$\begin{aligned}
\sin(-\alpha) &= -\sin\alpha \\
\cos(-\alpha) &= \cos\alpha
\end{aligned} \tag{13.23}$$

Sinusoidal-Phase

EXAMPLE 13.12 What is the phase relationship between the sinusoidal waveforms of each of the following sets?

a. $v = 10 \sin(\omega t + 30^\circ)$
   $i = 5 \sin(\omega t + 70^\circ)$

b. $i = 15 \sin(\omega t + 60^\circ)$
   $v = 10 \sin(\omega t - 20^\circ)$

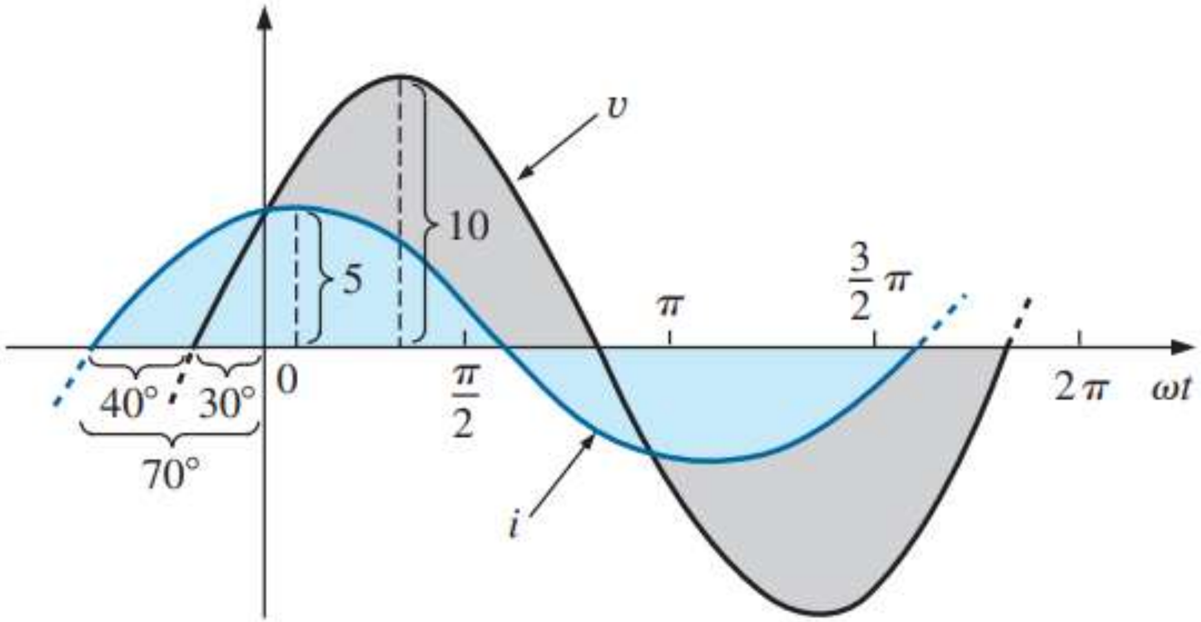


FIG. 13.31
Example 13.12(a): i leads v by 40°.

Sinusoidal-Phase

EXAMPLE 13.12 What is the phase relationship between the sinusoidal waveforms of each of the following sets?

a. $v = 10 \sin(\omega t + 30°)$
   $i = 5 \sin(\omega t + 70°)$

b. $i = 15 \sin(\omega t + 60°)$
   $v = 10 \sin(\omega t - 20°)$

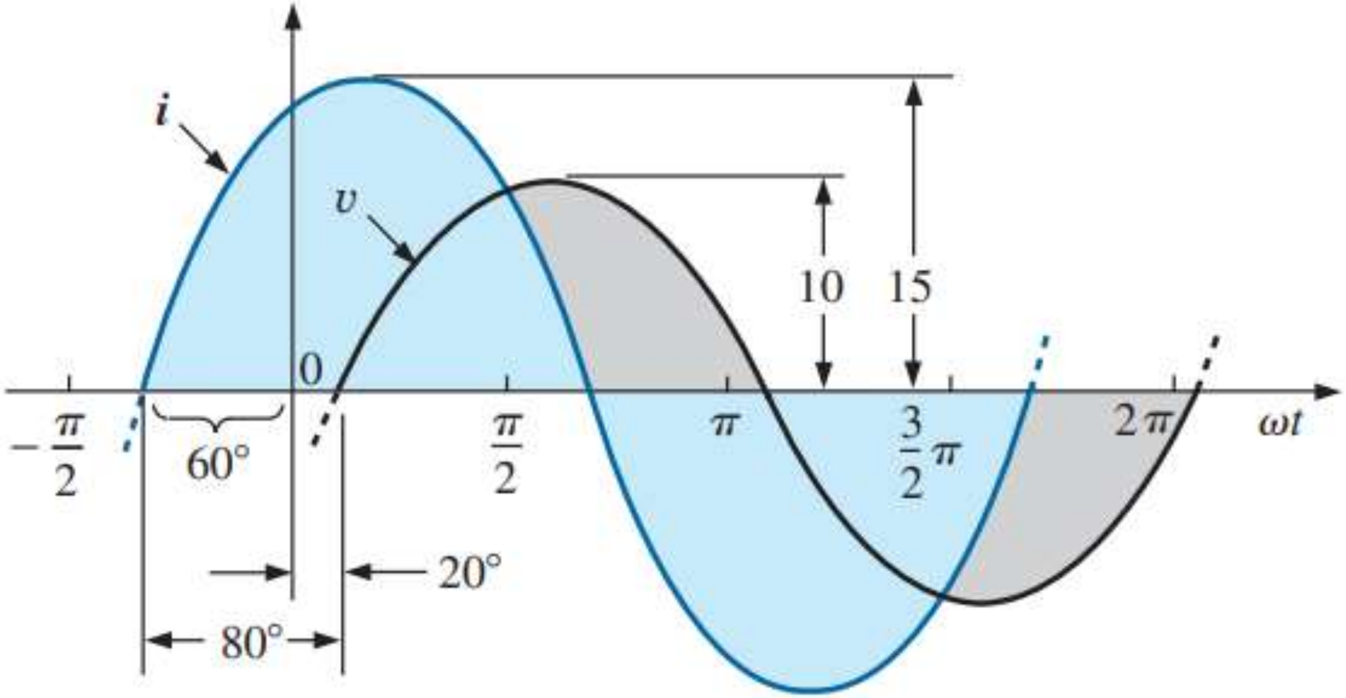


FIG. 13.32
Example 13.12(b): i leads v by 80°.

Sinusoidal-Phase-Difference

V1=5*sin(2*pi*f*t + p1)
V2=4*sin(2*pi*f*t + p2)

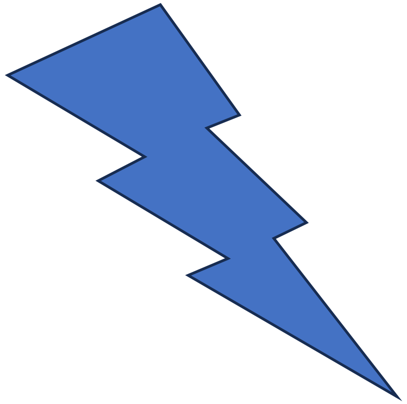
phase difference Dp=p2-p1

example: phase difference

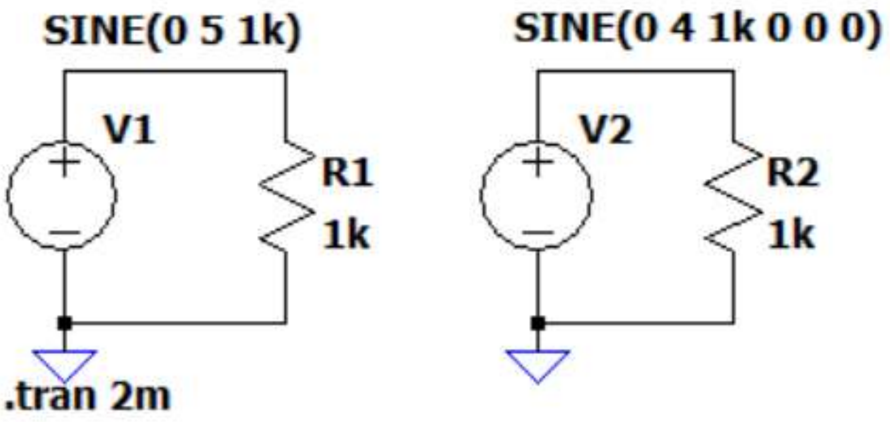
$$\boldsymbol{V1 = 5\sin(2\pi f t)}$$
$$\boldsymbol{V2 = 3\sin(2\pi f t + 90 deg)}$$

Dp = 90 – 0 = 90 degree

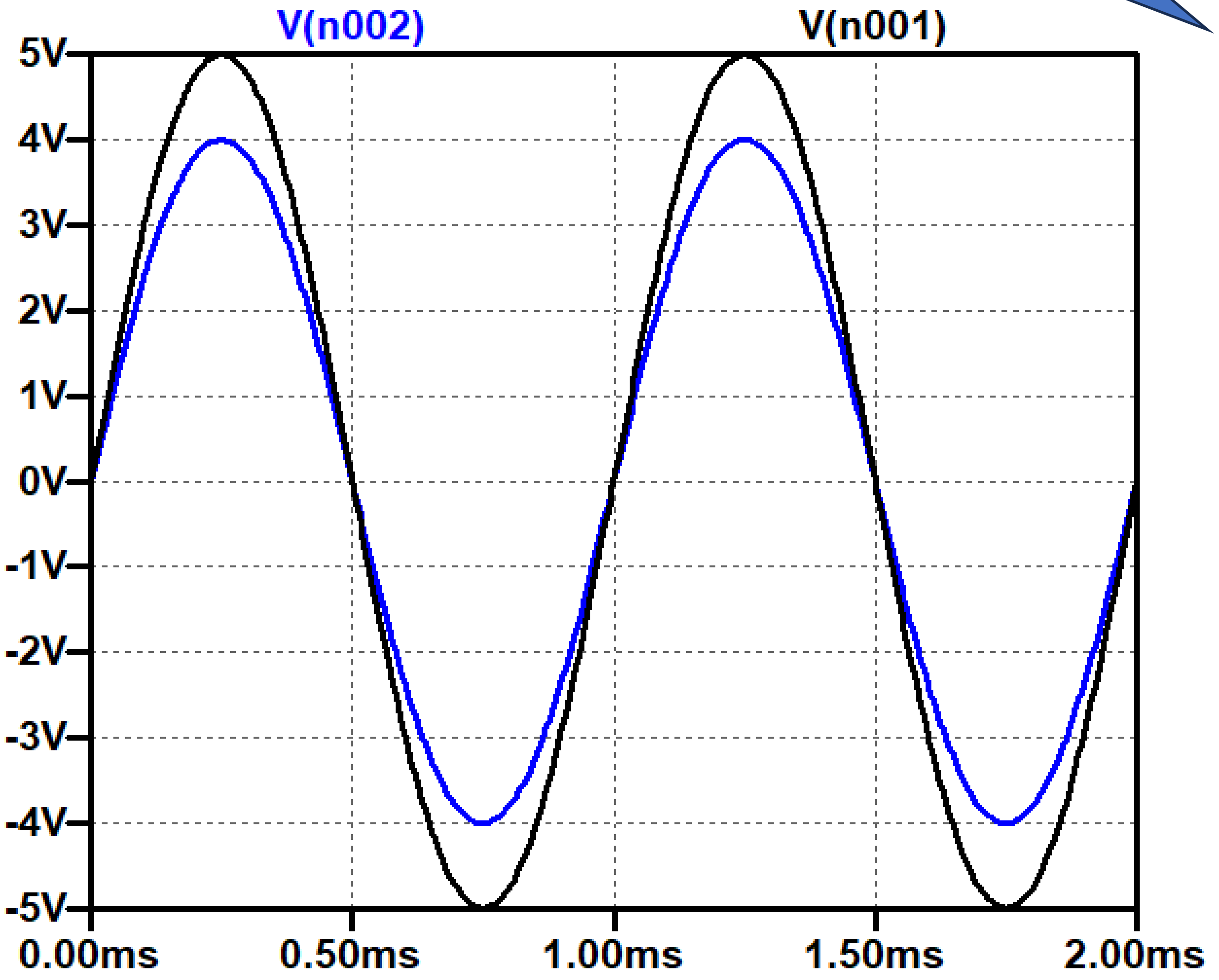
example2
V1=3*sin(2*pi*f*t + 90)
V2=5*sin(2*pi*f*t + 120)
Dp = 120 -90 = 30 degree



Sinusoidal-Phase-Difference=0



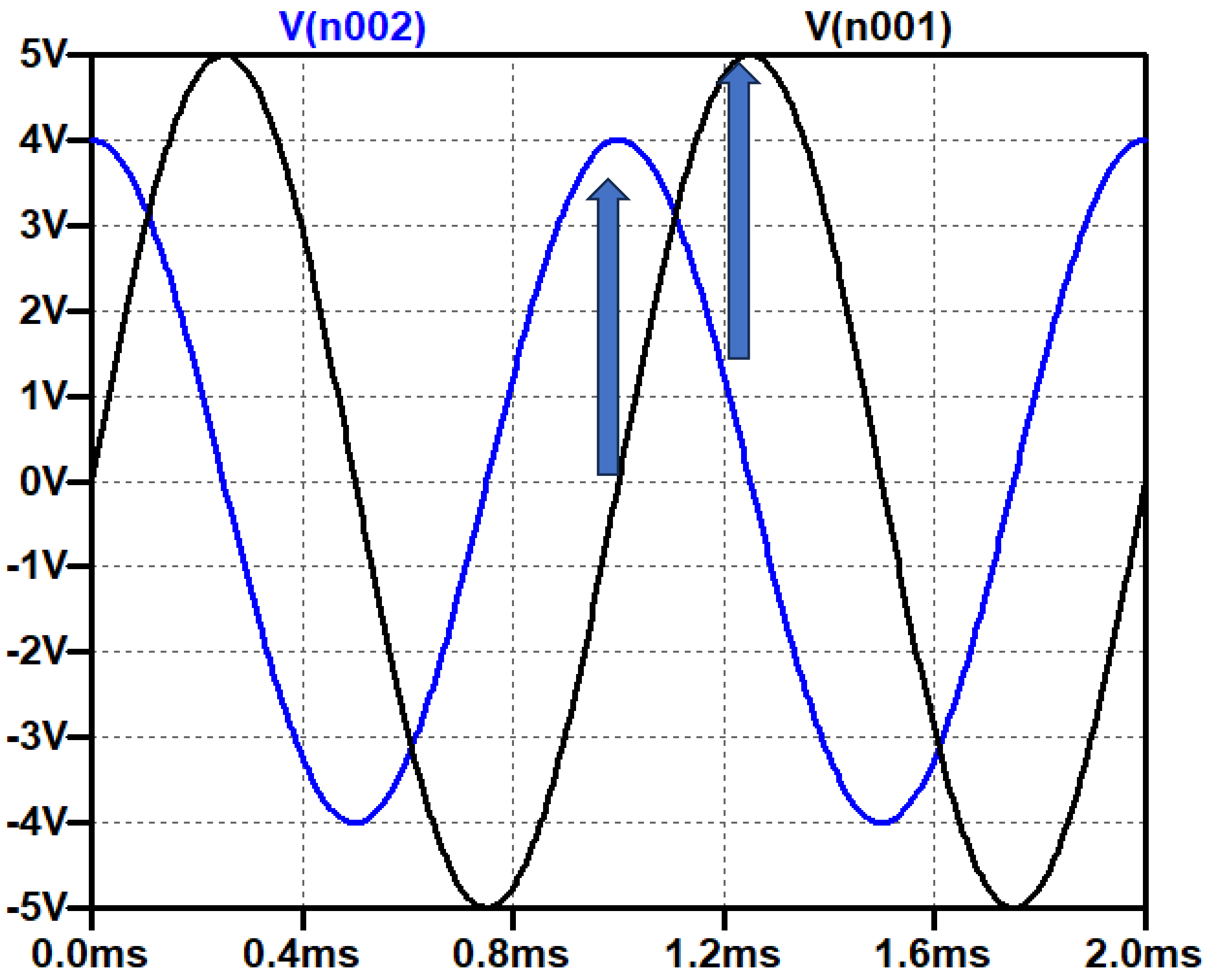
Zero Phase difference, different amplitudes
V1=5*sin(2*pi*1k*t)
V2=4*sin(2*pi*1k*t)



Sinusoidal-Phase-Difference=90

90 degree Phase difference, different amplitudes
V1=5*sin(2*pi*1k*t)
V2=4*sin(2*pi*1k*t + 90deg)

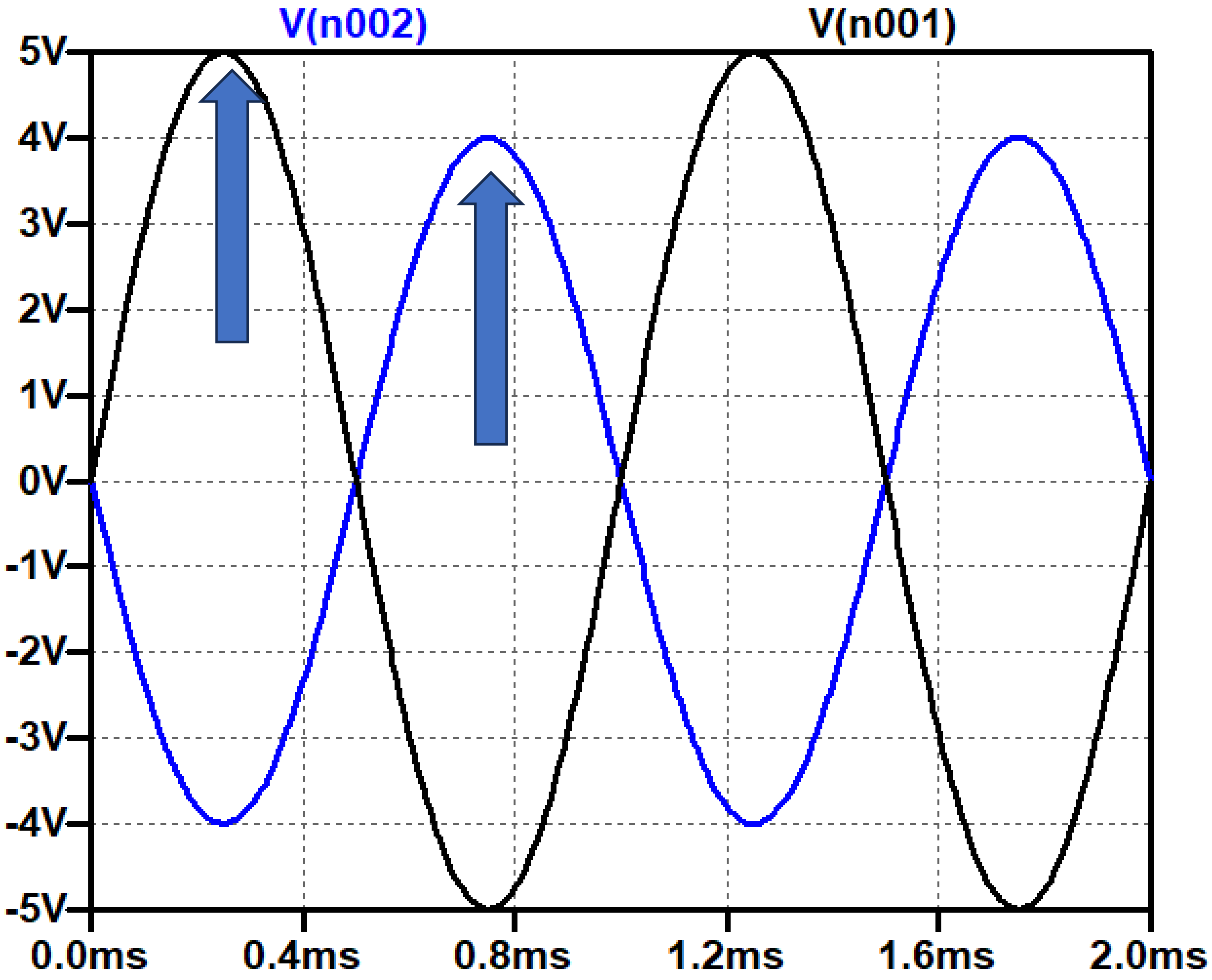
Dt between two peaks
Dt = 250us
Period 1ms=1000us=360deg
so 250us = (250/1000)*360=90 deg



Sinusoidal-Phase-Difference=180

90 degree Phase difference, different amplitudes
V1=5*sin(2*pi*1k*t)
V2=4*sin(2*pi*1k*t + 180deg)

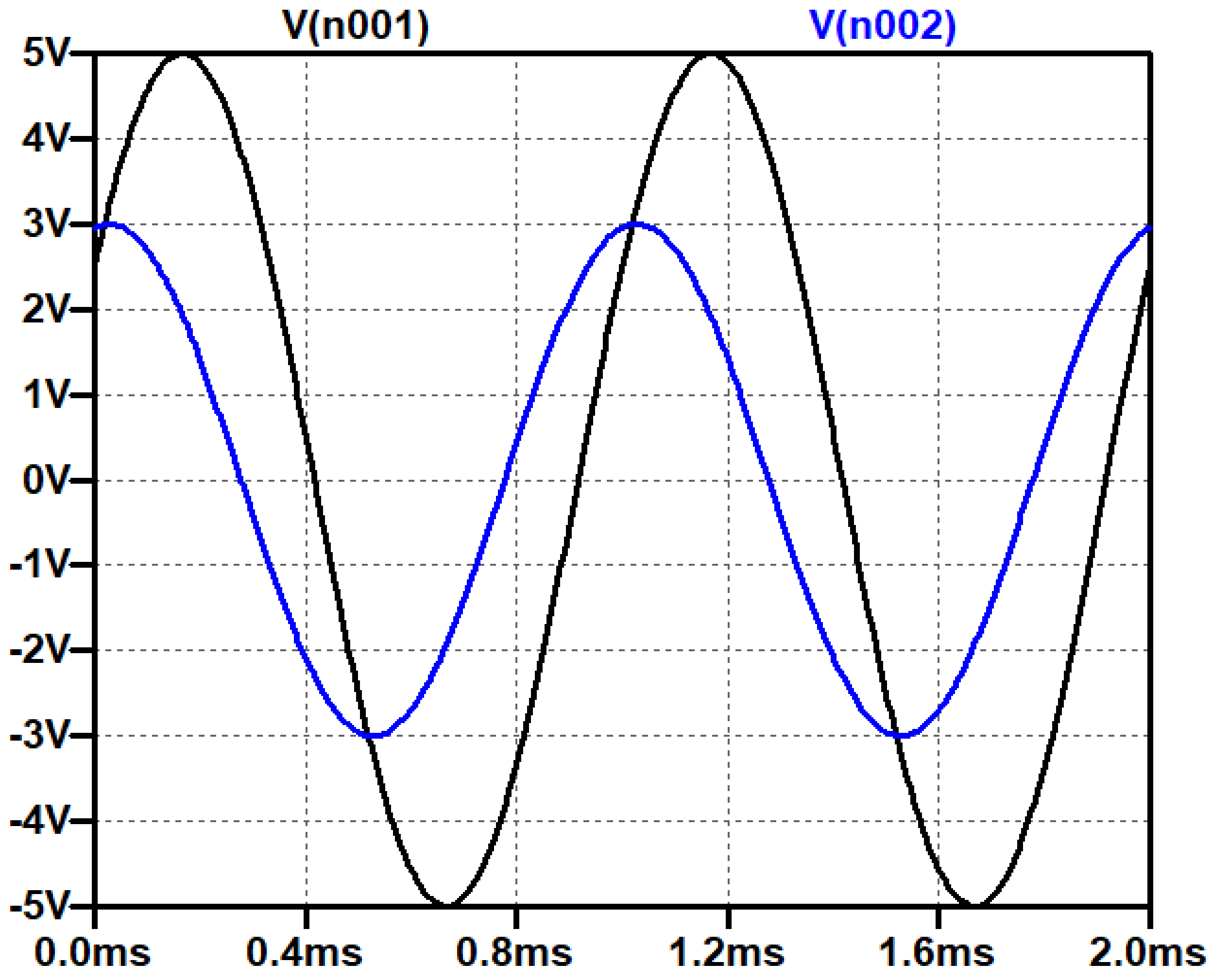
Dt between two signals
500us
Period 1ms=1000us=360deg
so 500us = (500/1000)*360=180 deg



Sinusoidal-Phase-Difference example

What is the phase difference of signals :
V1=5*sin(2*pi*1k*t + 30deg)
V2=4*sin(2*pi*1k*t + 80deg)

Dp = p2 – p1 = 80 – 30 = 50 deg

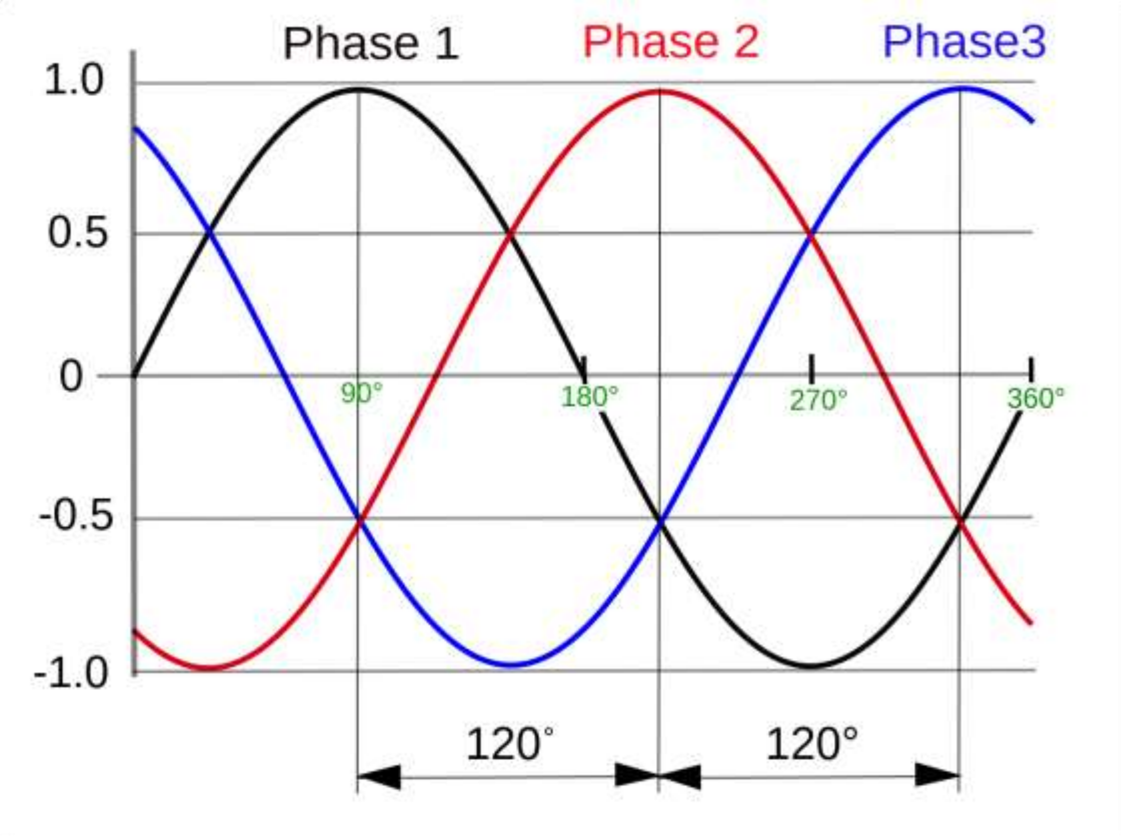


Graphical solution:

peak to peak Dt = 150 us
period T=1ms = 1000 us

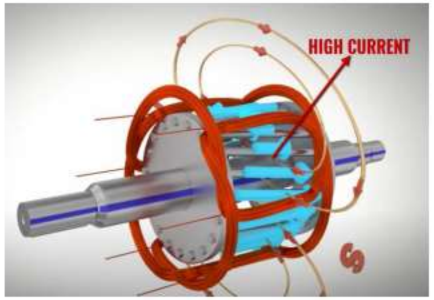
Dp = (150 / 1000) * 360 = 54 deg
measurement error

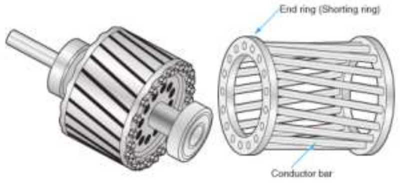
3-Phase AC -120 degree phase difference



- to distribute high power
- suitable for AC induction machines

AC MOTORS: 3 PHASE INDUCTION MOTOR





- Change of flux by rotating magnetic field creates current on conductor loop.
- As soon as current created on loop, magnetic field applies force on current carrying loop. Remember from DC motor and Lorentz Law
- And rotor start to rotate

Sinusoidal

The sinusoidal waveform is the only alternating waveform whose shape is unaffected by the response characteristics of R, L, and C elements.

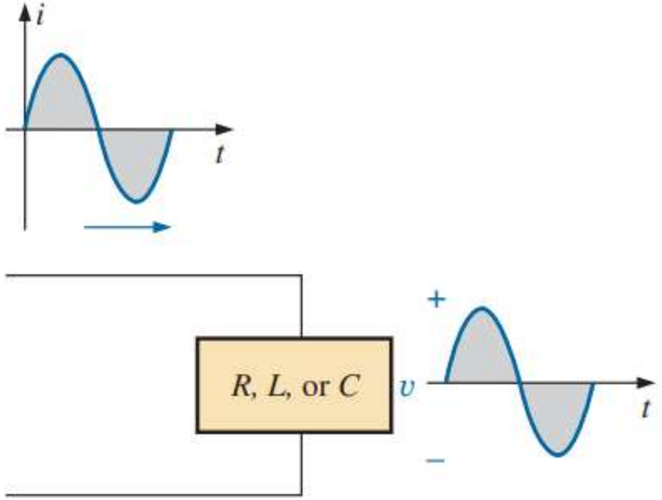


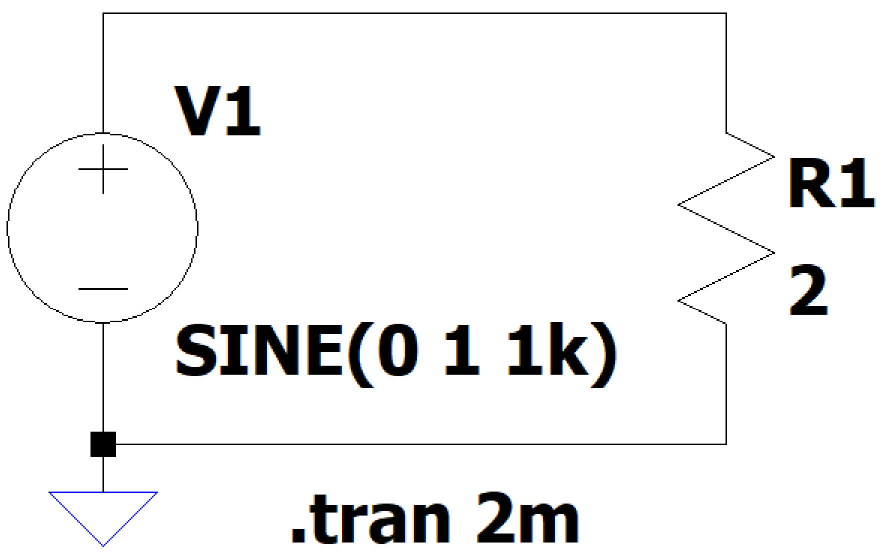
FIG. 13.12
The sine wave is the only alternating waveform whose shape is not altered by the response characteristics of a pure resistor, inductor, or capacitor.

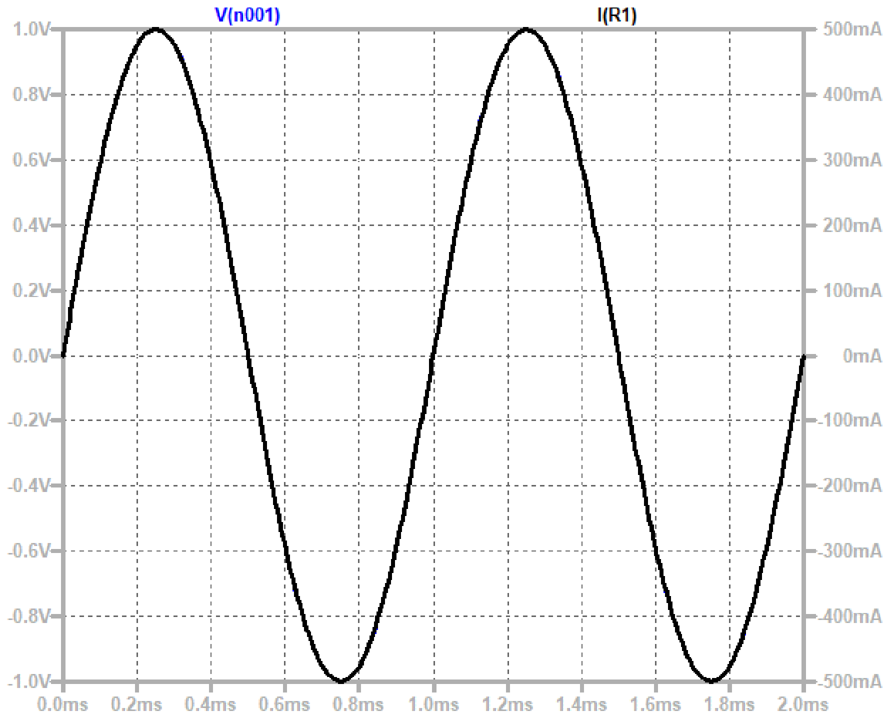
Sinusoidal-R Circuits

Ohms law, KVL and KCL is valid for AC circuits, too.

Resistors DOES NOT change the frequency and phase of AC signals

$$I = \frac{V1}{R1} = \frac{Asin(wt)}{R1} = \frac{A}{R1}\sin(wt)$$





Sinusoidal-R Circuits

Ohms law, KVL and KCL is valid for AC circuits, too.

Resistors DOES NOT change the frequency and phase of AC signals

example: what is the i1 current on R1

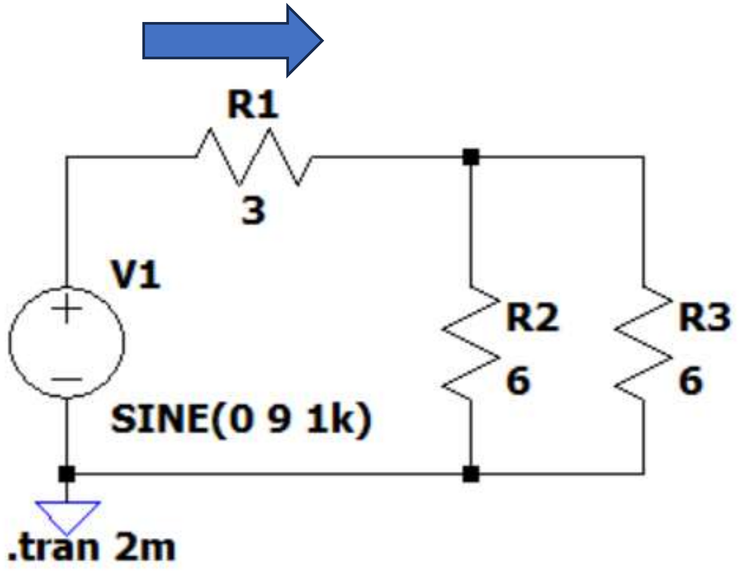
first: calculate total resistance

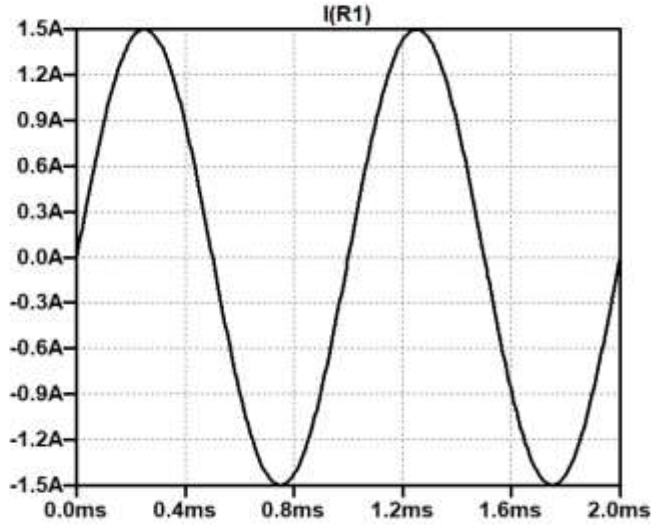
RT=R1 + R2//R3

RT = 3 + 6//6 = 3 + 3 = 6

i1=V1/RT

i1 = 9*sin(wt)/6 = 1.5*sin(wt) A





Sinusoidal

Function Generators

Function generators are an important component of the typical laboratory setting. The generator of Fig. 13.36 can generate six different outputs; sine, triangular, and square wave, ramp, +pulse, and −pulse, with frequencies extending from 0.5 Hz to 4 MHz. However, as shown in the output listing, it has a maximum amplitude of 20 $V_{p\text{-}p}$. A number of other characteristics are included to demonstrate how the text will cover each in some detail.

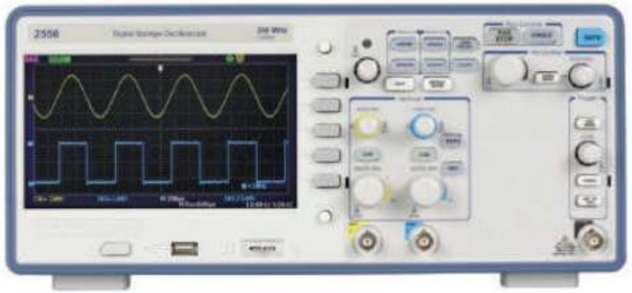


FIG. 13.37
Two-channel digital storage oscilloscope.
(Courtesy of B+K Precision)

The Oscilloscope

The **oscilloscope** of Fig. 13.37 is an instrument that will display the sinusoidal alternating waveform in a way that will permit the reviewing of all of the waveform's characteristics. In some ways, the screen and the dials give an oscilloscope the appearance of a small TV, but remember that *it can display only what you feed into it.* You can't turn it on and ask for a sine wave, a square wave, and so on; it must be connected to a source or an active circuit to display the desired waveform.

The screen has a standard appearance, with 10 horizontal divisions and 8 vertical divisions. The distance between divisions is 1 cm on the vertical

Average

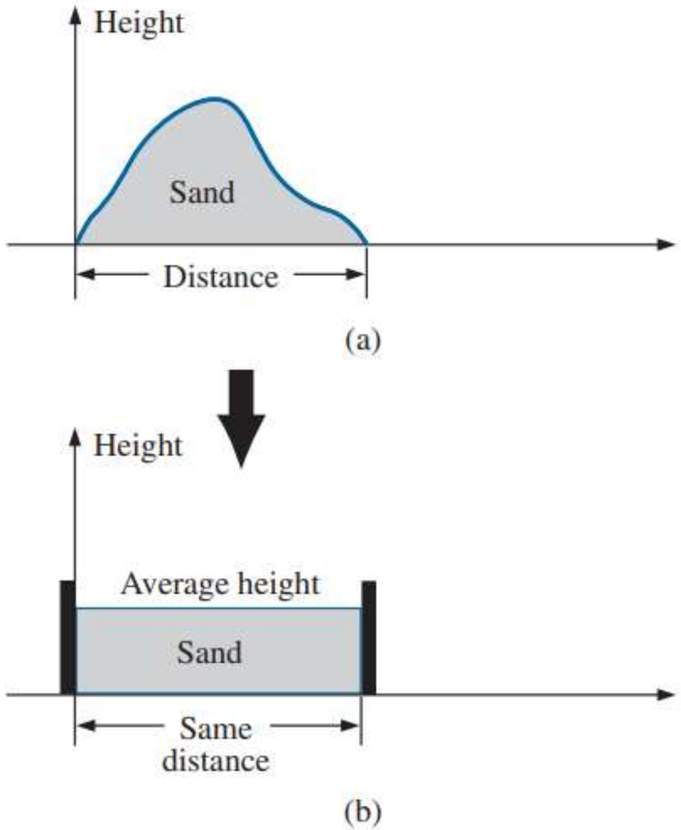


FIG. 13.40
Defining average value.

$$\boxed{G(\text{average value}) = \frac{\text{algebraic sum of areas}}{\text{length of curve}}} \qquad \textbf{(13.26)}$$

Average

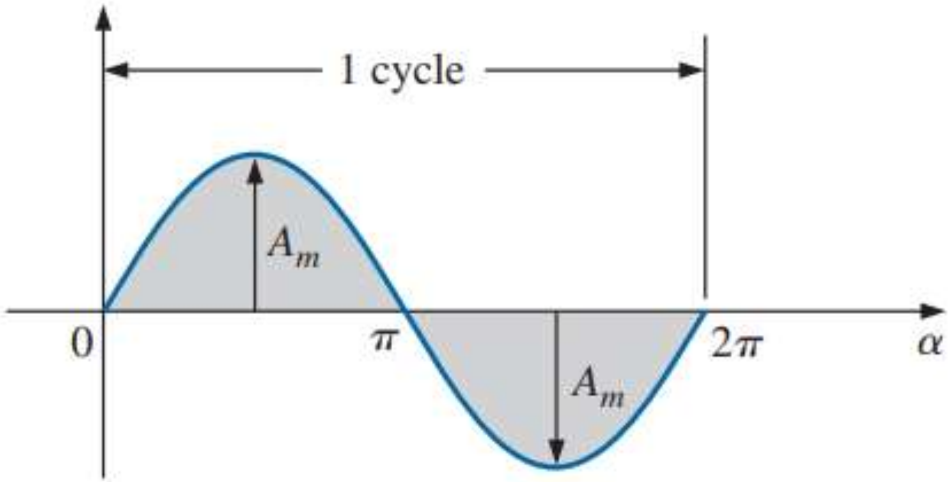


FIG. 13.53
Example 13.16.

EXAMPLE 13.16 Determine the average value of the sinusoidal waveform in Fig. 13.53.

Solution: By inspection it is fairly obvious that

the average value of a pure sinusoidal waveform over one full cycle is zero.

$$\boxed{G(\text{average value}) = \frac{\text{algebraic sum of areas}}{\text{length of curve}}} \qquad \textbf{(13.26)}$$

Sinusoidal

EXAMPLE 13.17 Determine the average value of the waveform in Fig. 13.54.

Solution: The peak-to-peak value of the sinusoidal function is $16 \text{ mV} + 2 \text{ mV} = 18 \text{ mV}$. The peak amplitude of the sinusoidal waveform is, therefore, $18 \text{ mV}/2 = 9 \text{ mV}$. Counting down 9 mV from 2 mV (or 9 mV up from -16 mV) results in an average or dc level of $\mathbf{-7\ mV}$, as noted by the dashed line in Fig. 13.54.

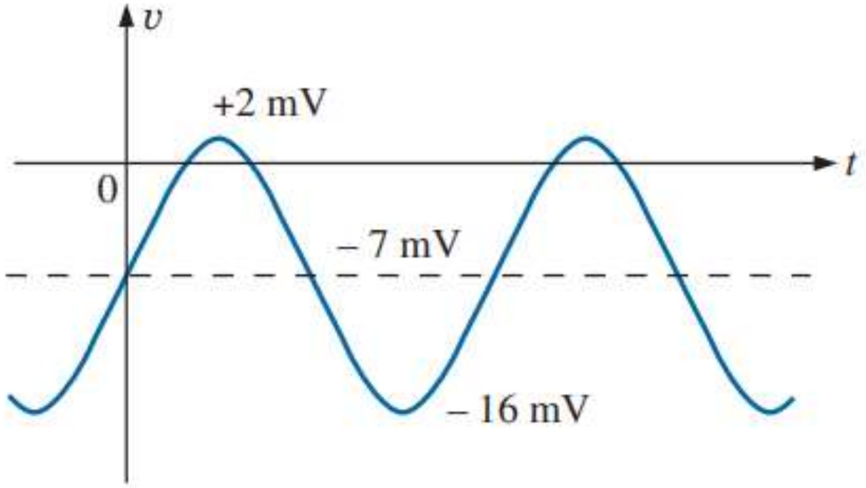
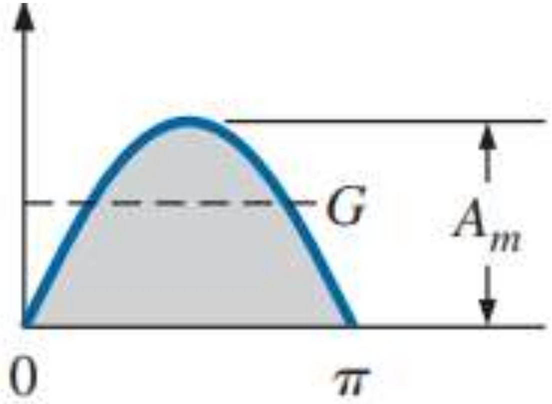


FIG. 13.54
Example 13.17.

$$\boxed{G(\text{average value}) = \frac{\text{algebraic sum of areas}}{\text{length of curve}}} \qquad \textbf{(13.26)}$$

Average

$$\boxed{G = \frac{2A_m}{\pi} = 0.637A_m}$$



(13.28)

$$\boxed{G(\text{average value}) = \frac{\text{algebraic sum of areas}}{\text{length of curve}}}$$ (13.26)

EFFECTIVE (rms) VALUES

Square Root of Mean Squares

Calculus format:

$$\boxed{I_{\text{rms}} = \sqrt{\frac{\int_0^T i^2(t)\,dt}{T}}} \qquad \textbf{(13.31)}$$

which means

$$\boxed{I_{\text{rms}} = \sqrt{\frac{\text{area }(i^2(t))}{T}}} \qquad \textbf{(13.32)}$$

EFFECTIVE (rms) VALUES

V_{RMS}

What is a V_{RMS}?

Definition

V_{RMS} stands for root-mean-square voltage.

Why is RMS used?

Unlike DC voltages which are constant over time, AC (alternating current) voltages are time varying and sinusoidal in shape. The RMS value of an AC signal is equivalent to the DC voltage that would be required to produce the same heating effect (power). The RMS of mains electricity in the U.S. is $110V_{RMS}$ and in Europe it is $220V_{RMS}$.

EFFECTIVE (rms) VALUES

- The power of an AC signal is used on both the positive and negative cycles.
- RMS is calculated using the square of signal voltage values at specific points in time.
- Since squaring eliminates negative numbers, it incorporates the contribution of the negative values

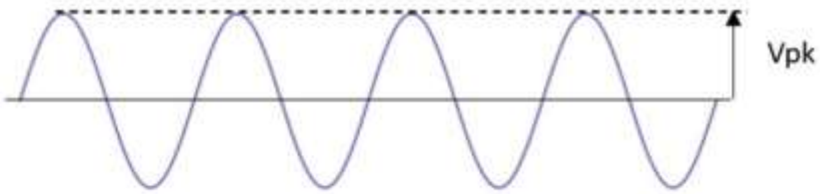


Figure 1. Sinusoidally varying AC signal

What is the relationship between RMS and peak voltage?

The formula that relates V_{RMS} and V_{pk} is:

$V_{pk}=\sqrt{2}\ V_{RMS}$

$$\boxed{Vrms = \frac{Vpeak}{\sqrt{2}}}$$

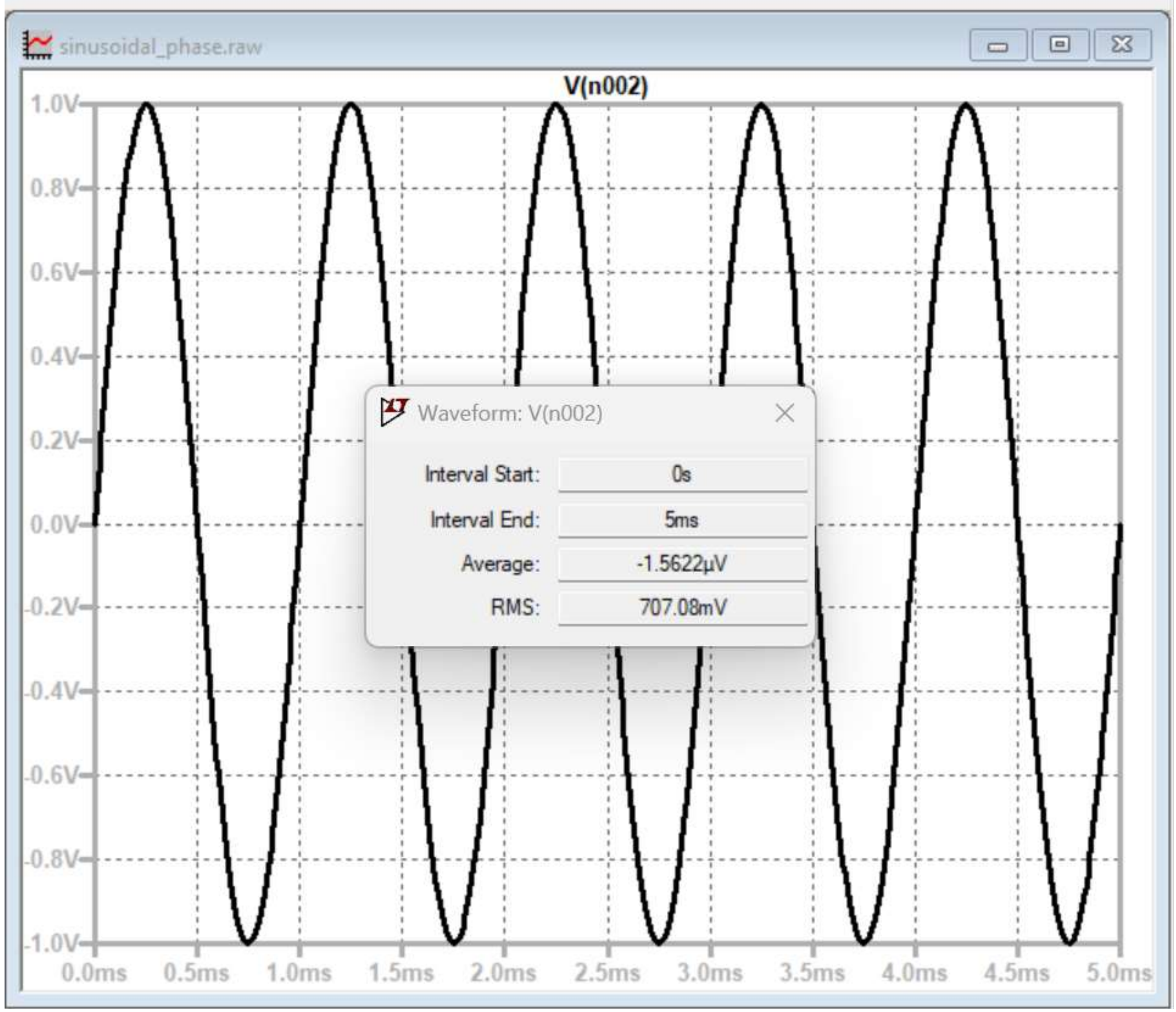
220VAC is rms,

220 = Vpeak/1.4 = 1.4*220 = 311V peak

example: given 311V peak, what is the RMS of this signal

Vrms= 314/sqr(2) = 220V

EFFECTIVE (rms) VALUES



to see rms in Ltspice :

Ctrl – Left Click on V(n002)

EFFECTIVE (rms) VALUES

dc + ac

A unique situation arises if a waveform has both a dc and an ac component that may be due to a source, such as the one in Fig. 13.68. The combination appears frequently in the analysis of electronic networks where both dc and ac levels are present in the same system.

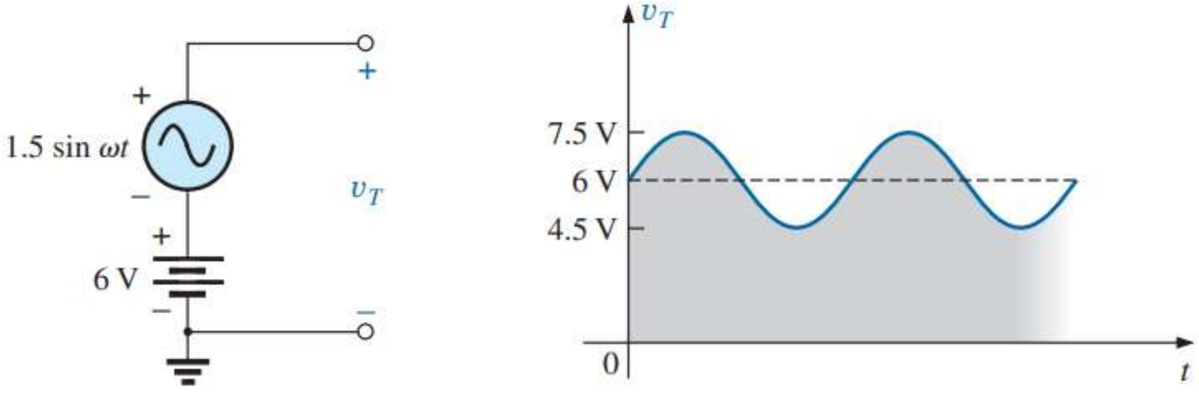


FIG. 13.68
Generation and display of a waveform having a dc and an ac component.

$$\boxed{V_{\text{rms}} = \sqrt{V_{\text{dc}}^2 + V_{\text{ac(rms)}}^2}} \qquad \textbf{(13.35)}$$

which for the waveform in Fig. 13.68 is

$$V_{\text{rms}} = \sqrt{(6\text{ V})^2 + (1.06\text{ V})^2} = \sqrt{37.124\text{ V}^2} \cong \mathbf{6.1\ V}$$

CONVERTER

If you need to convert ac to dc, the piece of equipment used is called a converter

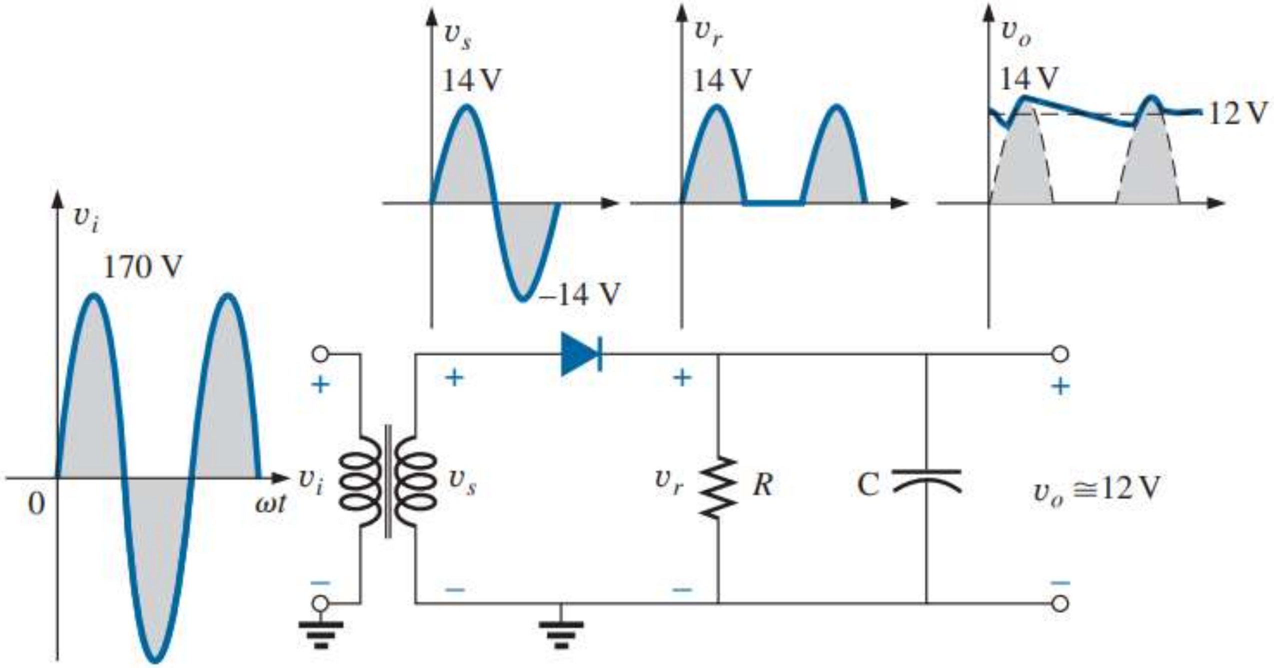


FIG. 13.71
Establishing a 12 V dc level.

INVERTERS

An inverter is an electronic package, such as shown in Fig. 13.72, that will convert a dc supply into an ac source

Signal types:

1. **DC**
2. **PWM, square wave**
3. **Sinusoidal**

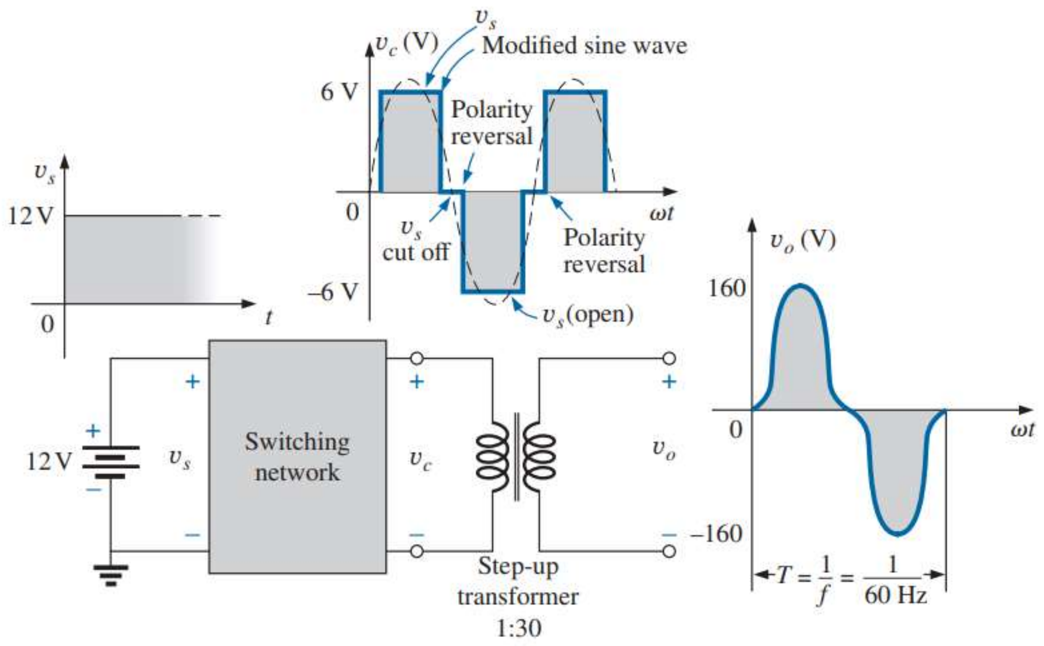
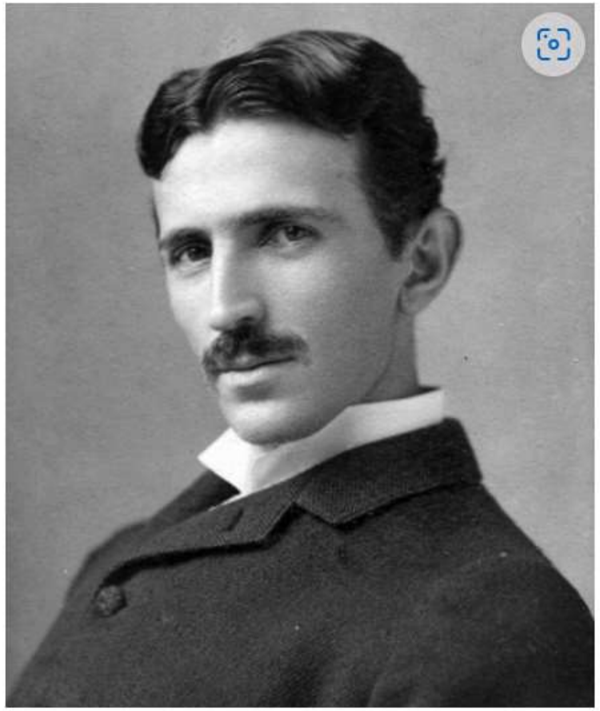


FIG. 13.73
Basic components of an inverter.

AC vs DC



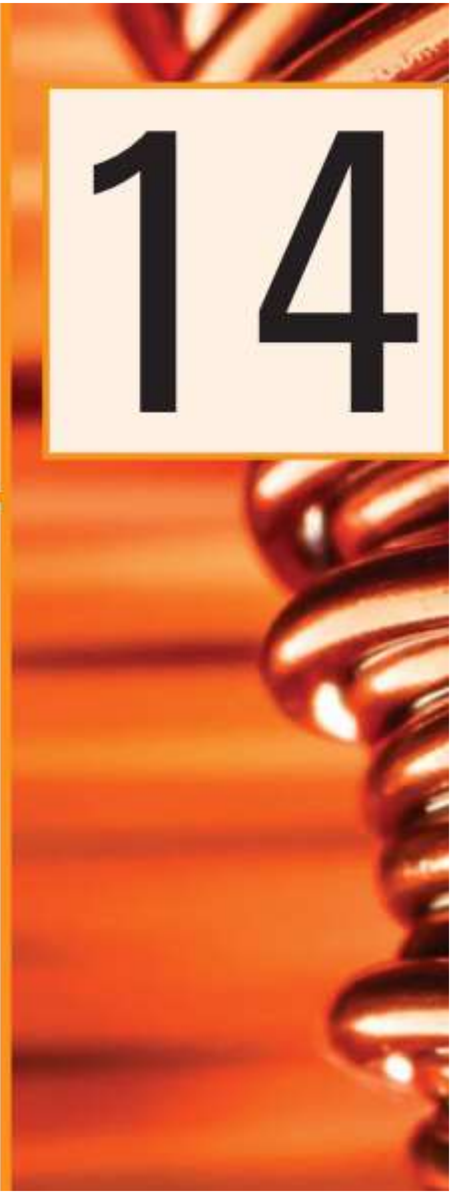
Nikola Tesla (Image courtesy of wikipedia.org)

George Westinghouse (Image courtesy of pbs.org)

- AC is easy to generate using rotating mechanical magnetic fields
- AC is easy to step down using transformers 10KV between cities but 220V AC rms
- it starter with DC using Dynamo (DC motor) in New York Pearl Street power station but later AC is accepted widely

14

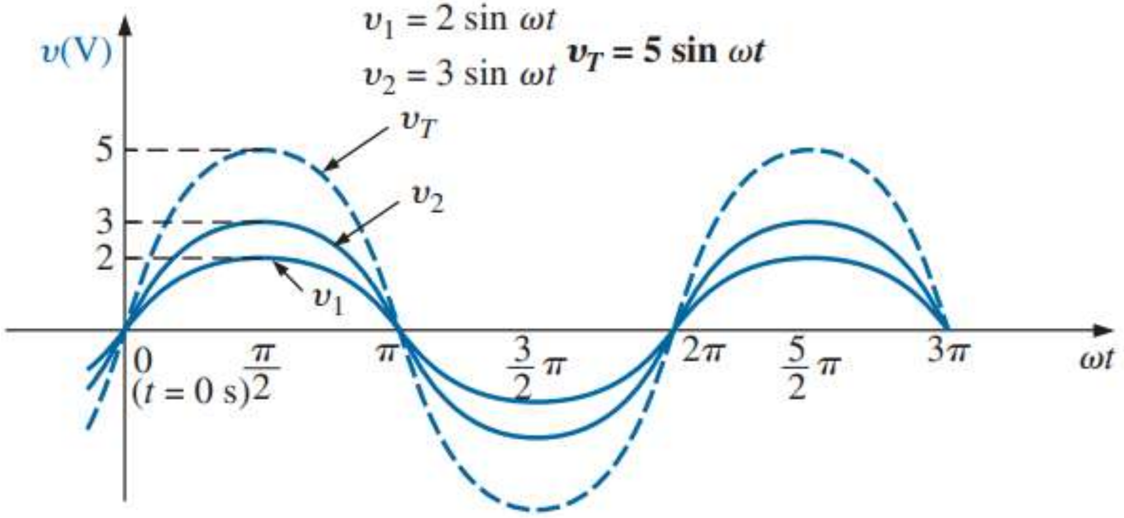
The Basic Elements and Phasors



Objectives

- *Become familiar with the response of a resistor, an inductor, and a capacitor to the application of a sinusoidal voltage or current.*
- *Learn how to apply the phasor format to add and subtract sinusoidal waveforms.*
- *Understand how to calculate the real power to resistive elements and the reactive power to inductive and capacitive elements.*
- *Become aware of the differences between the frequency response of ideal and practical elements.*
- *Become proficient in the use of a calculator to work with complex numbers.*

Addition of Sinusoidal Signals-In Phase



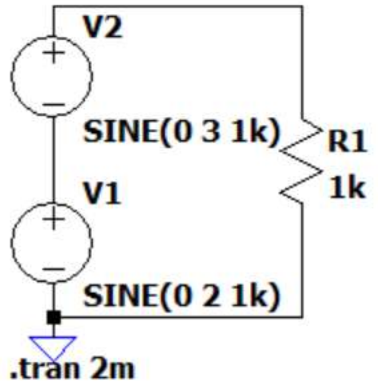
the addition (or subtraction) of two sinusoidal voltages of the same frequency and phase angle is simply the sum (or difference) of the peak values of each with the sum (or difference) having the same phase angle.

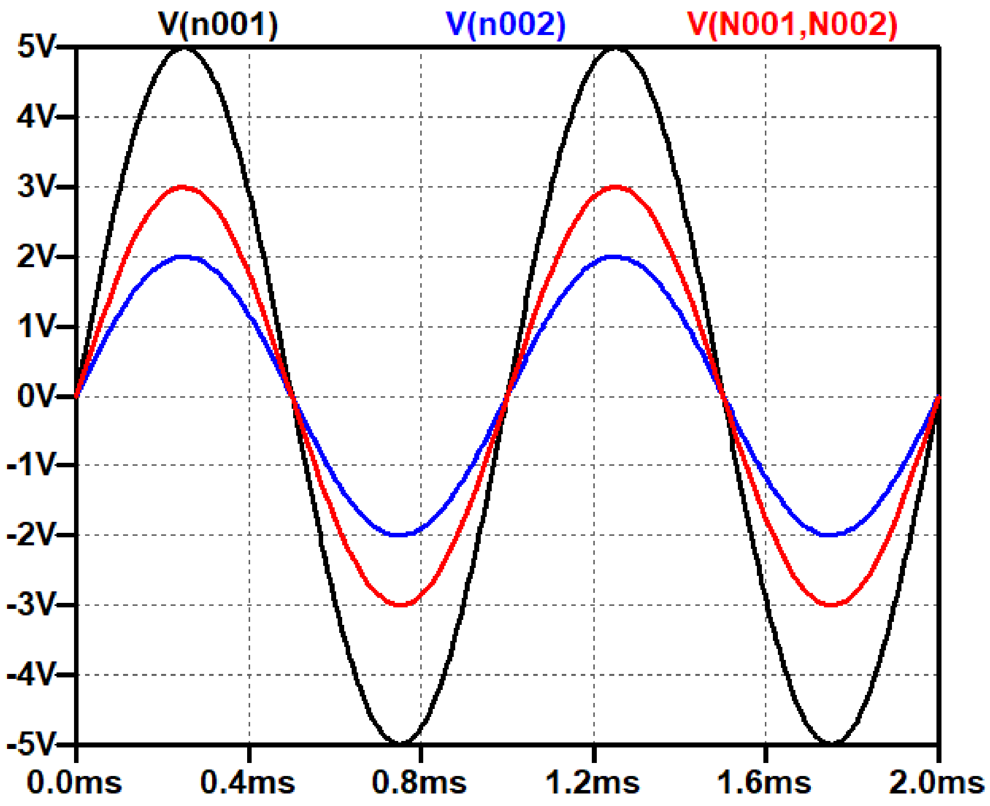
$$2\sin(wt) + 3\sin(wt) = 5\sin(wt)$$

$$2\sin(wt+\theta) + 3\sin(wt+\theta) = 5\sin(wt+\theta)$$

Addition of Sinusoidal Signals-In Phase

the addition (or subtraction) of two sinusoidal voltages of the same frequency and phase angle is simply the sum (or difference) of the peak values of each with the sum (or difference) having the same phase angle.

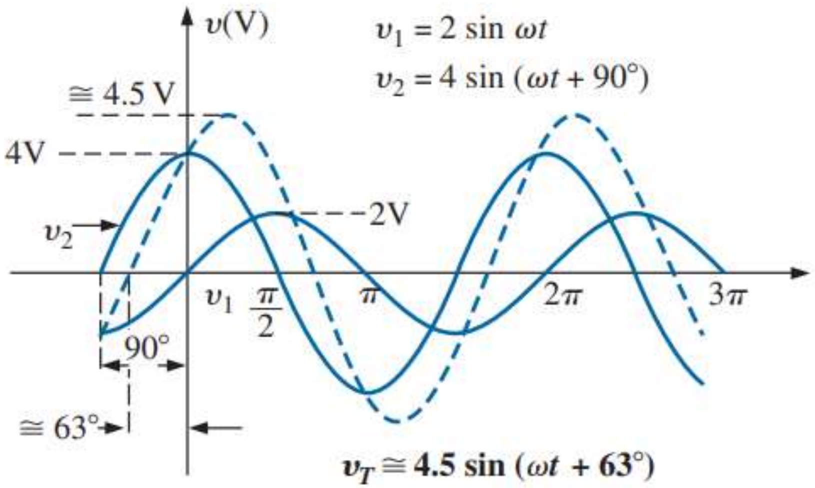




$$2\sin(wt) + 3\sin(wt) = 5\sin(wt)$$

$$2\sin(wt+\theta) + 3\sin(wt+\theta) = 5\sin(wt+\theta)$$

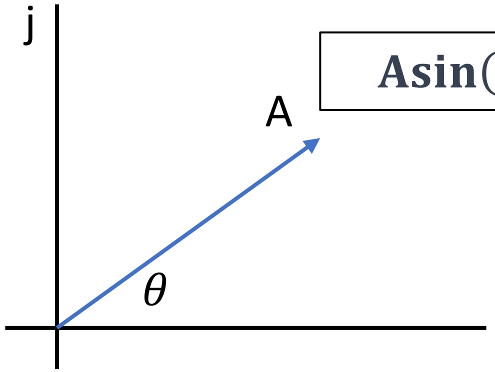
Addition of Sinusoidal Signals-Out of Phase



Addition of two sinusoidal signal is ALSO sinusoidal with the same frequency and different phase

$$\sin(A + B) = \sin(A)\cos(B) + \cos(A)\sin(B)$$
$$\text{A}\sin(wt + \theta) = A\cos(\theta)\,.\sin(wt) + \text{A}\sin(\theta)\cos(wt)$$

$$Euler's\ Formula$$
$$e^{jwt} = \cos(wt) + j\sin(wt)$$
$$\text{A}e^{j(wt+\theta)} = Ae^{jwt}.e^{j\theta} = e^{jwt}A(cos\theta + jsin\theta)$$



$\mathbf{A\sin(}\boldsymbol{wt+\theta}\mathbf{)}$

we can use vectors or complex numbers to simplify addition of sinusoidal signals with phase difference.

Addition of Sinusoidal Signals-Out of Phase

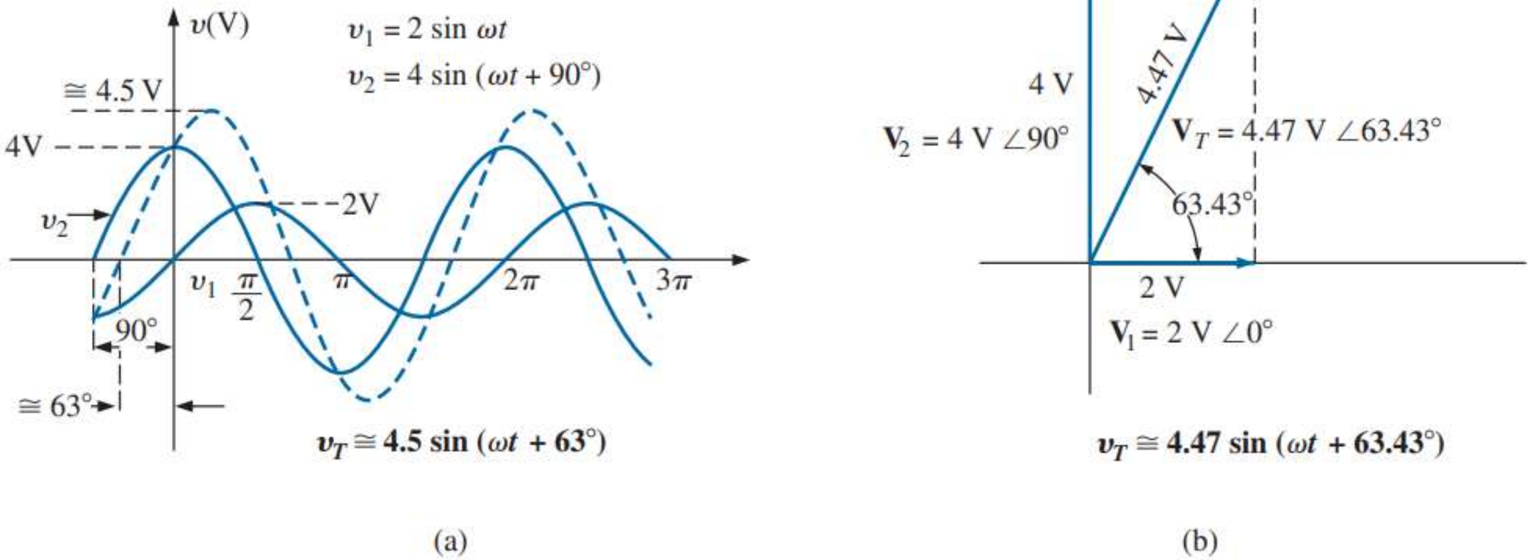
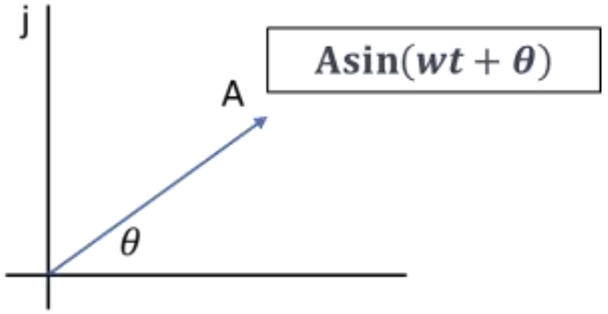


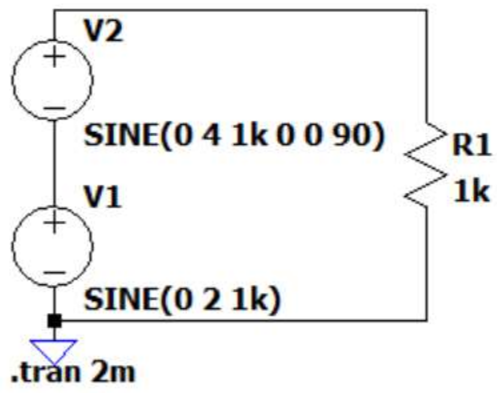
FIG. 14.67
Finding the sum of two sinusoidal waveforms that are out of phase.



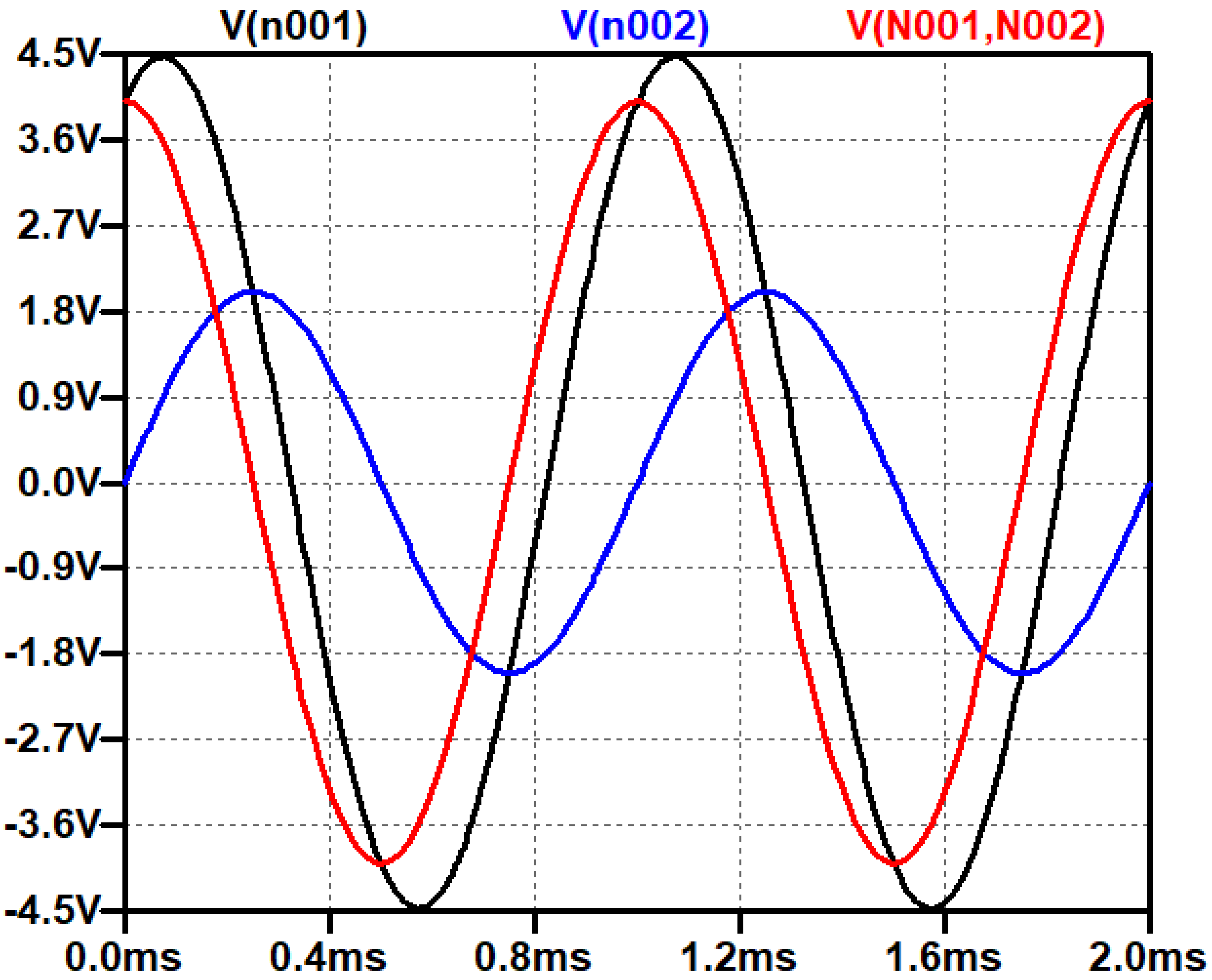
v1=2sin(wt)
v2=4sin(wt + 90)
v1 + v2 = ?
Add real parts $Acos(\theta)$ and complex parts $Asin(\theta)$ separately

$$\tan(\theta) = \frac{4}{2}$$
$$\theta = arctan(2)$$
$$\theta = 63.43°$$

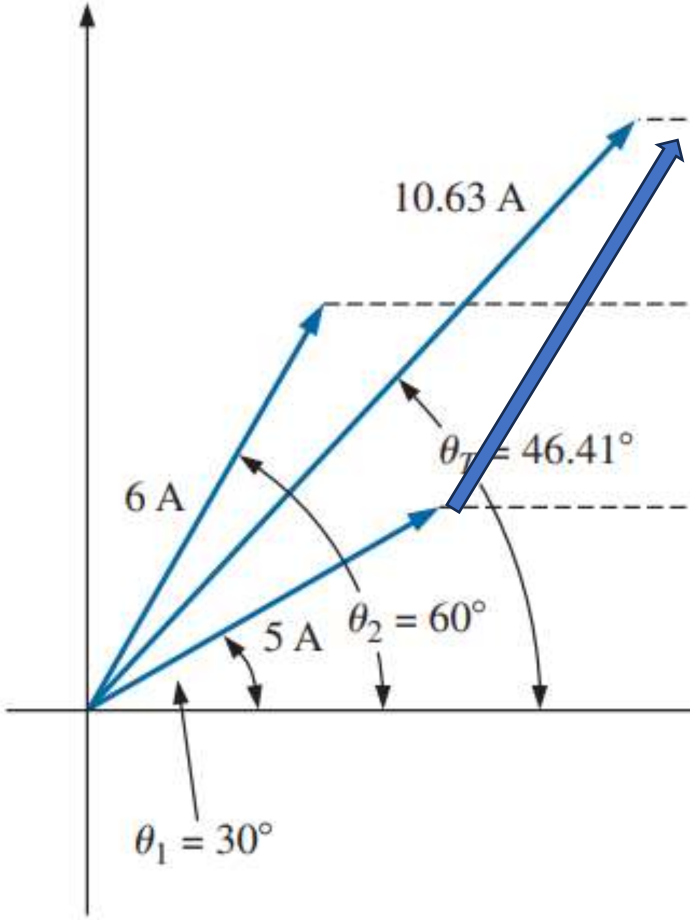
Addition of Sinusoidal Signals-Out of Phase



$$v_T \cong 4.47 \sin(\omega t + 63.43^\circ)$$



Addition of Sinusoidal Signals-Out of Phase



(a)

EXAMPLE 14.27 Find the sum of the following sinusoidal functions

$$i_1 = 5\sin(\omega t + 30°)$$

$$i_2 = 6\sin(\omega t + 60°)$$

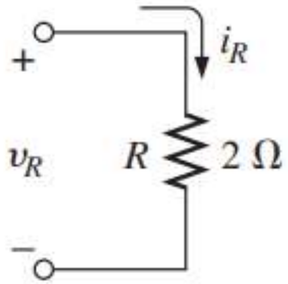
$$= (4.33\text{ A} + j2.5\text{ A}) + (3\text{ A} + j5.2\text{ A})$$
$$= 7.33\text{ A} + j7.7\text{ A}$$
$$= 10.63\text{ A}\angle 46.41°$$

and $i_T = \mathbf{10.63\sin(\omega t + 46.41°)}$ as obtained graphically.

What is the phase difference ?

Dp = p2 – p1, if frerquencies are the same
Dp = 60 -30 = 30

14.4 AVERAGE POWER AND POWER FACTOR



$$P_{av} = \frac{V_m I_m}{2} = \frac{(\sqrt{2}\,V_{rms})(\sqrt{2}\,I_{rms})}{2} = \frac{2\,V_{rms} I_{rms}}{2}$$

$$\boxed{P_{av} = \frac{V_m \times I_m}{2}}$$

$$\boxed{P_{av} = V_{rms} I_{rms}} \qquad (14.14)$$

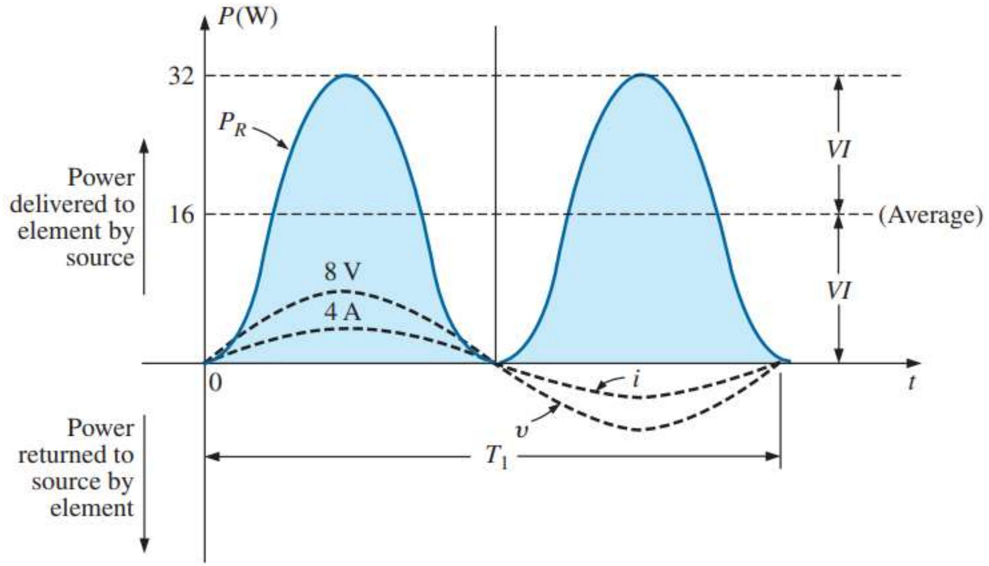
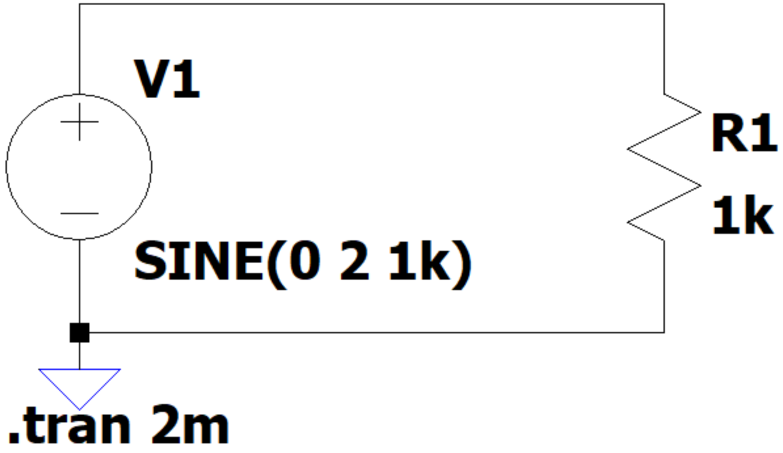


FIG. 14.27
Power versus time for a purely resistive load.

14.4 AVERAGE POWER AND POWER FACTOR

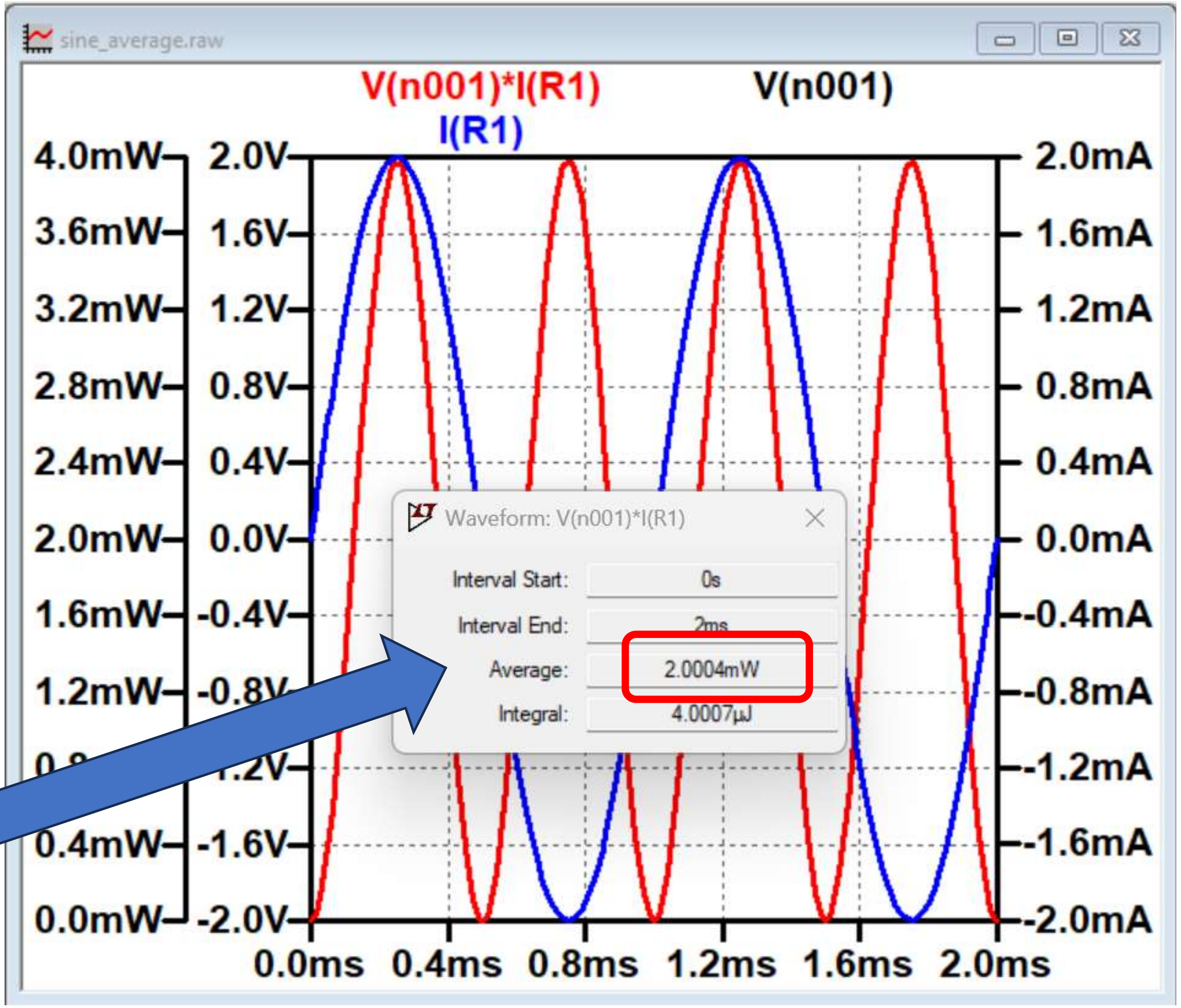


Pav = Vm * Im / 2

Vm = 2V*sin(wt)

Im = Vm/R1 = 2mA*sin(wt)

Pav = 2*2 / 2 = 2 mW



14.4 AVERAGE POWER AND **POWER FACTOR**

Out of Phase

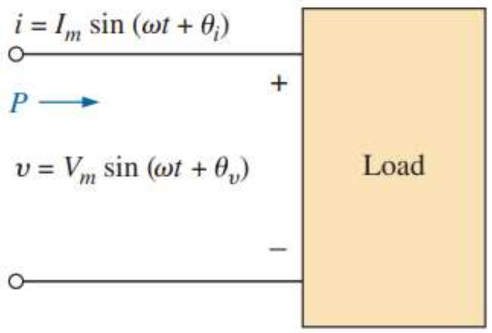


FIG. 14.28
Determining the power

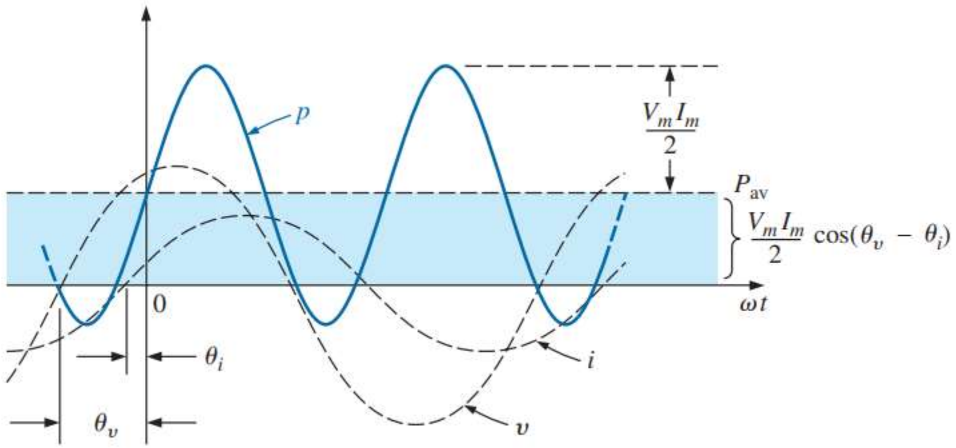


FIG. 14.29
Defining the average power for a sinusoidal ac network.

The power delivered at each instant of time is then defined by

$$p = vi = V_m \sin(\omega t + \theta_v) I_m \sin(\omega t + \theta_i)$$

$$= V_m I_m \sin(\omega t + \theta_v)\sin(\omega t + \theta_i)$$

where θ_v is simply the phase angle associated with the applied voltage and θ_i is the phase angle associated with the resulting current.

Using the trigonometric identity

$$\sin A \sin B = \frac{\cos(A - B) - \cos(A + B)}{2}$$

we see that the function $\sin(\omega t + \theta_v)\sin(\omega t + \theta_i)$ becomes

$$\sin(\omega t + \theta_v)\sin(\omega t + \theta_i)$$

$$= \frac{\cos[(\omega t + \theta_v) - (\omega t + \theta_i)] - \cos[(\omega t + \theta_v) + (\omega t + \theta_i)]}{2}$$

$$= \frac{\cos(\theta_v - \theta_i) - \cos(2\omega t + \theta_v + \theta_i)}{2}$$

so that

$$p = \overbrace{\left[\frac{V_m I_m}{2}\cos(\theta_v - \theta_i)\right]}^{\text{Fixed value}} - \overbrace{\left[\frac{V_m I_m}{2}\cos(2\omega t + \theta_v - \theta_i)\right]}^{\text{Time-varying (due to } \omega t \text{ in equation)}}$$

simply the difference in phase angles

$$\boxed{P = \frac{V_m I_m}{2} \cos\theta} \quad (\text{watts, W}) \qquad \textbf{(14.15)}$$

14.4 AVERAGE POWER AND POWER FACTOR

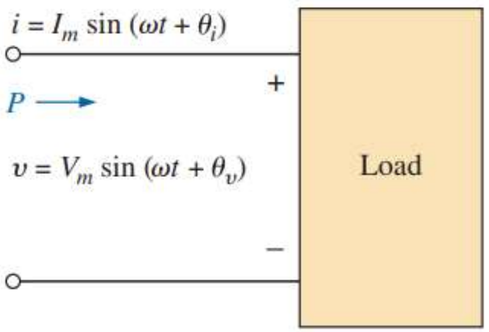


FIG. 14.28
Determining the power

$$\boxed{P = \frac{V_m I_m}{2} \cos\theta} \quad (\text{watts, W}) \qquad \textbf{(14.15)}$$

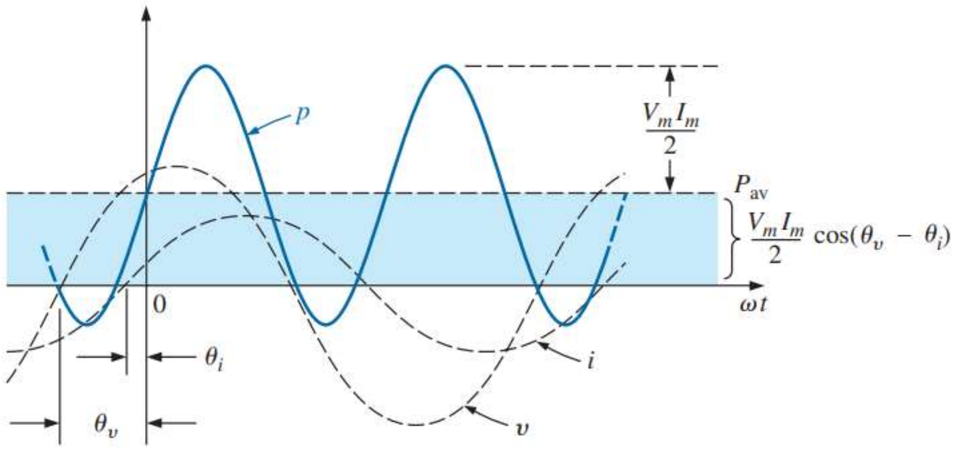


FIG. 14.29
Defining the average power for a sinusoidal ac network.

$$\boxed{P = V_{rms} I_{rms} \cos\theta} \qquad \textbf{(14.16)}$$

14.4 AVERAGE POWER AND POWER FACTOR

$$\boxed{P = \frac{V_m I_m}{2} \cos \theta} \quad \text{(watts, W)} \qquad \textbf{(14.15)}$$

14.4 AVERAGE POWER AND POWER FACTOR

Power Factor

In the equation $P = (V_m I_m/2)\cos\theta$, the factor that has significant control over the delivered power level is the $\cos\theta$. No matter how large the voltage or current, if $\cos\theta = 0$, the power is zero; if $\cos\theta = 1$, the power delivered is a maximum. Since it has such control, the expression was given the name **power factor** and is defined by

$$\boxed{\text{Power factor} = F_p = \cos\theta} \qquad \textbf{(14.19)}$$

14.4 AVERAGE POWER AND POWER FACTOR

EXAMPLE 14.12 Determine the power factors of the following loads, and indicate whether they are leading or lagging:

a. Fig. 14.32
b. Fig. 14.33
c. Fig. 14.34

Solutions:

a. $F_p = \cos\theta = \cos|\theta_v - \theta_i| = \cos|-20° - 40°| = \cos 60° = \mathbf{0.5\ leading}$

b. $F_p = \cos|\theta_v - \theta_i| = \cos|80° - 30°| = \cos 50° = \mathbf{0.64\ lagging}$

c. $F_p = \cos\theta = \dfrac{P}{V_{\text{eff}} I_{\text{eff}}} = \dfrac{100\ \text{W}}{(20\ \text{V})(5\ \text{A})} = \dfrac{100\ \text{W}}{100\ \text{W}} = \mathbf{1}$

The load is resistive, and F_p is neither leading nor lagging.

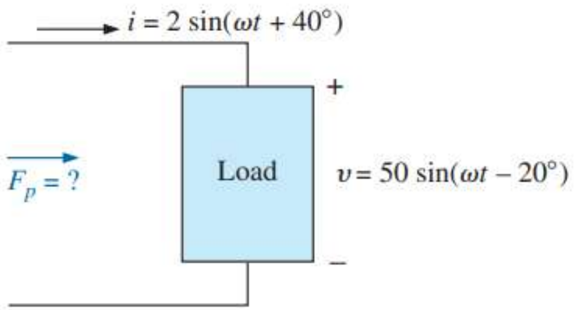
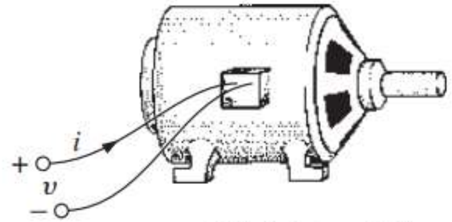


FIG. 14.32
Example 14.12(a).



$v = 120 \sin(\omega t + 80°)$
$i = 5 \sin(\omega t + 30°)$

FIG. 14.33
Example 14.12(b).

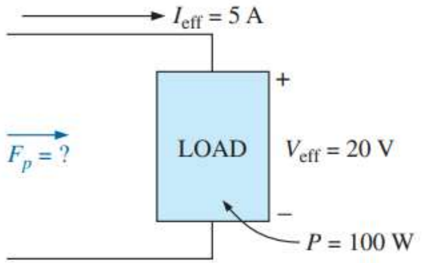
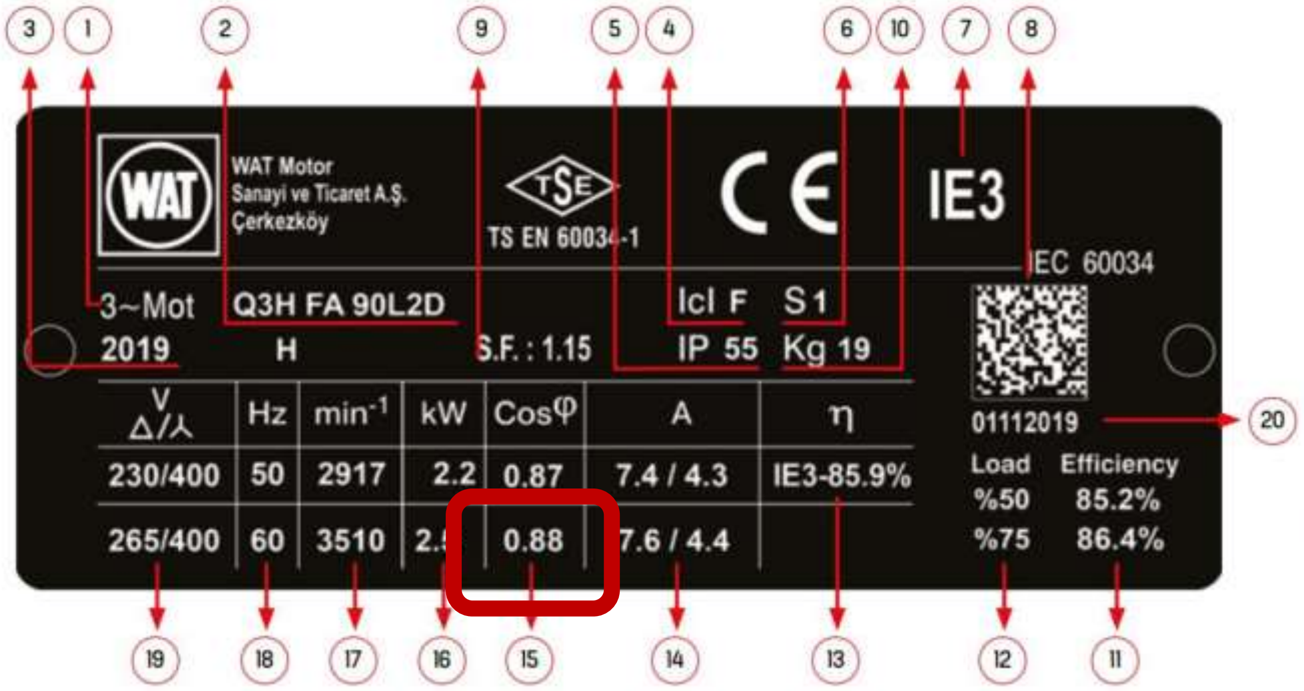


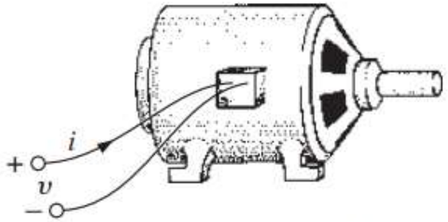
FIG. 14.34
Example 14.12(c).

14.4 AVERAGE POWER AND POWER FACTOR



1 Motor type
2 Motor code
3 Year of manufacture
4 Insulation class
5 IP class
6 Service type
7 Efficiency class (acc. to IEC 60034-30)
8 2D Barcode
9 Service factor *
10 Motor weight

11 Efficiency value (acc. to IEC 60034-2-1)
12 Load value
13 Efficiency value (acc. to IEC 60034-2-1)
14 Nominal current
15 Power factor
16 Motor output power
17 Rated speed
18 Motor nominal frequency
19 Operation voltage
20 Production tracing number



$$v = 120 \sin(\omega t + 80^\circ)$$
$$i = 5 \sin(\omega t + 30^\circ)$$

FIG. 14.33
Example 14.12(b).

14.5 COMPLEX NUMBERS-ANNEX

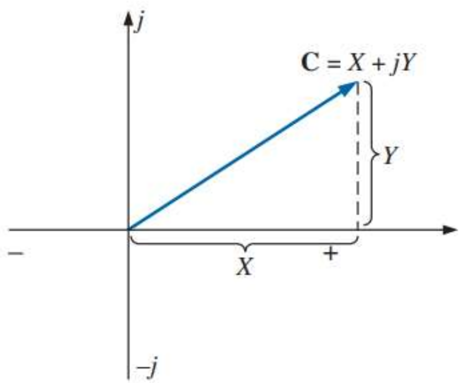


FIG. 14.36
Defining the rectangular form.

$$\boxed{\boldsymbol{C} = X + jY} \qquad (14.21)$$

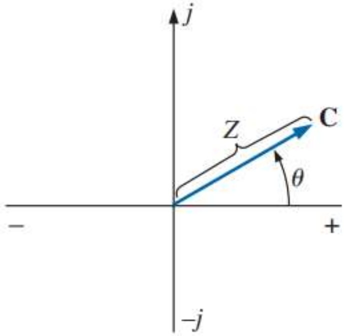


FIG. 14.40
Defining the polar form.

$$\boxed{\mathbf{C} = Z \angle \theta} \qquad (14.22)$$

14.5 COMPLEX NUMBERS-ANNEX

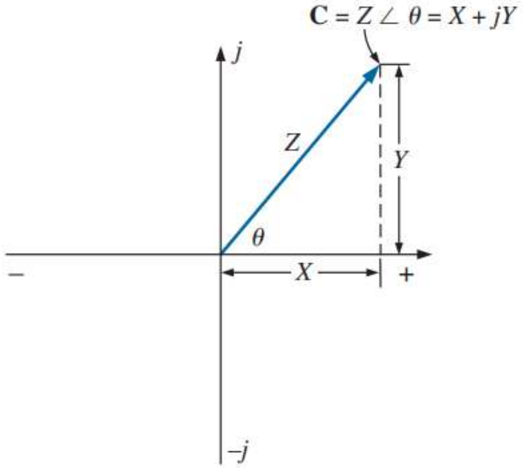


FIG. 14.45
Conversion between forms.

Polar to Rectangular

$$\boxed{X = Z\cos\theta} \qquad (14.26)$$

$$\boxed{Y = Z\sin\theta} \qquad (14.27)$$

14.5 COMPLEX NUMBERS-Addition

Addition

To add two or more complex numbers, add the real and imaginary parts separately. For example, if

$$\mathbf{C}_1 = \pm X_1 \pm jY_1 \quad \text{and} \quad \mathbf{C}_2 = \pm X_2 \pm jY_2$$

then

$$\boxed{\mathbf{C}_1 + \mathbf{C}_2 = (\pm X_1 \pm X_2) + j(\pm Y_1 \pm Y_2)} \qquad \textbf{(14.31)}$$

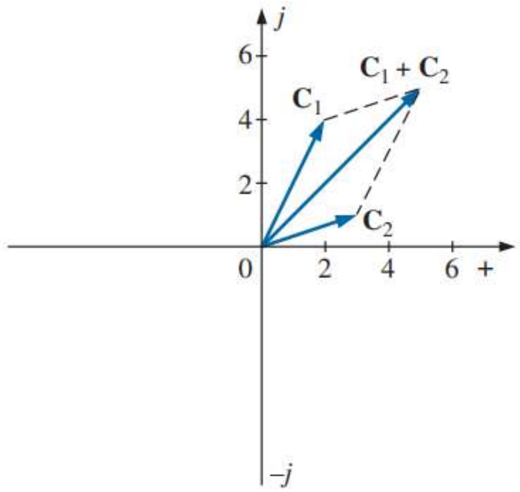


FIG. 14.52
Example 14.19(a).

EXAMPLE 14.19

a. Add $\mathbf{C}_1 = 2 + j4$ and $\mathbf{C}_2 = 3 + j1$.
b. Add $\mathbf{C}_1 = 3 + j6$ and $\mathbf{C}_2 = -6 + j3$.

Solutions:

a. By Eq. (14.31),

$$\mathbf{C}_1 + \mathbf{C}_2 = (2 + 3) + j(4 + 1) = \mathbf{5 + j5}$$

Note Fig. 14.52. An alternative method is

$$\begin{array}{c} 2 + j4 \\ \underline{3 + j1} \\ \downarrow \quad \downarrow \\ \mathbf{5 + j5} \end{array}$$

b. By Eq. (14.31),

$$\mathbf{C}_1 + \mathbf{C}_2 = (3 - 6) + j(6 + 3) = \mathbf{-3 + j9}$$

Inductors

11

Objectives

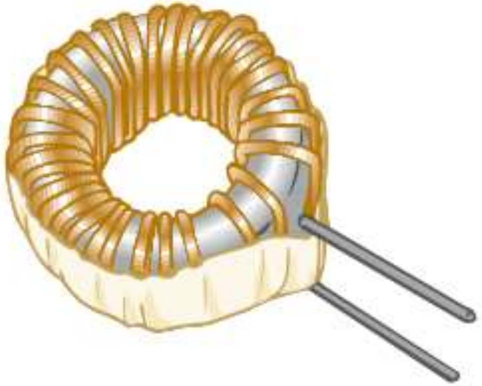
- *Become familiar with the basic construction of a variety of inductors and the factors that affect the inductance level.*
- *Become aware of the magnetic flux pattern for a variety of electrical devices employing magnetism.*
- *Be able to read the labeling on inductive elements and measure the inductance using a Universal LCR meter.*
- *Be able to determine the transient (time varying) response of an inductive network to an applied dc level and plot the resulting voltages and currents.*
- *Learn how to connect inductors in series and parallel and how to determine the total inductance.*

Inductor

An inductor typically consists of an **insulated** wire wound into a coil.

Type: Air-core inductors (1–32 turns)
Typical values: 2.5 nH–1 μH
Applications: High-frequency applications

Type: Toroid coil
Typical values: 10 μH–30 mH
Applications: Used as a choke in ac power line circuits to filter transient and reduce EMI interference. This coil is found in many electronic appliances.



11.11 INDUCTORS IN SERIES AND IN PARALLEL

$$\boxed{L_T = L_1 + L_2 + L_3 + \cdots + L_N} \qquad \textbf{(11.30)}$$

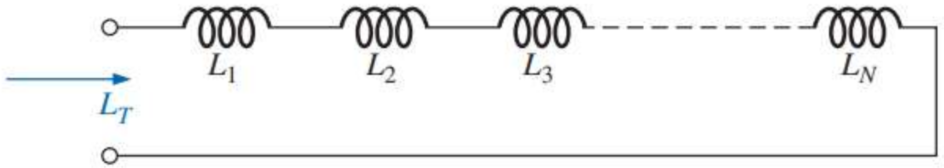


FIG. 11.56
Inductors in series.

For inductors in parallel, the total inductance is found in the same manner as the total resistance of resistors in parallel (Fig. 11.57):

$$\boxed{\frac{1}{L_T} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \cdots + \frac{1}{L_N}} \qquad \textbf{(11.31)}$$

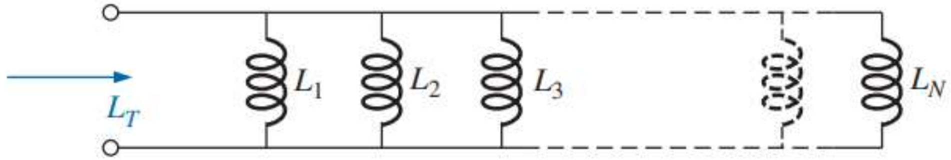
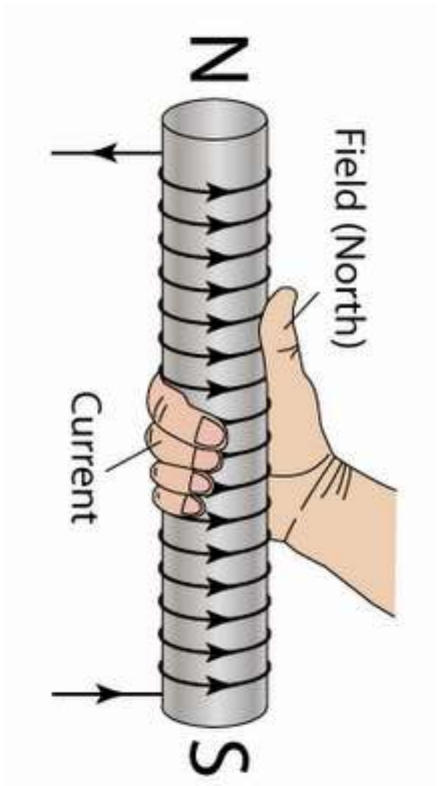


FIG. 11.57
Inductors in parallel.

Inductor-Magnetic Field



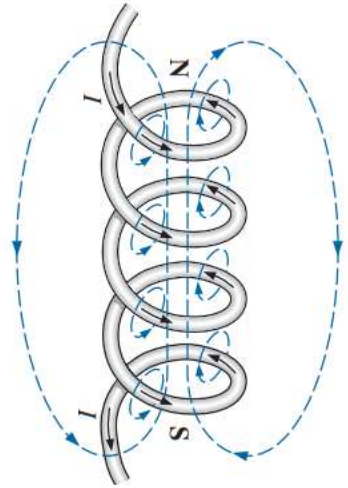


FIG. 11.8 *Flux distribution of a current-carrying coil.*

A coil of more than one turn produces a magnetic field that exists in a continuous path through and around the coil (Fig. 11.8)

$$\boxed{B = \mu I N}$$

$$\boxed{\mu_o = 4\pi \times 10^{-7}\ \text{Wb/Am}} \qquad \textbf{(11.4)}$$

The ratio of the permeability of a material to that of free space is called its **relative permeability**; that is,

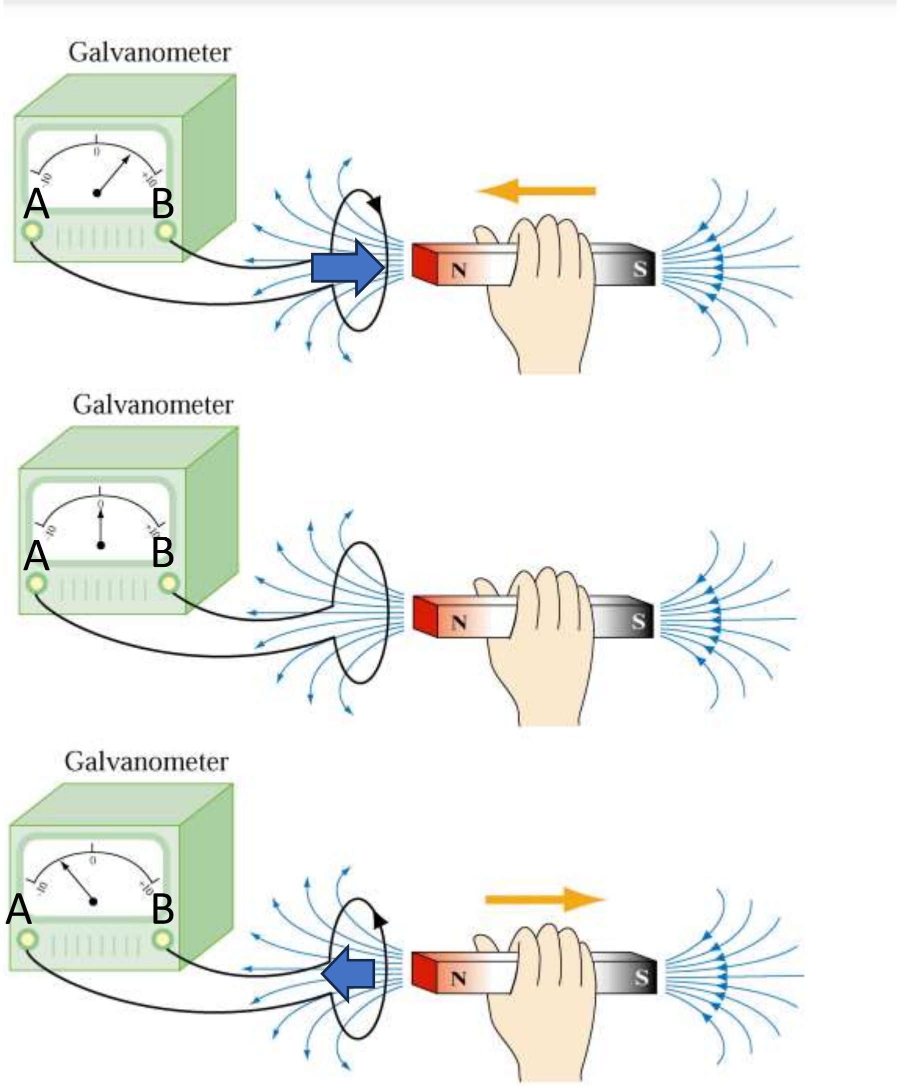
$$\boxed{\mu_r = \frac{\mu}{\mu_0}} \qquad \textbf{(11.5)}$$

Inductor-Faraday's Law

Faraday's Law: Change of Flux Generates Current

$$\boxed{V_{AB} = -\frac{d\emptyset_B}{dt}}$$

Direction of current defined by Lenz Law: The induced current produces magnetic fields that tend to **oppose** the change in magnetic flux that induces such currents.



Inductor-Faraday's Law

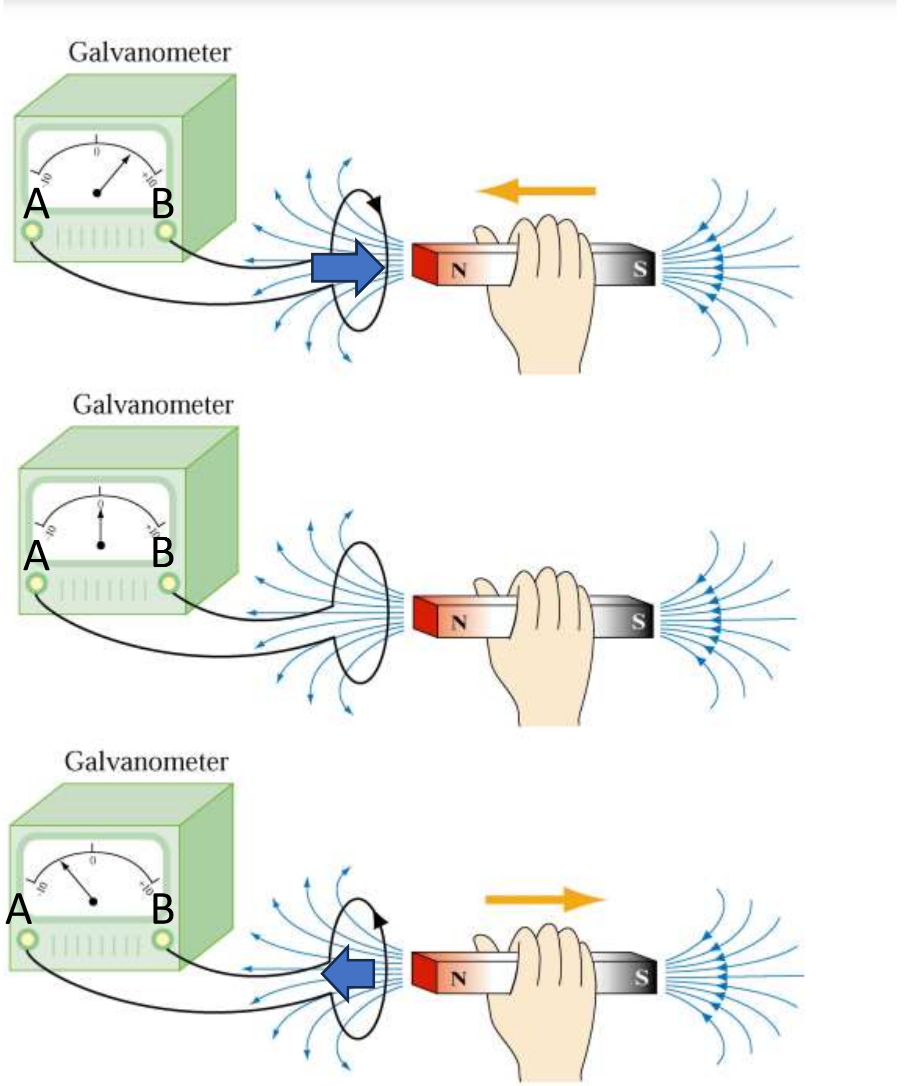
Faraday's Law: Change of Flux Generates Current

$$\boxed{V_{AB} = -\frac{d\emptyset_B}{dt}}$$

Direction of current defined by Lenz Law: The induced current produces magnetic fields that tend to **oppose** the change in magnetic flux that induces such currents.

$$\boxed{v_L = L\frac{di_L}{dt}} \qquad \text{(volts, V)} \qquad \textbf{(11.12)}$$

$$\boxed{L = 4\pi \times 10^{-7}\frac{\mu_r N^2 A}{l}} \qquad \text{(henries, H)} \qquad \textbf{(11.7)}$$



11.5 RL TRANSIENTS: THE STORAGE PHASE

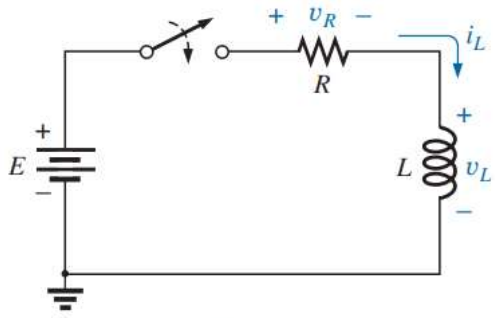


FIG. 11.31
Basic R-L transient network.

The equation for the transient response of the current through an inductor is

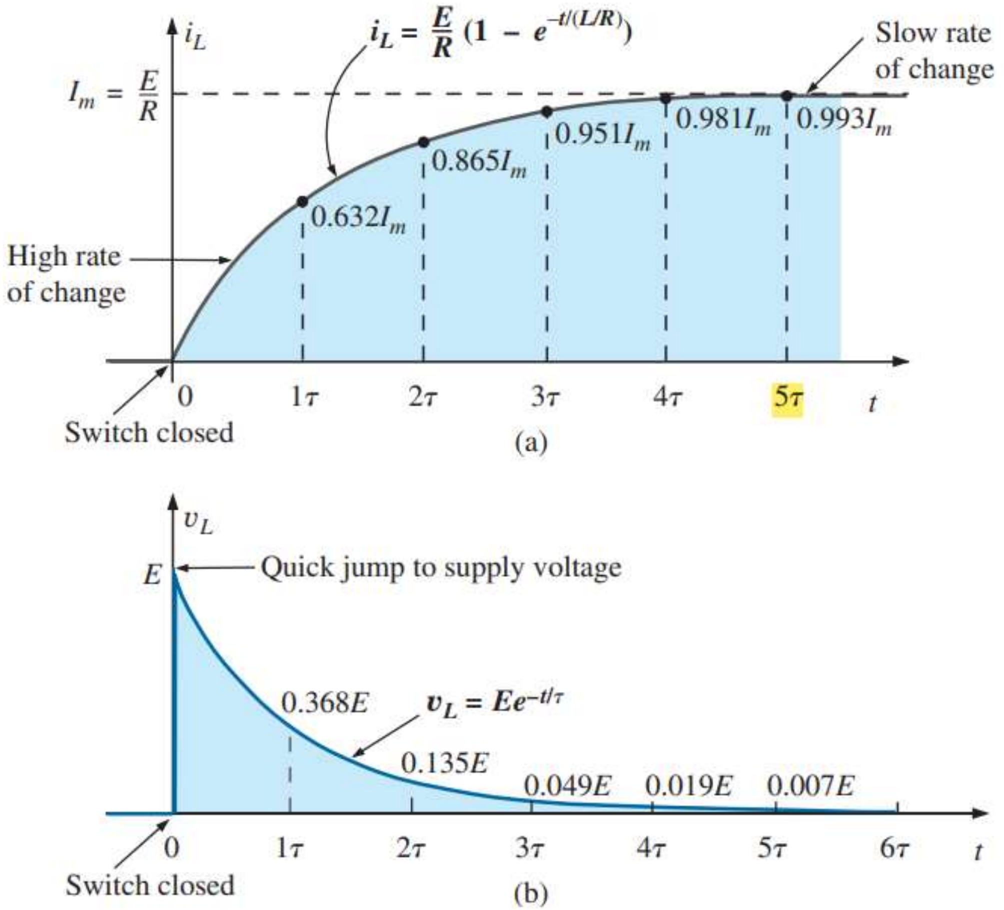
$$\boxed{i_L = \frac{E}{R}(1 - e^{-t/\tau})} \quad \text{(amperes, A)} \qquad \textbf{(11.13)}$$

with the time constant now defined by

$$\boxed{\tau = \frac{L}{R}} \quad \text{(seconds, s)} \qquad \textbf{(11.14)}$$

The equation for the voltage across the coil is

$$\boxed{v_L = Ee^{-t/\tau}} \quad \text{(volts, V)} \qquad \textbf{(11.15)}$$



inductor is open circuit (I=0) initially and at 5T inductor assumed stabilized and becomes short circuit (V=0)

11.5 R-L TRANSIENTS: THE STORAGE PHASE

EXAMPLE 11.3 Find the mathematical expressions for the transient behavior of i_L and v_L for the circuit in Fig. 11.36 if the switch is closed at $t = 0$ s. Sketch the resulting curves.

Solution: First, we determine the time constant:

$$\tau = \frac{L}{R_1} = \frac{4\ \text{H}}{2\ \text{k}\Omega} = 2\ \text{ms}$$

Then the maximum or steady-state current is

$$I_m = \frac{E}{R_1} = \frac{50\ \text{V}}{2\ \text{k}\Omega} = 25 \times 10^{-3}\ \text{A} = 25\ \text{mA}$$

Substituting into Eq. (11.13) gives

$$i_L = \mathbf{25\ mA\,(1 - e^{-t/2\ ms})}$$

Using Eq. (11.15) gives

$$v_L = \mathbf{50\,V}e^{-t/2\,\text{ms}}$$

The resulting waveforms appear in Fig. 11.37.

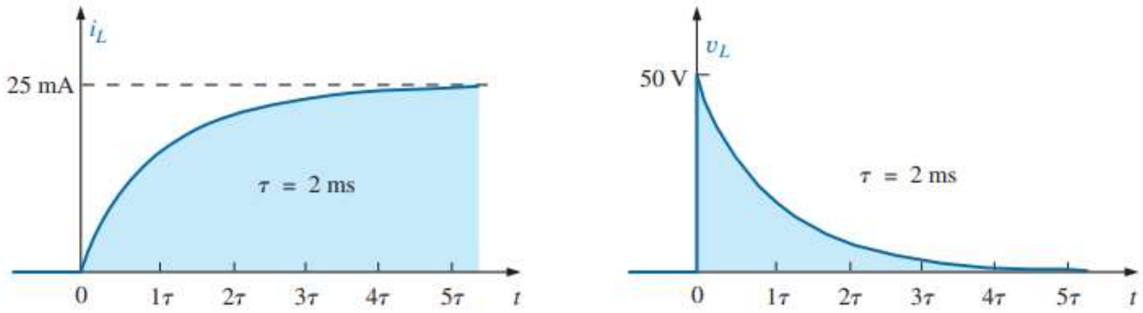


FIG. 11.37
i_L and v_L for the network in Fig. 11.36.

FIG. 11.35
Circuit in Fig. 11.31 under steady-state conditions.

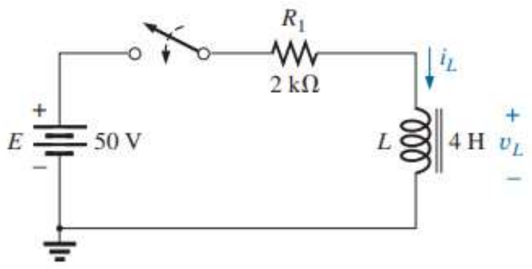
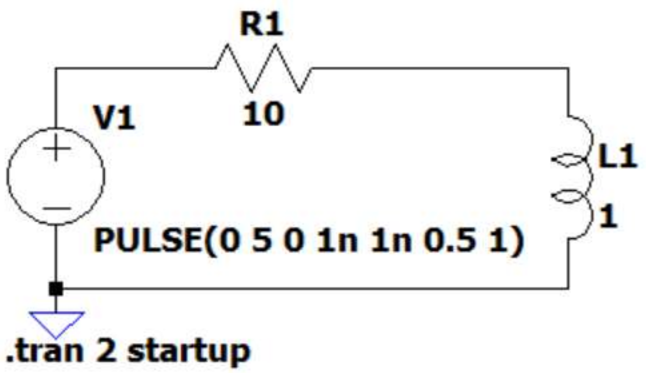


FIG. 11.36
Series R-L circuit for Example 11.3.

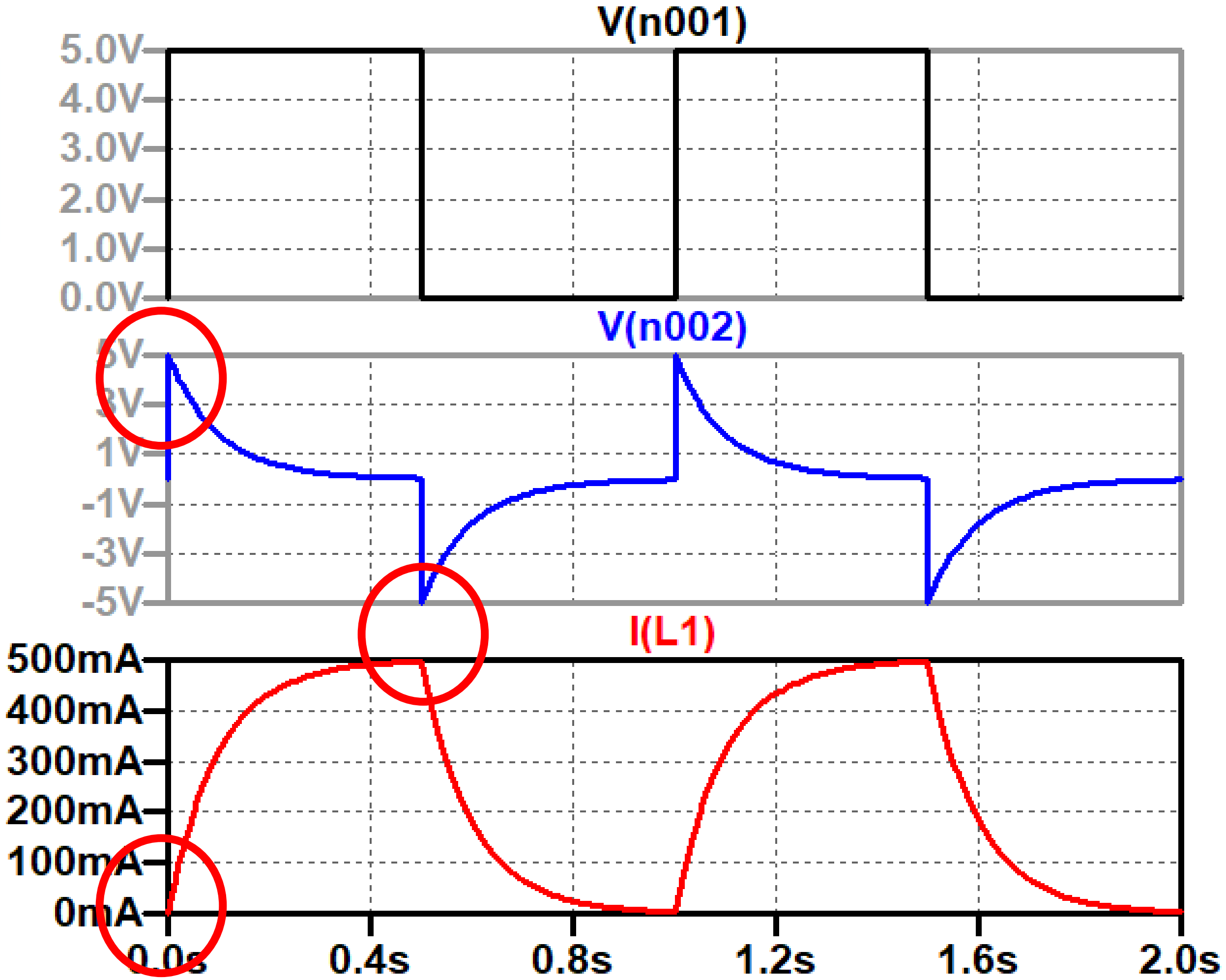
11.5 R-L TRANSIENTS: LTSpice



$$v_L = L\frac{di_L}{dt}$$

T= L/R = 1/10=0.1s
charging
imin = 0A → Vmax=5V
imax=V/R=5/10=500mA → Vmin=0V

discharging
decrease from 500mA to 0
V is flipping start -5V discharging to 0V



11.7 R-L TRANSIENTS: THE RELEASE PHASE

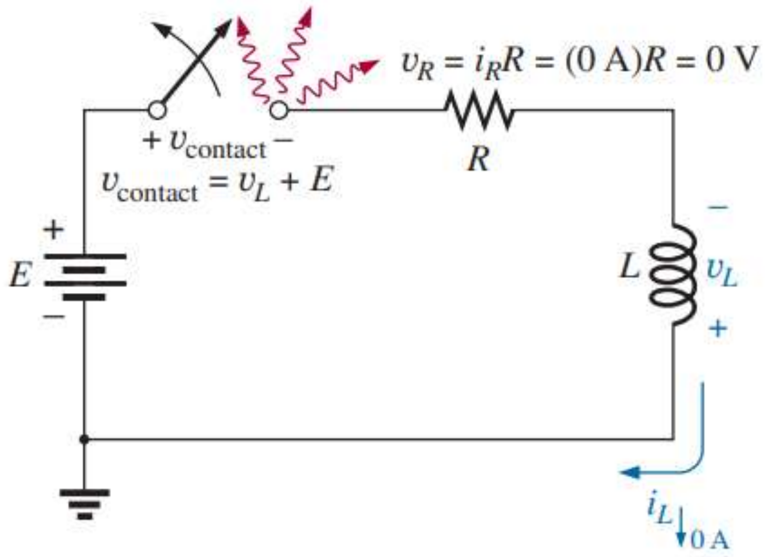


FIG. 11.41
Demonstrating the effect of opening a switch in series with an inductor with a steady-state current.

If the series R-L circuit in Fig. 11.41 reaches steady-state conditions and the switch is quickly opened, a spark will occur across the contacts due to the **rapid change in current** from a maximum of E/R to zero amperes.

The change in current di/dt of the equation

$\upsilon = L\, di/dt$

establishes a high voltage across the coil

Some 25,000 V are generated by the rapid decrease in ignition coil current that occurs when the switch in the system is opened

air resistivity is around 10^10 ohm.m, means in 0.1mm it becomes 10^6, 1Megaohm and can have a spark while removing the contact

11.7 R-L TRANSIENTS: THE RELEASE PHASE

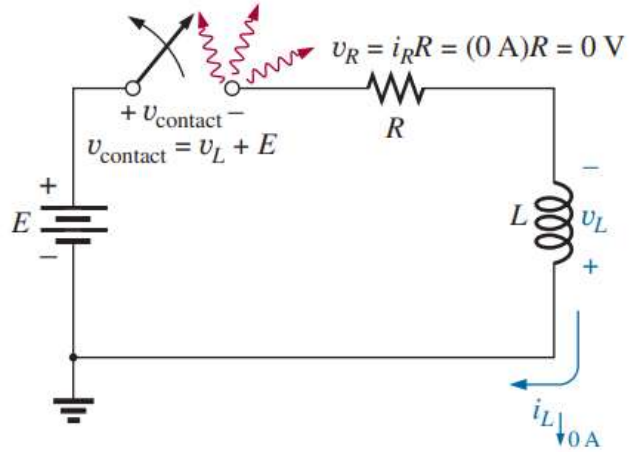
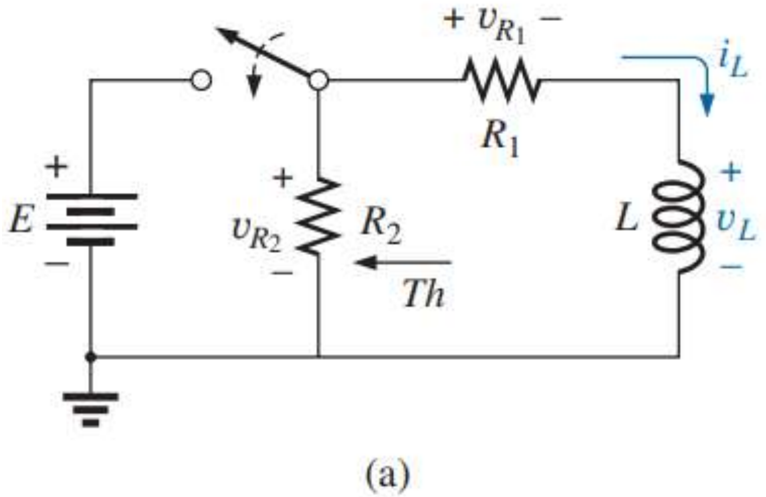


FIG. 11.41
Demonstrating the effect of opening a switch in series with an inductor with a steady-state current.



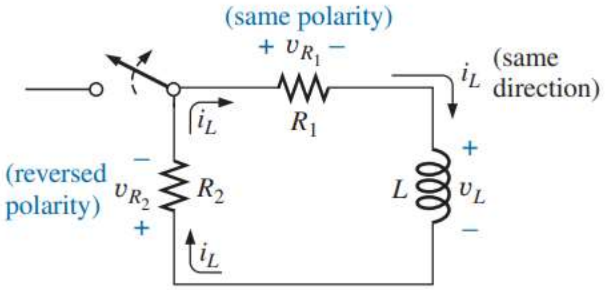


FIG. 11.43
Network in Fig. 11.42 the instant the switch is opened.

11.7 R-L TRANSIENTS: THE RELEASE PHASE

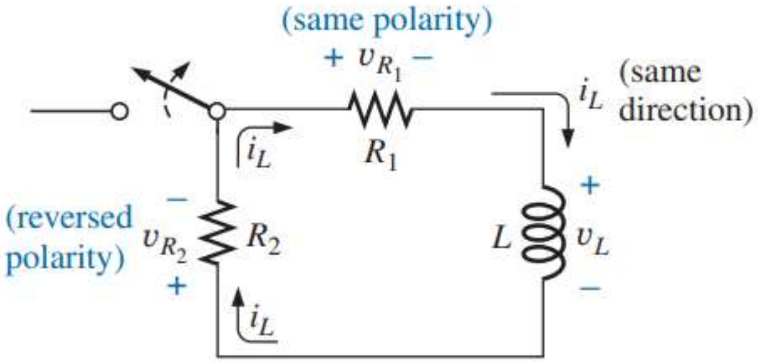


FIG. 11.43
Network in Fig. 11.42 the instant the switch is opened.

After the storage phase has passed and steady-state conditions are established, the switch can be opened without the sparking effect or rapid discharge due to resistor R2 which provides a complete path for the current iL

The current decays from a maximum of $I_m = E/R_1$ to zero.
Using Eq. (11.17) gives

$$I_i = \frac{E}{R_1} \quad \text{and} \quad I_f = 0 \text{ A}$$

so that $$i_L = I_f + (I_i - I_f)e^{-t/\tau'} = 0 \text{ A} + \left(\frac{E}{R_1} - 0 \text{ A}\right)e^{-t/\tau'}$$

and $$\boxed{i_L = \frac{E}{R_1}e^{-t/\tau'}} \tag{11.21}$$

with $$\tau' = \frac{L}{R_1 + R_2}$$

$$\boxed{v_L = -V_i e^{-t/\tau'}} \tag{11.20}$$

$$\boxed{V_i = E/R1 \times (R1+R2)}$$

11.7 R-L TRANSIENTS: THE RELEASE PHASE

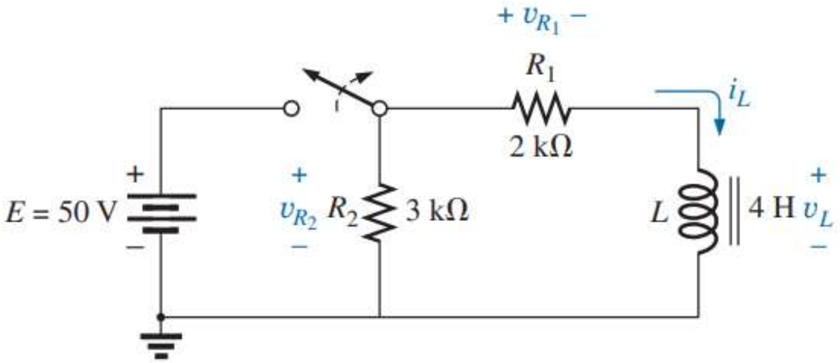


FIG. 11.44

Defined polarities for v_{R_1}, v_{R_2}, v_L, and current direction for i_L for Example 11.5.

Solutions:

a. From Example 11.3:

$$\begin{aligned} i_L &= \mathbf{25\,mA(1 - e^{-t/2\,ms})} \\ v_L &= \mathbf{50\,V e^{-t/2\,ms}} \\ v_{R_1} &= i_{R_1}R_1 = i_L R_1 \\ &= \left[\frac{E}{R_1}(1 - e^{-t/\tau})\right]R_1 \\ &= E(1 - e^{-t/\tau}) \end{aligned}$$

b. $$\tau' = \frac{L}{R_1 + R_2} = \frac{4\text{ H}}{2\text{ k}\Omega + 3\text{ k}\Omega} = \frac{4\text{ H}}{5 \times 10^3\ \Omega}$$
$$= 0.8 \times 10^{-3}\text{ s} = 0.8\text{ ms}$$

By Eqs. (11.19) and (11.20):

$$V_i = \left(1 + \frac{R_2}{R_1}\right)E = \left(1 + \frac{3\,\text{k}\Omega}{2\,\text{k}\Omega}\right)(50\,\text{V}) = 125\text{V}$$

and $$v_L = -V_i e^{-t/\tau'} = \mathbf{-125\ Ve^{-t/0.8\ ms}}$$

By Eq. (11.21):

$$I_m = \frac{E}{R_1} = \frac{50\text{ V}}{2\text{ k}\Omega} = 25\text{ mA}$$

and $$i_L = I_m e^{-t/\tau'} = \mathbf{25\ mAe^{-t/0.8\ ms}}$$

By Eq. (11.22):

11.7 R-L TRANSIENTS: THE RELEASE PHASE

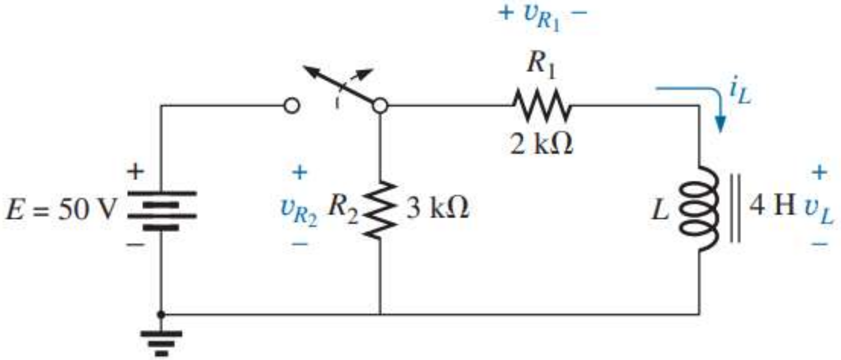
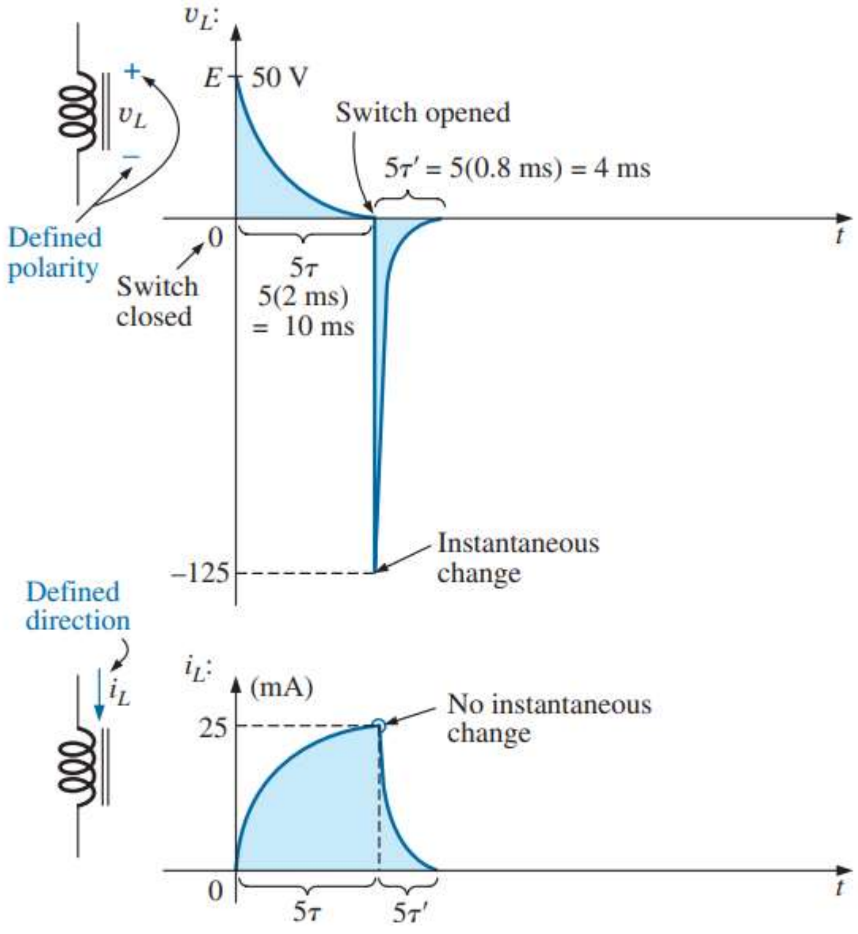


FIG. 11.44

Defined polarities for v_{R_1}, v_{R_2}, v_L, and current direction for i_L for Example 11.5.



11.7 R-L TRANSIENTS: THE RELEASE PHASE

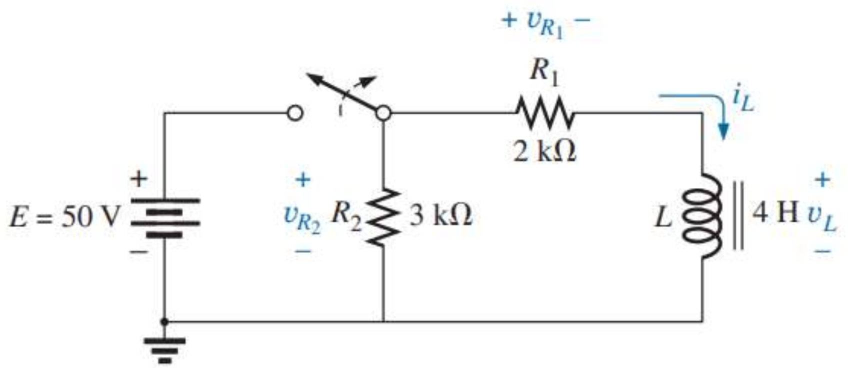
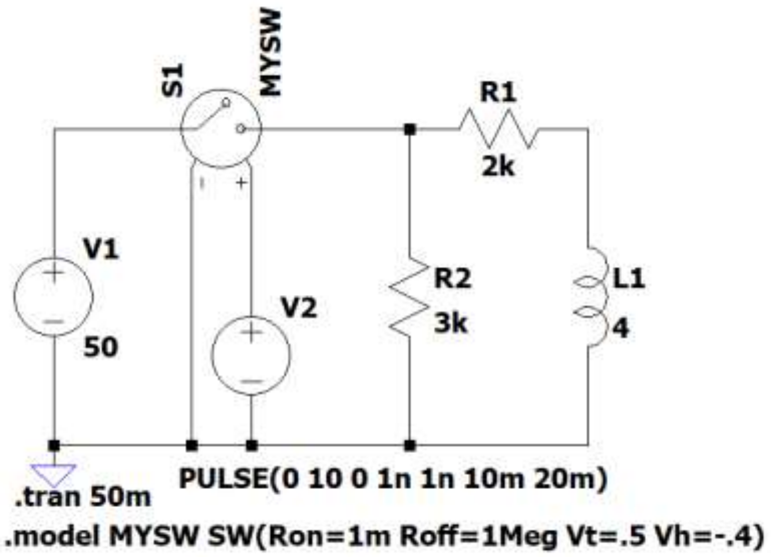
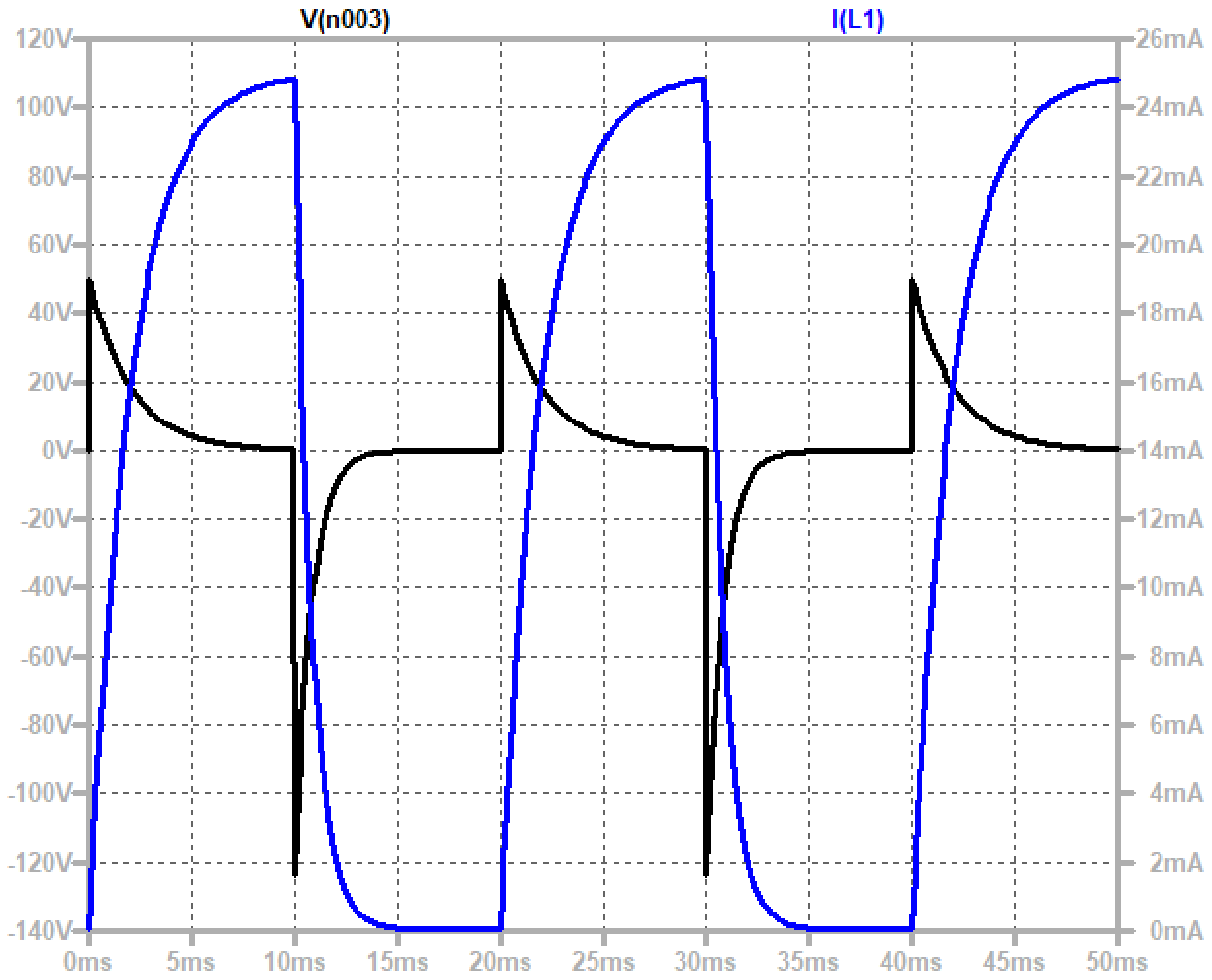
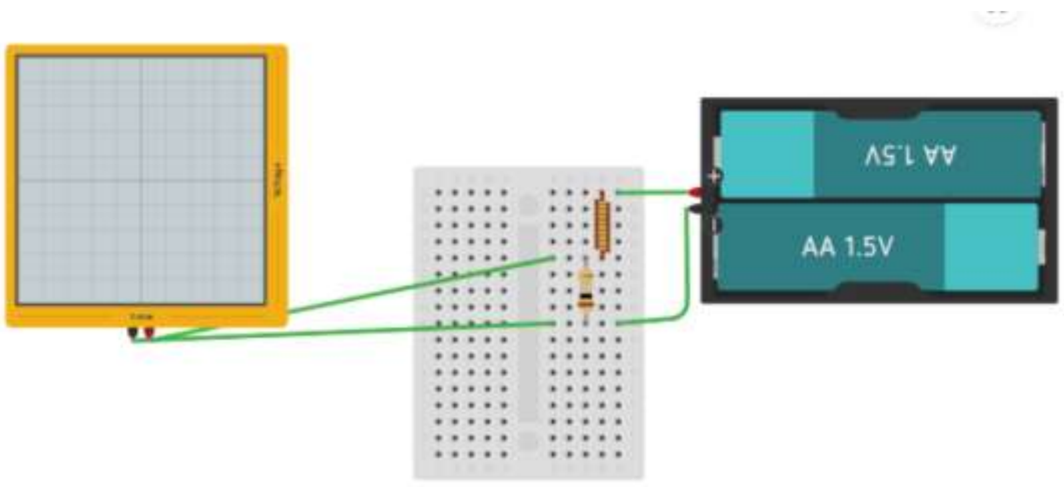


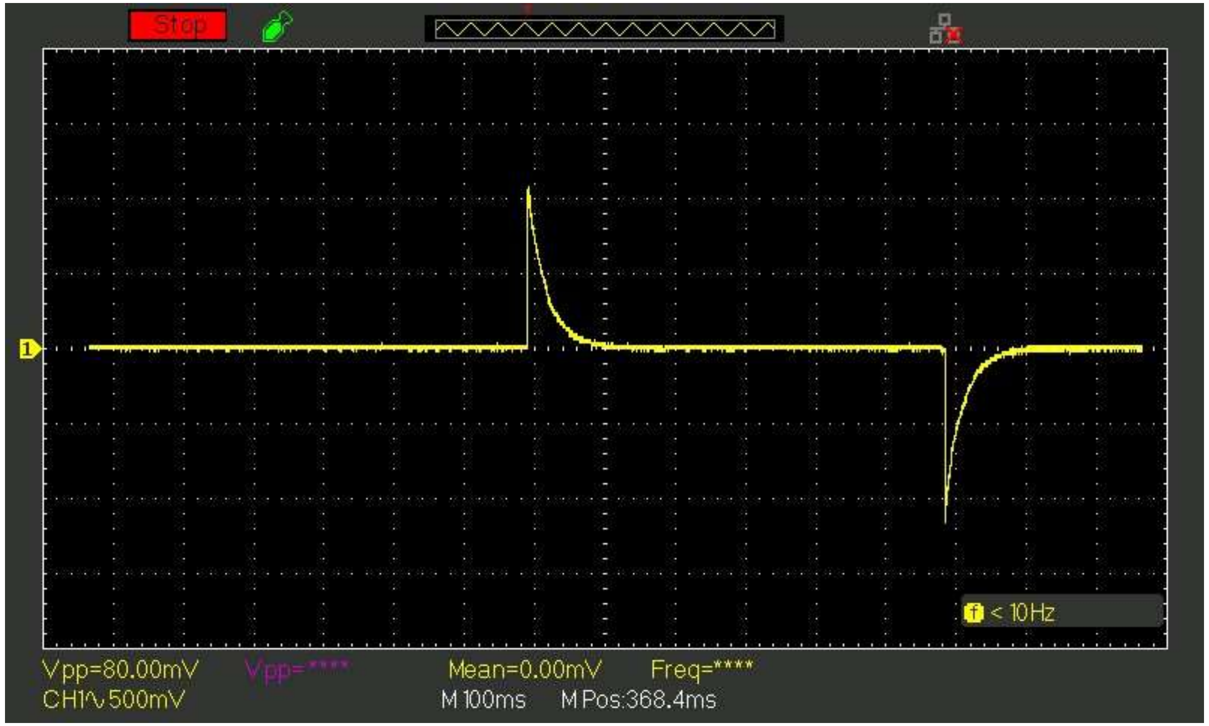
FIG. 11.44





11.7 R-L TRANSIENTS: THE RELEASE PHASE





3V, R=1ohm, L=220uH

11.14 APPLICATIONS-Electromagnet

we can turn ON/OFF the magnet

$$\boxed{B = \mu I N}$$

11.14 APPLICATIONS-Plunger

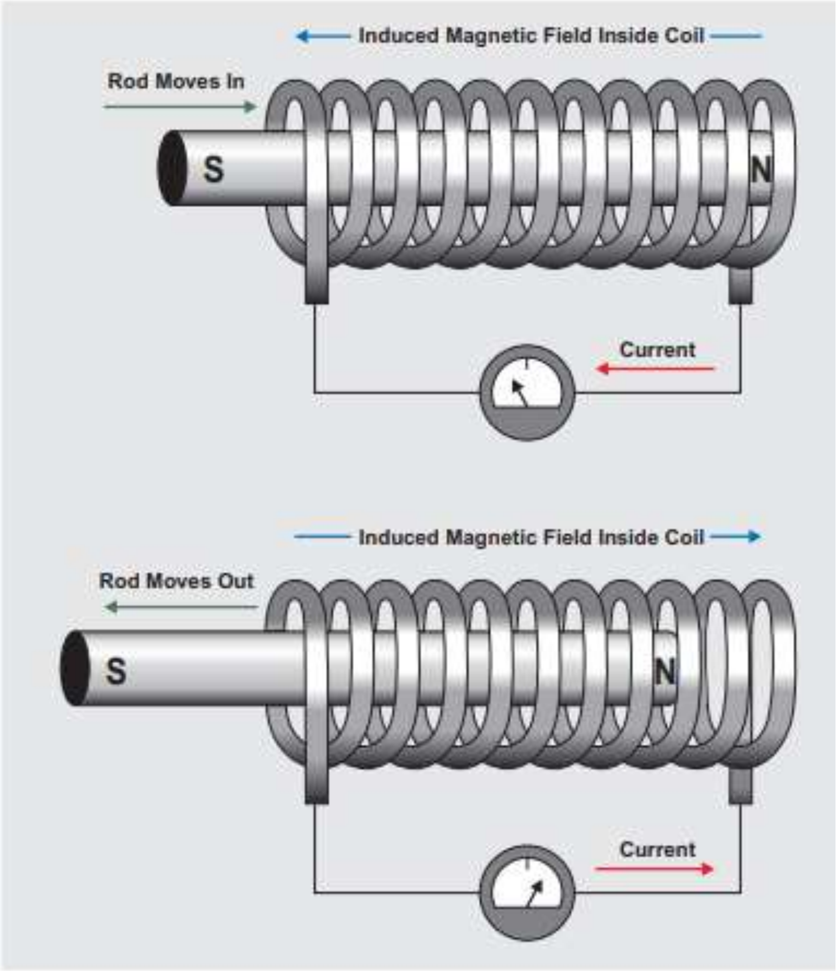
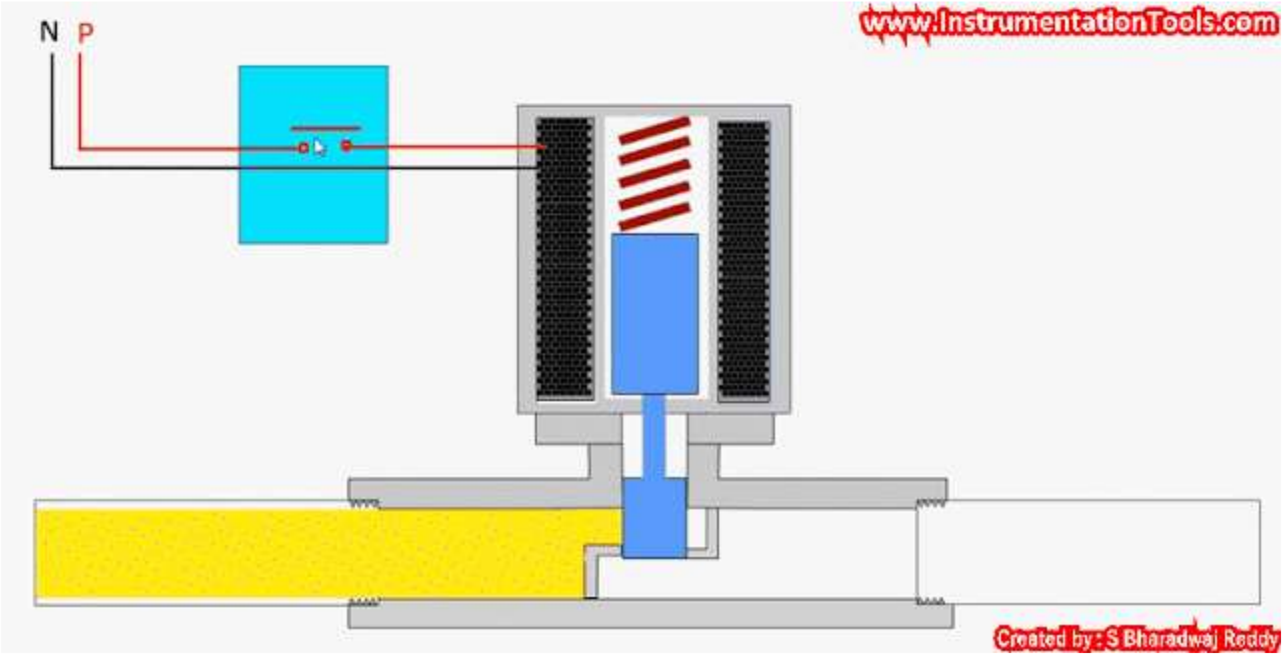
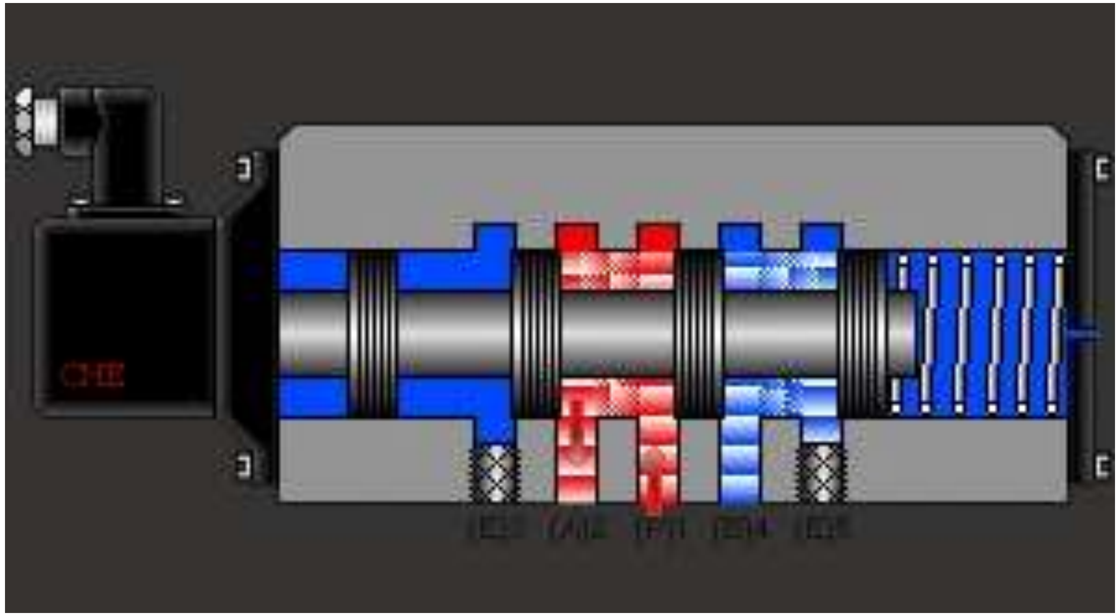


Figure 1. Working of a Solenoid

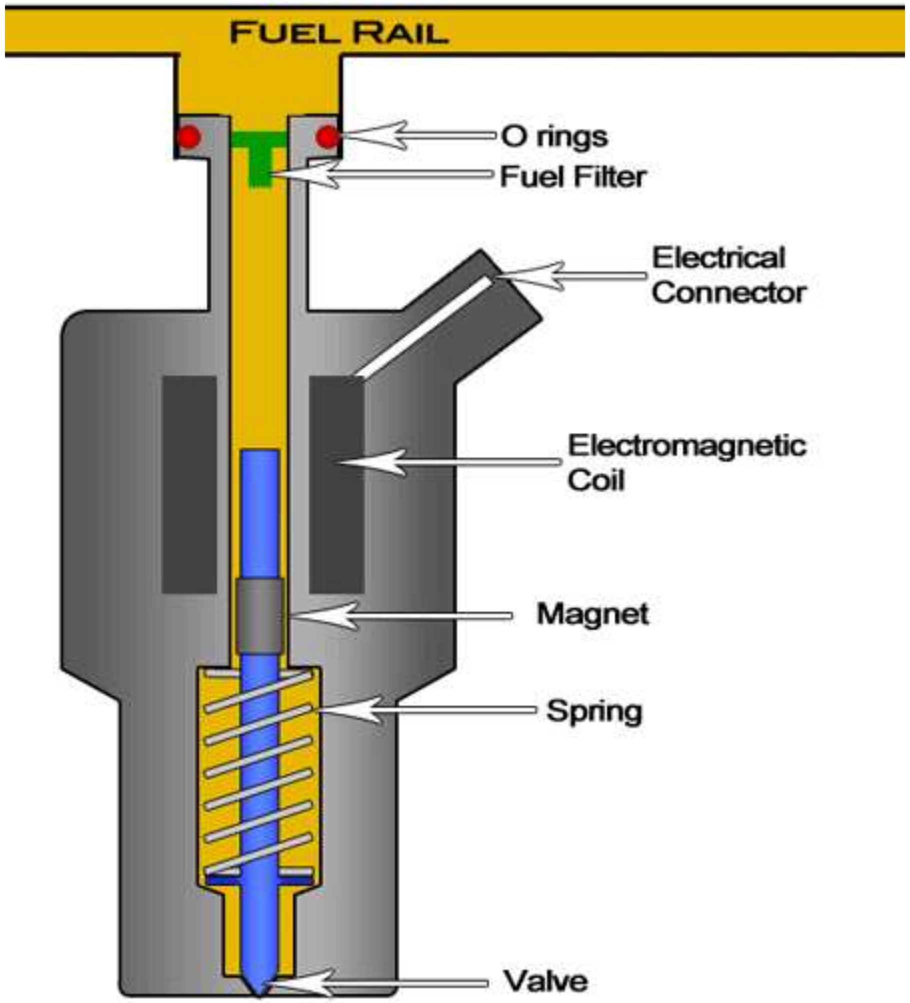
11.14 APPLICATIONS-Plunger



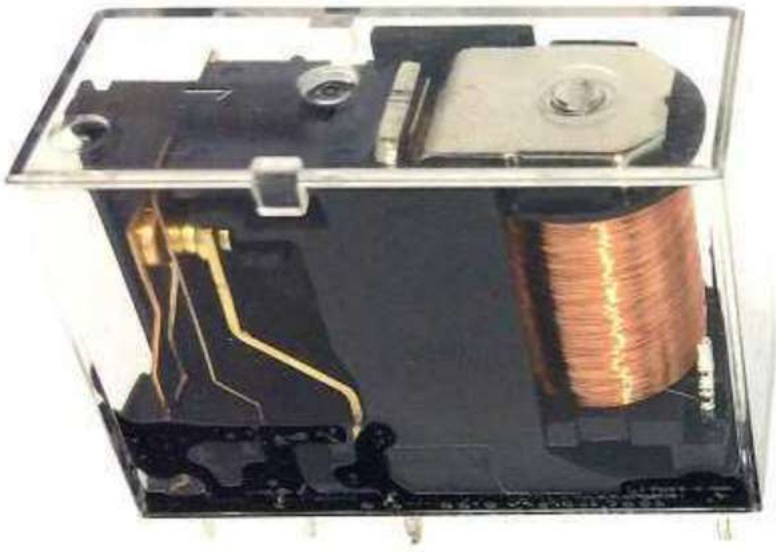
11.14 APPLICATIONS-Plunger

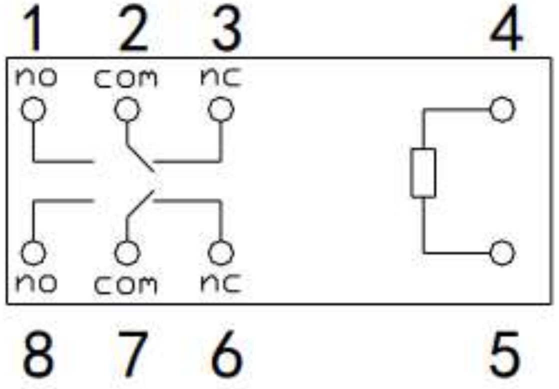


11.14 APPLICATIONS-Injector



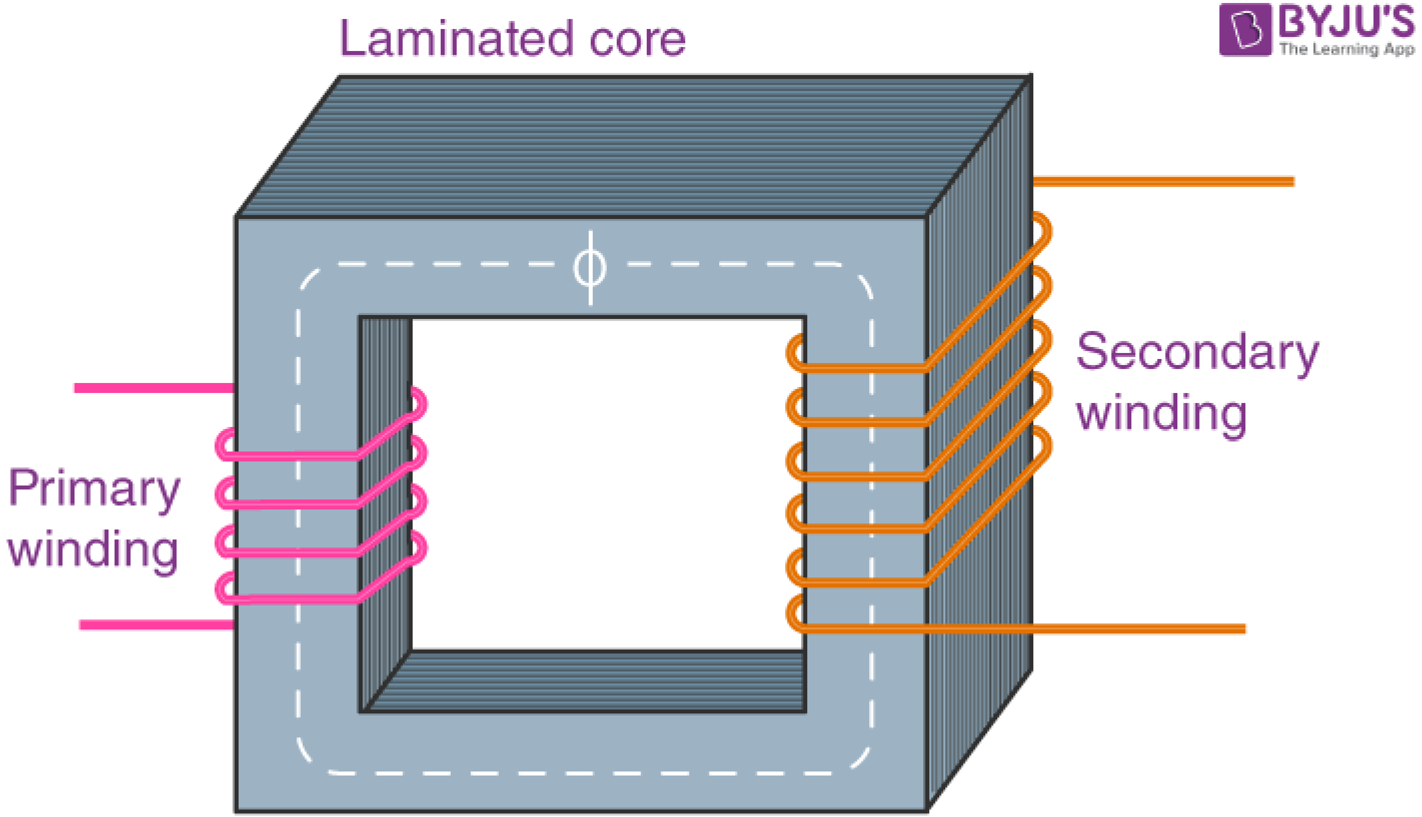
11.14 APPLICATIONS-Relays





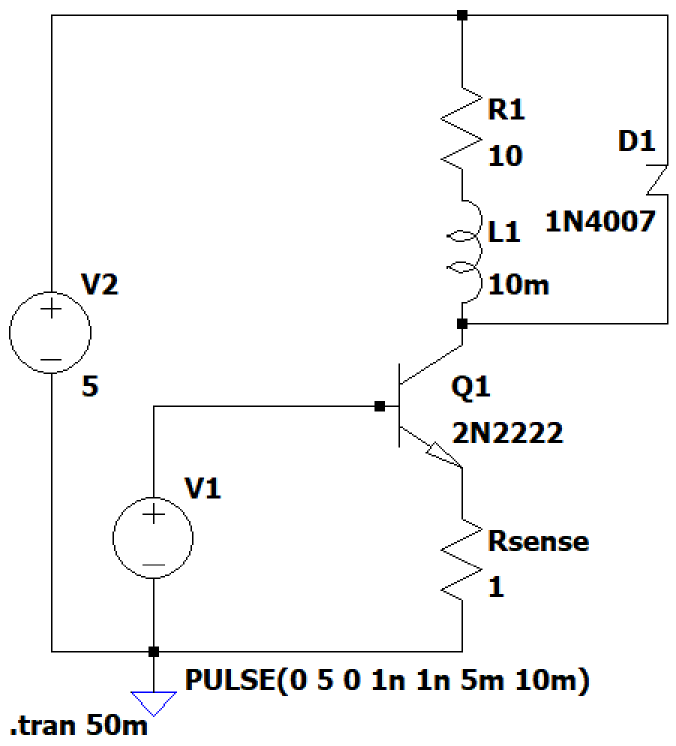
Form C

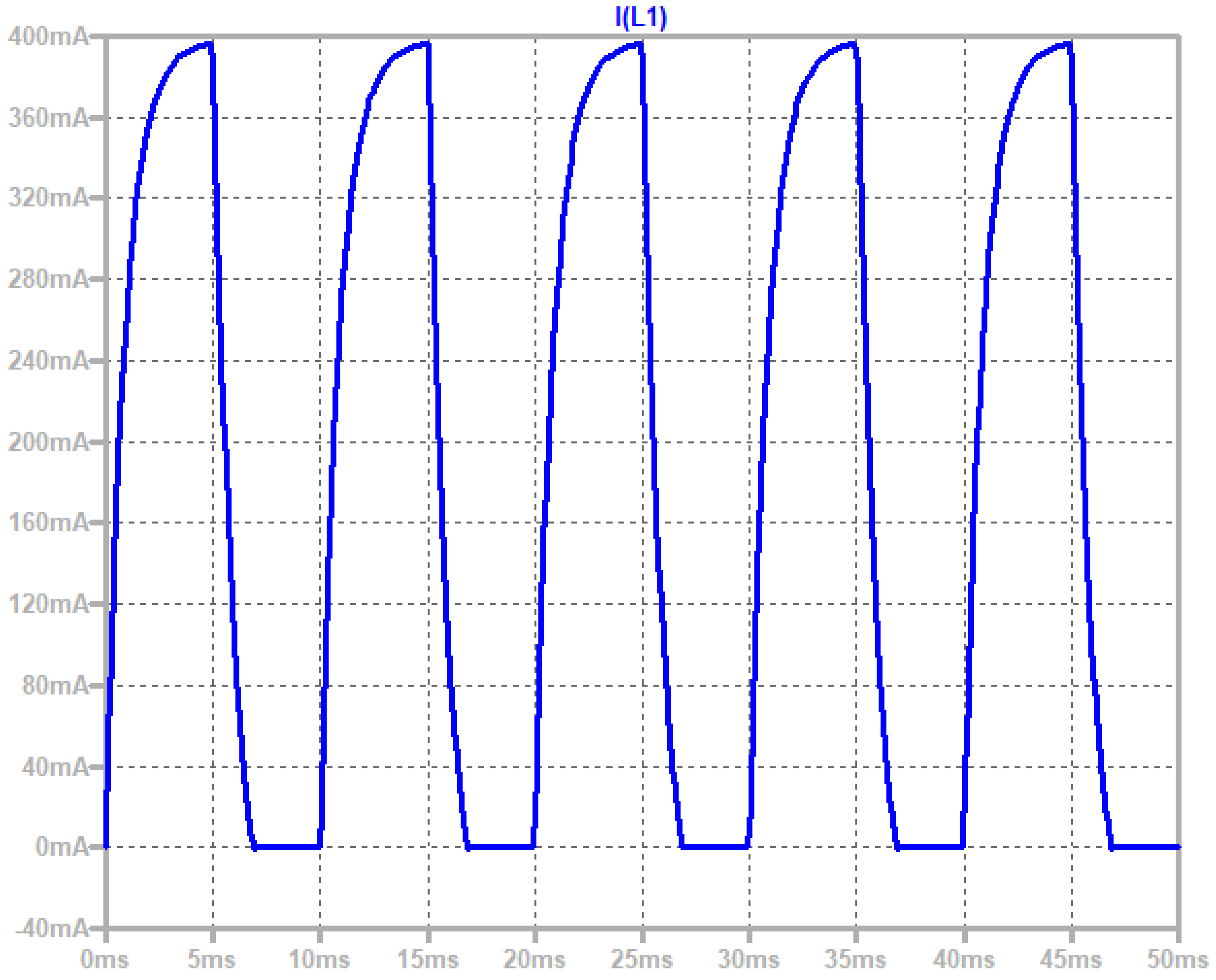
11.14 APPLICATIONS-Transformer



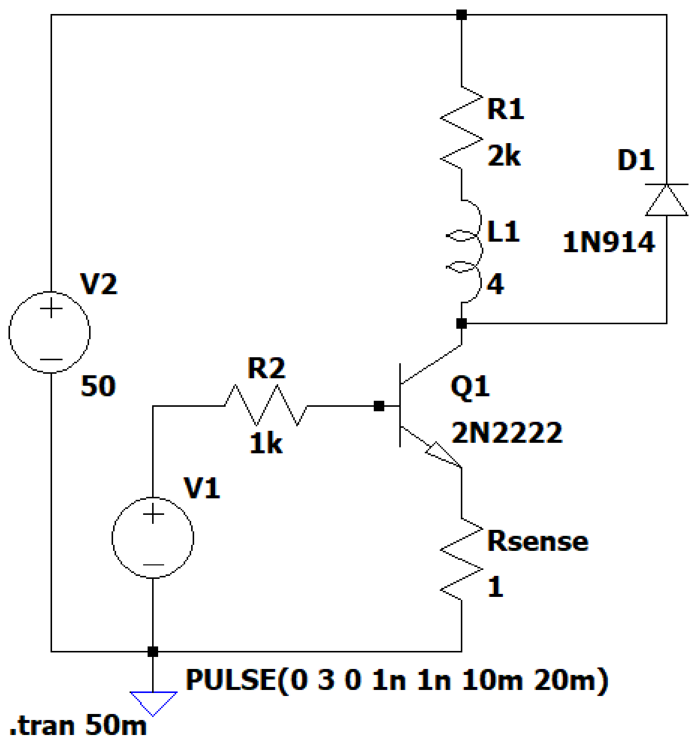
11.14 APPLICATIONS-Solenoid Driver
No Protection

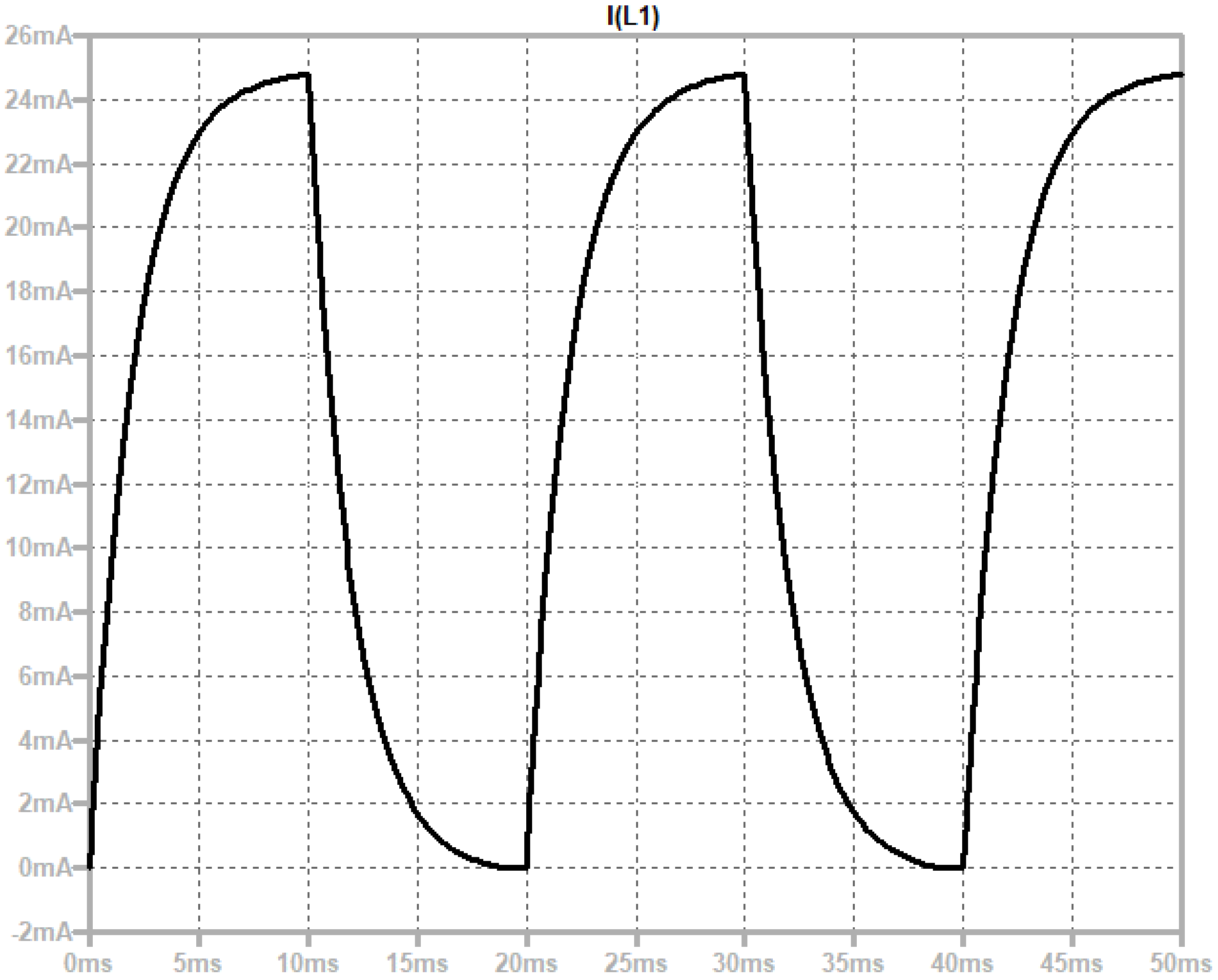
Current flow back to power supply device may damage the circuit, we need to avoid





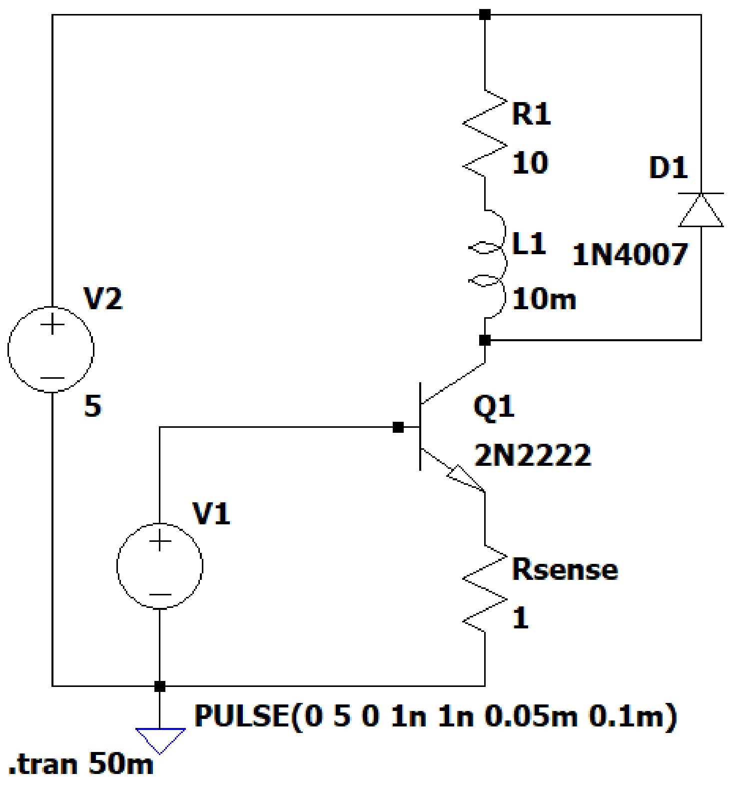
11.14 APPLICATIONS-Solenoid Driver With Protection Diode

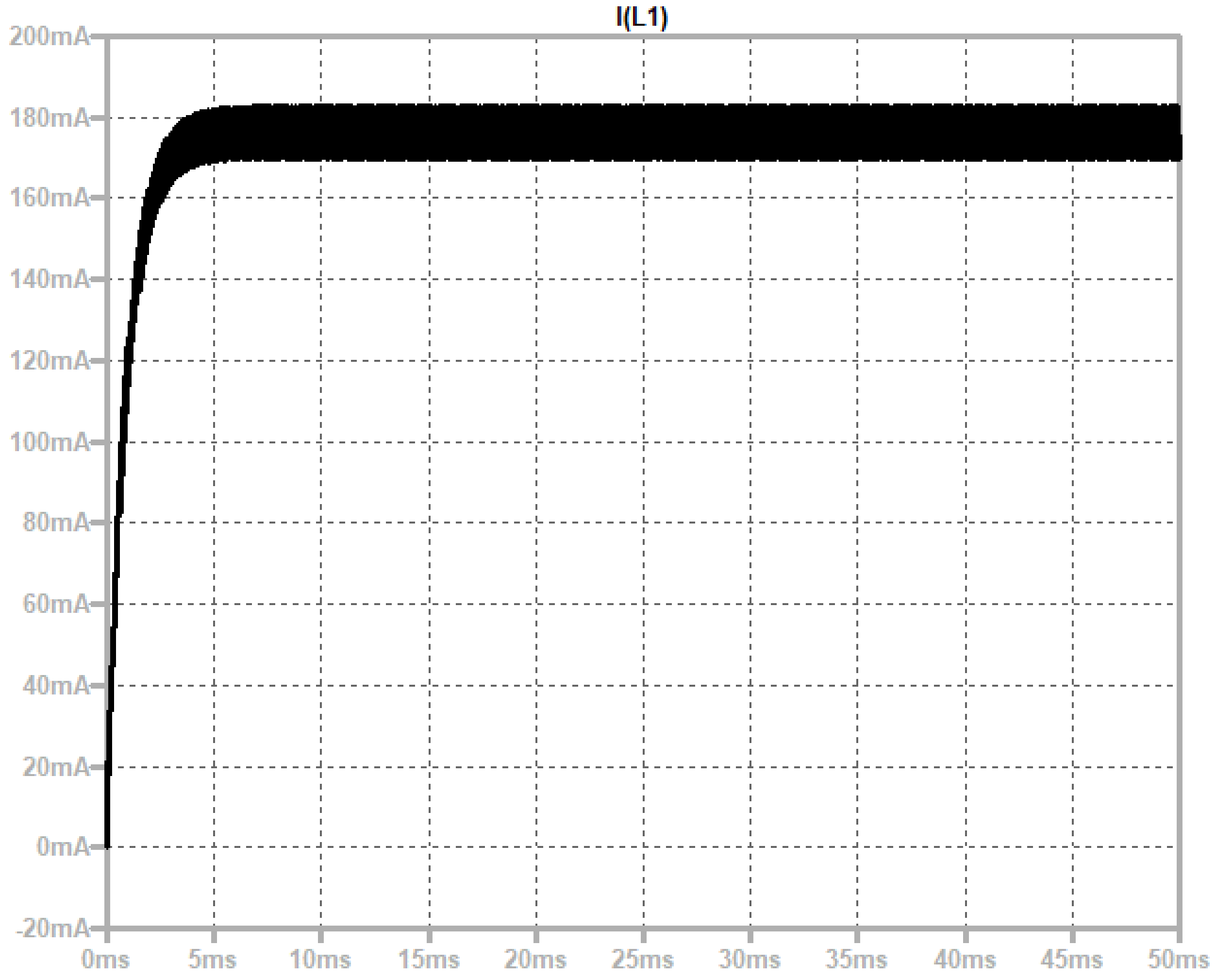




11.14 APPLICATIONS-Solenoid Driver High Frequency

Manually change the power supply is not preferred, thus we can control the current using duty cycle of high frequency PWM (10-15Khz)





14.2 RESPONSE OF BASIC R, L, AND C ELEMENTS TO A SINUSOIDAL VOLTAGE OR CURRENT

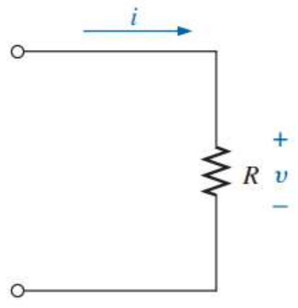


FIG. 14.4
Determining the sinusoidal response for a resistive element.

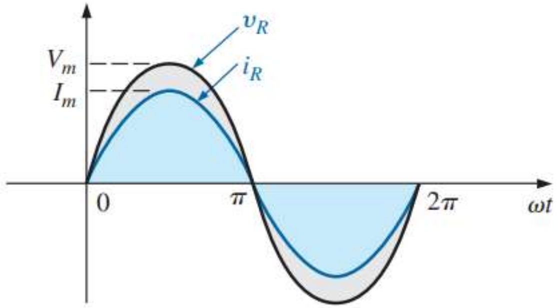


FIG. 14.5
The voltage and current of a resistive element are in phase.

applied as follows. For $v = V_m \sin \omega t$,

$$i = \frac{v}{R} = \frac{V_m \sin \omega t}{R} = \frac{V_m}{R} \sin \omega t = I_m \sin \omega t$$

where

$$\boxed{I_m = \frac{V_m}{R}} \qquad \textbf{(14.2)}$$

In addition, for a given i,

$$v = iR = (I_m \sin \omega t) R = I_m R \sin \omega t = V_m \sin \omega t$$

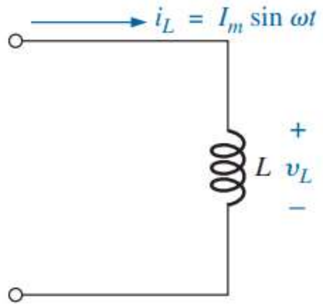
where

$$\boxed{V_m = I_m R} \qquad \textbf{(14.3)}$$

A plot of v and i in Fig. 14.5 reveals that

For a purely resistive element, the voltage across and the current through the element are in phase, with their peak values related by Ohm's law.

14.2 RESPONSE OF BASIC R, L, AND C ELEMENTS TO A SINUSOIDAL VOLTAGE OR CURRENT



$$\boxed{v_L = L\frac{di_L}{dt}}$$

FIG. 14.6
Investigating the sinusoidal response of an inductive element.

For a sinusoidal current defined by

$$i_L = I_m \sin \omega t$$

$$v_L = L\frac{di_L}{dt} = L\frac{d}{dt}(I_m \sin \omega t) = LI_m\frac{d}{dt}(\sin \omega t)$$
$$= LI_m(\omega \cos \omega t)$$

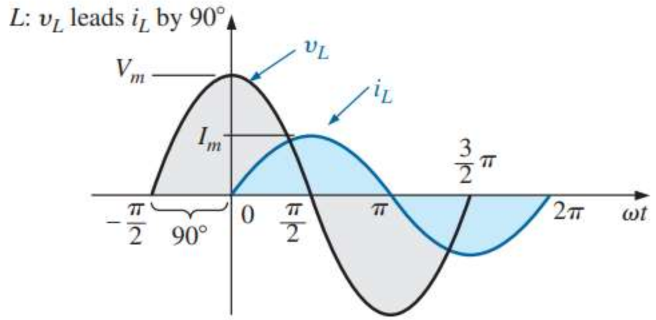


FIG. 14.7
For a pure inductor, the voltage across the coil leads the current through the coil by 90°.

with the final solution of

$$v_L = \omega LI_m \sin(\omega t + 90°)$$

The peak value of the voltage across a coil is directly related to the applied frequency ($\omega = 2\pi f$), the inductance of the coil L, and the peak value of the applied current I_m. A plot of v_L and i_L in Fig. 14.7 reveals that for an inductor, v_L leads i_L by 90°, or i_L lags v_L by 90°.

14.2 RESPONSE OF BASIC R, L, AND C ELEMENTS TO A SINUSOIDAL VOLTAGE OR CURRENT

The quantity ωL, called the **reactance** (from the word *reaction*) of an inductor, is symbolically represented by X_L and is measured in ohms; that is,

$$\boxed{X_L = \omega L} \quad (\text{ohms}, \Omega) \qquad \textbf{(14.4)}$$

w = 2 * pi * f

Inductor at AC circuits

inductor impedance (=resistance)
increases with frequency

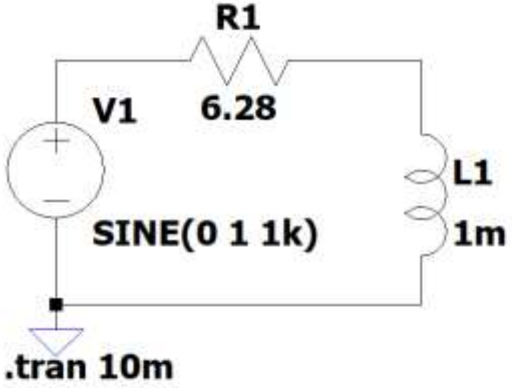
ZL=jwL
ZL=2.pi.f.L

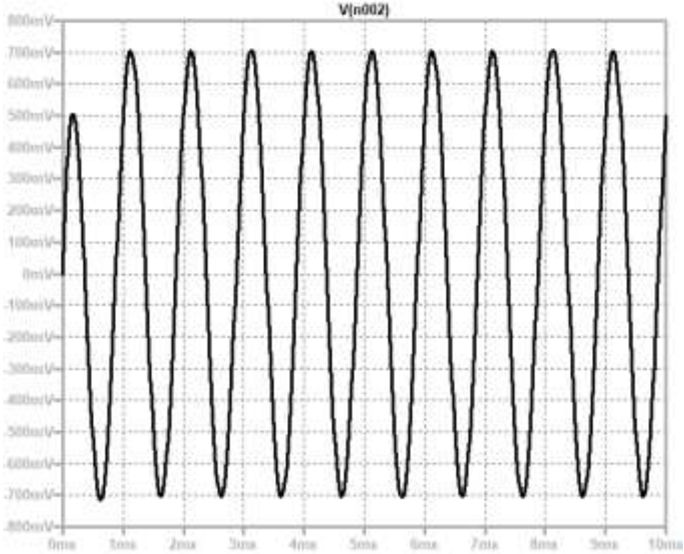
example:
ZL = 2.pi.1k.1m=6.28ohm

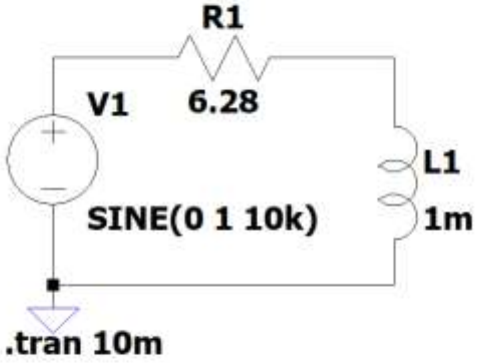
at 10kHz
ZL = 2.pi.10k.1m = 62.8ohm

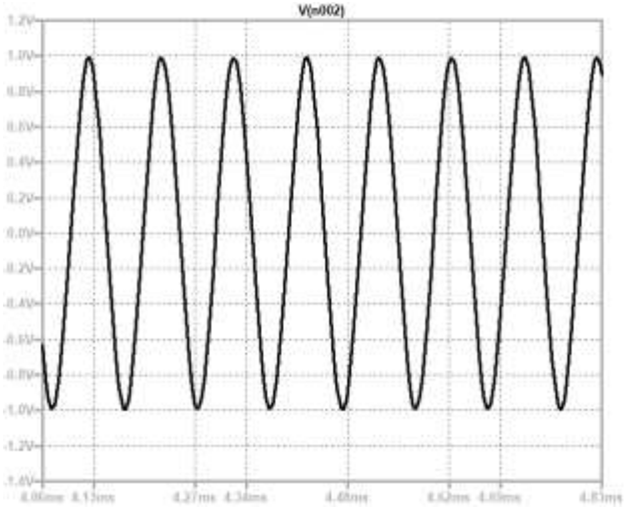
due to phase differences are different from arithmetic additions we will see later

high frequency signal is passing better, means this is an high pass filter

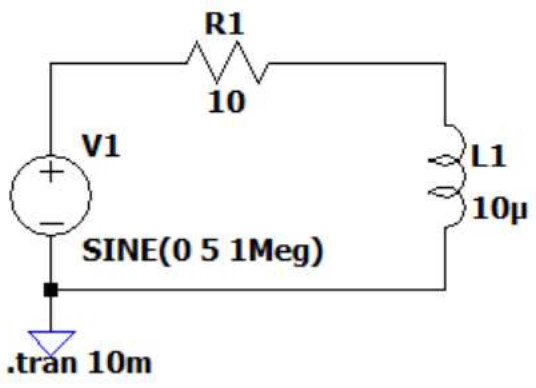


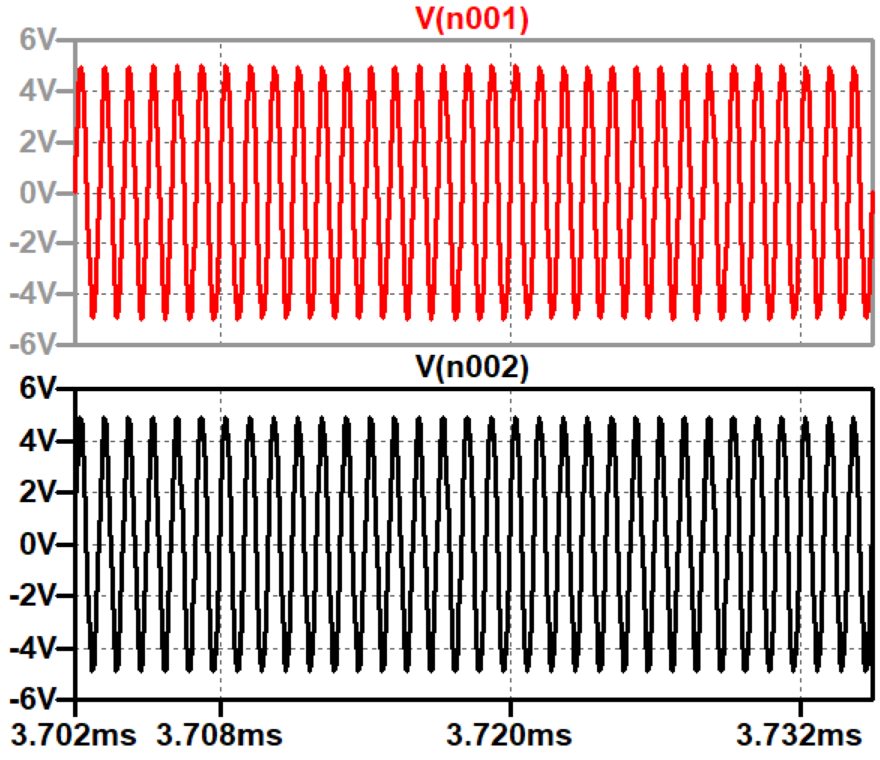






Inductor at AC circuits





F=1Mgeg

ZL = wL = 2*pi*10^6*10*10^-6

ZL = 628 ohm

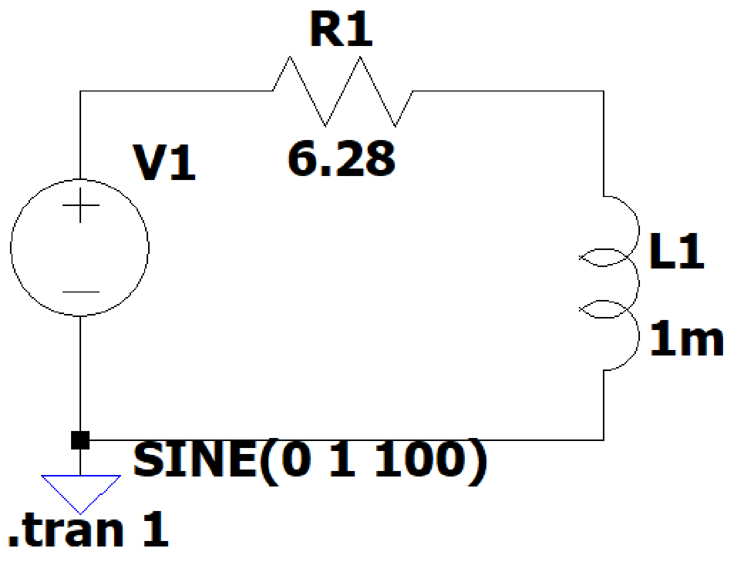
F=1K

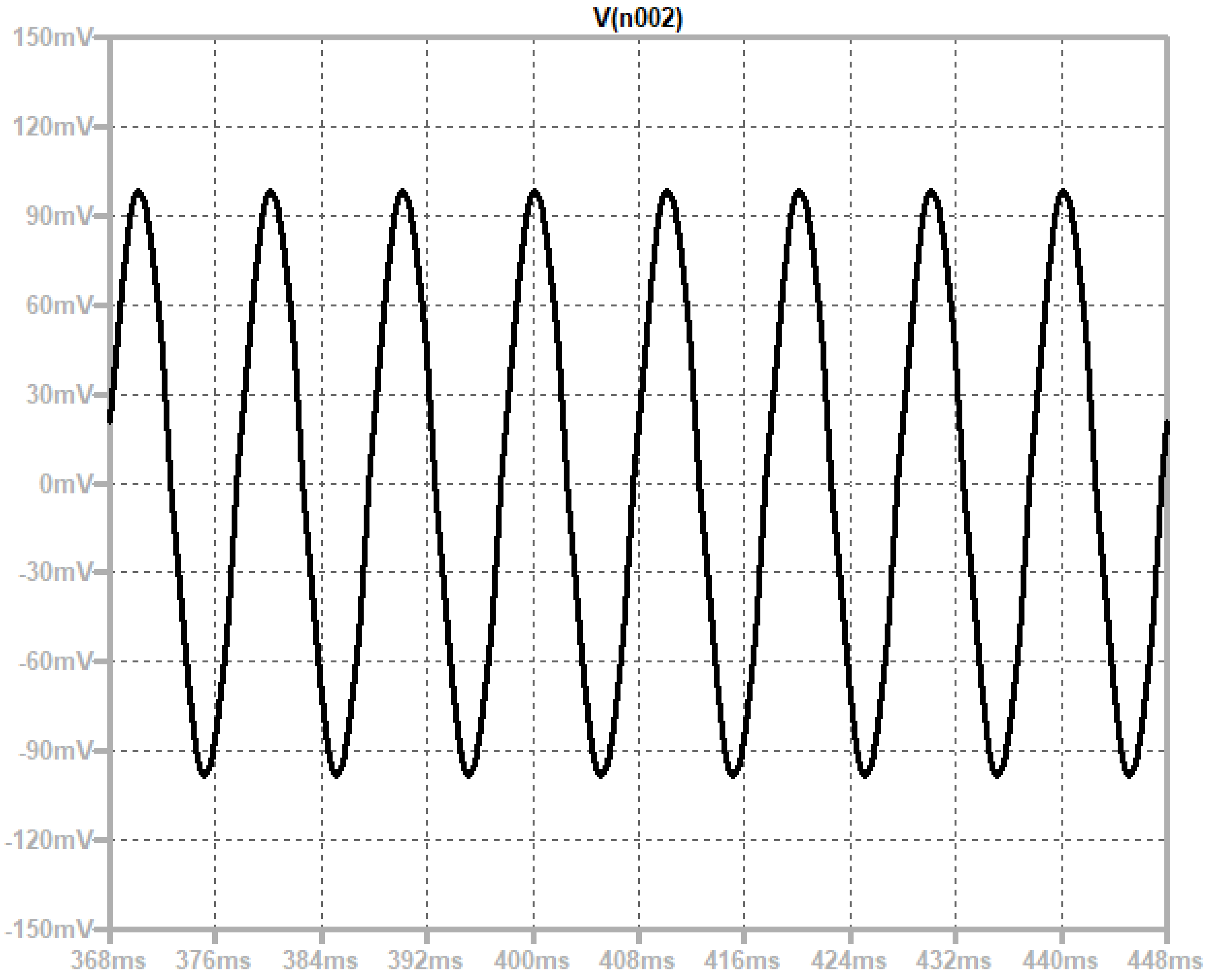
ZL = wL = 2*pi*10^3*10*10^-6

ZL=628 10^-3 = 0.628 ohm

Inductor at AC circuits

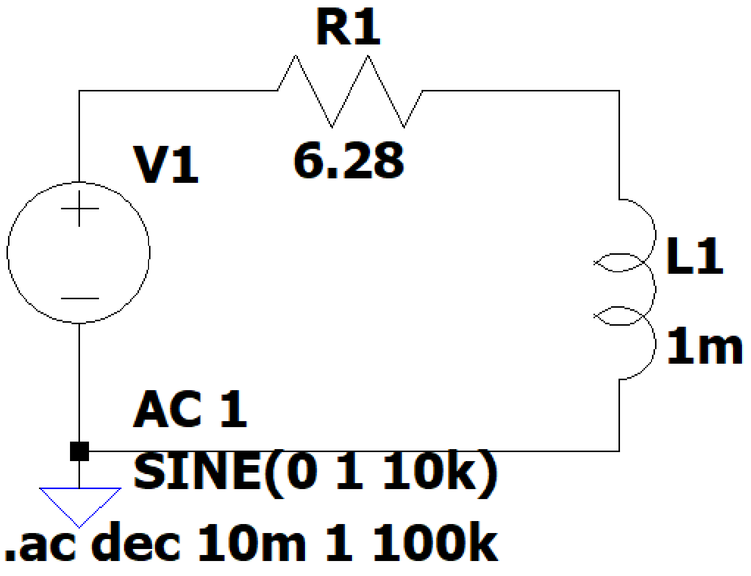
at low frequencies f=100hz we see very low VL. Low freq signals are blocked





Inductor at AC circuits-AC Analysis

AC analysis shows amplitude and phase response of the circuit



at a frequency of 0 Hz, an inductor takes on the characteristics of a short circuit, as shown in Fig. 14.18.

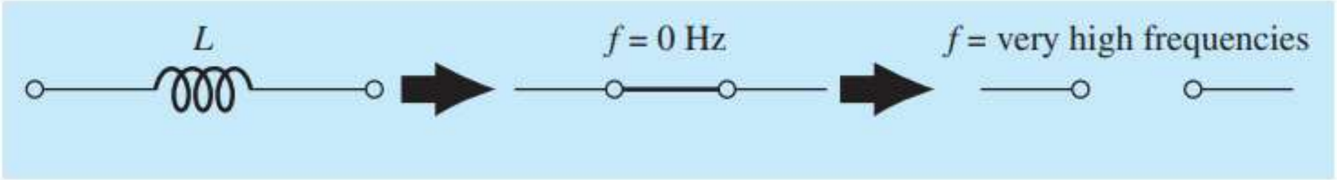
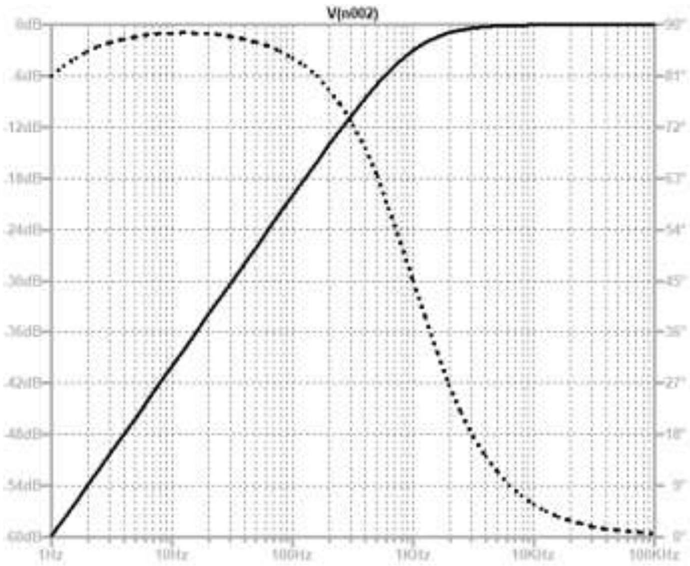


FIG. 14.18

Effect of low and high frequencies on the circuit model of an inductor.



Inductor at High/Low Frequency

at a frequency of 0 Hz, an inductor takes on the characteristics of a short circuit, as shown in Fig. 14.18.

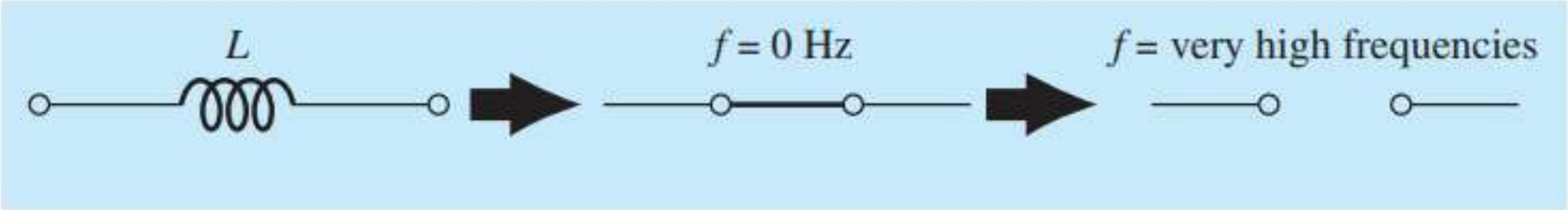
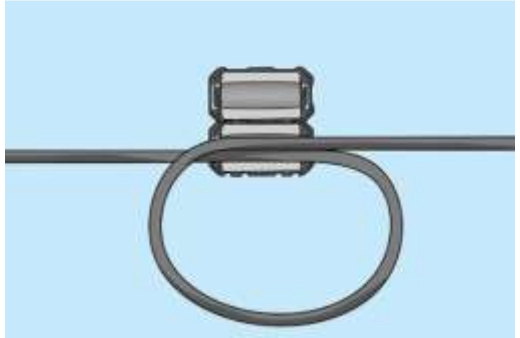
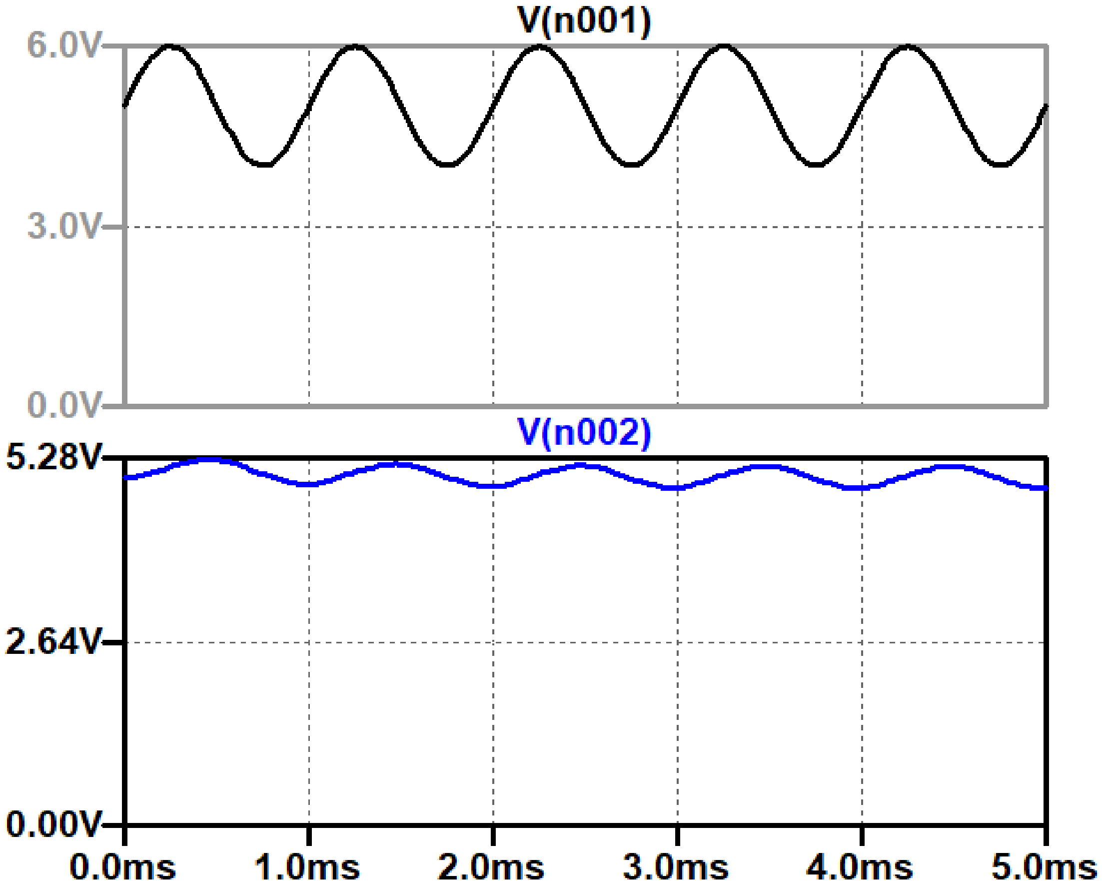


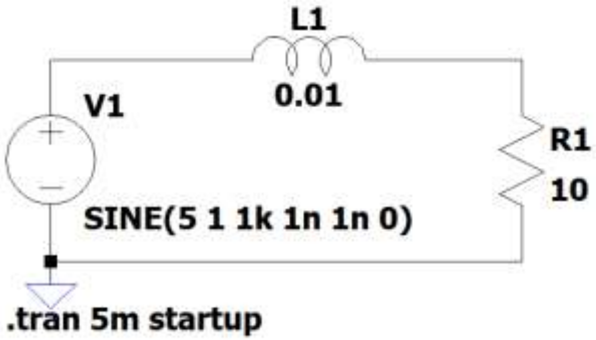
FIG. 14.18
Effect of low and high frequencies on the circuit model of an inductor.

$$\boxed{X_L = \omega L} \quad (\text{ohms}, \Omega) \qquad \textbf{(14.4)}$$

Inductor Applications – Ferrite Chokes

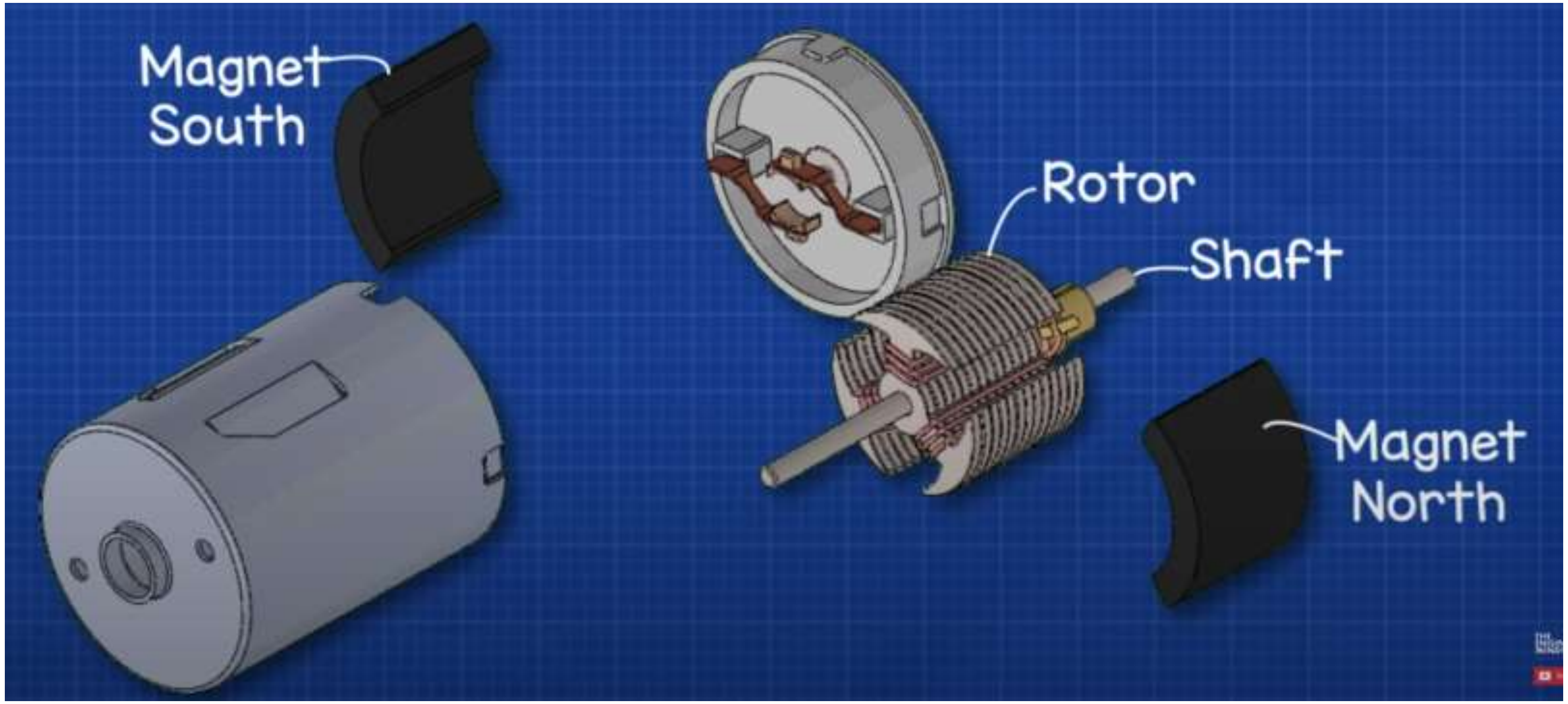




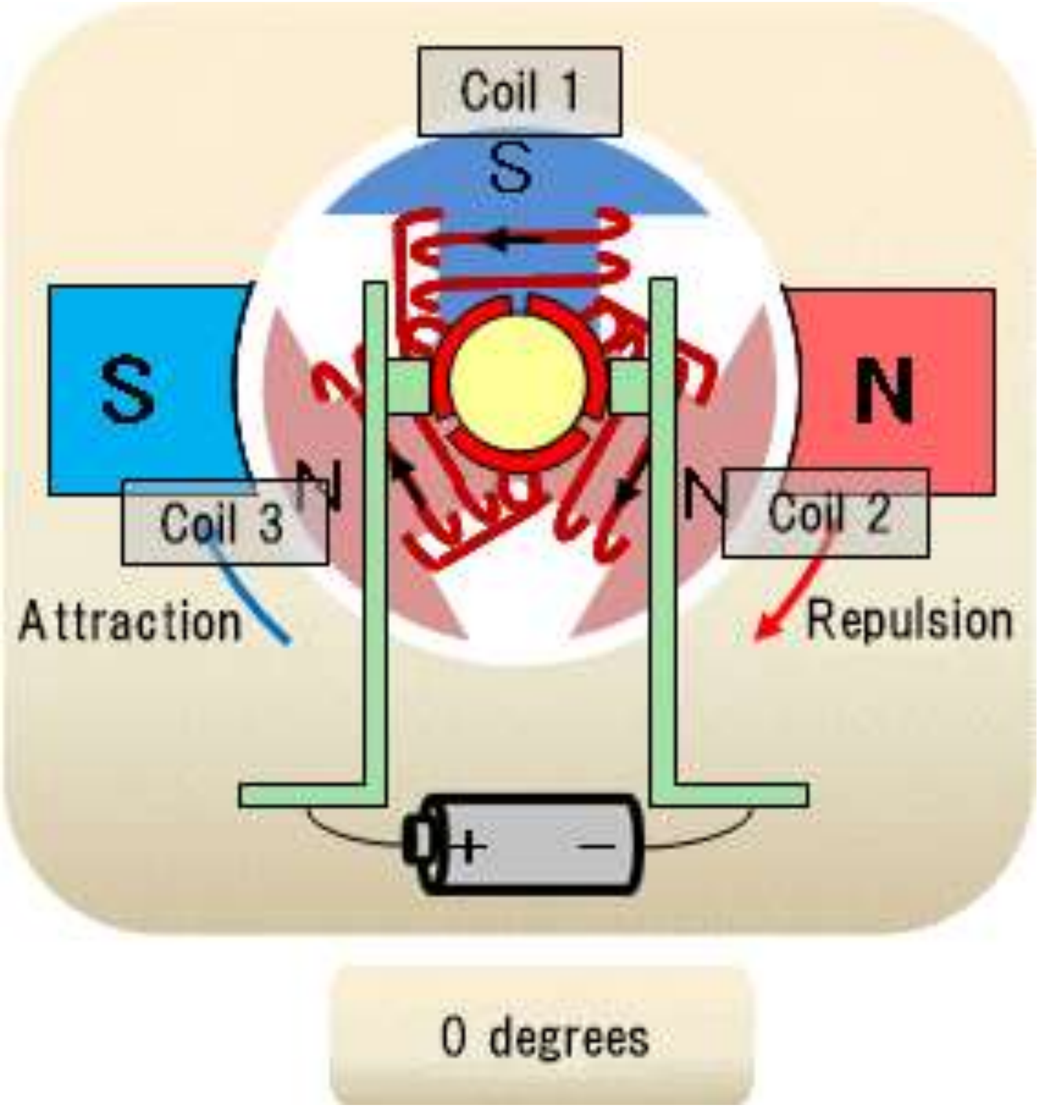


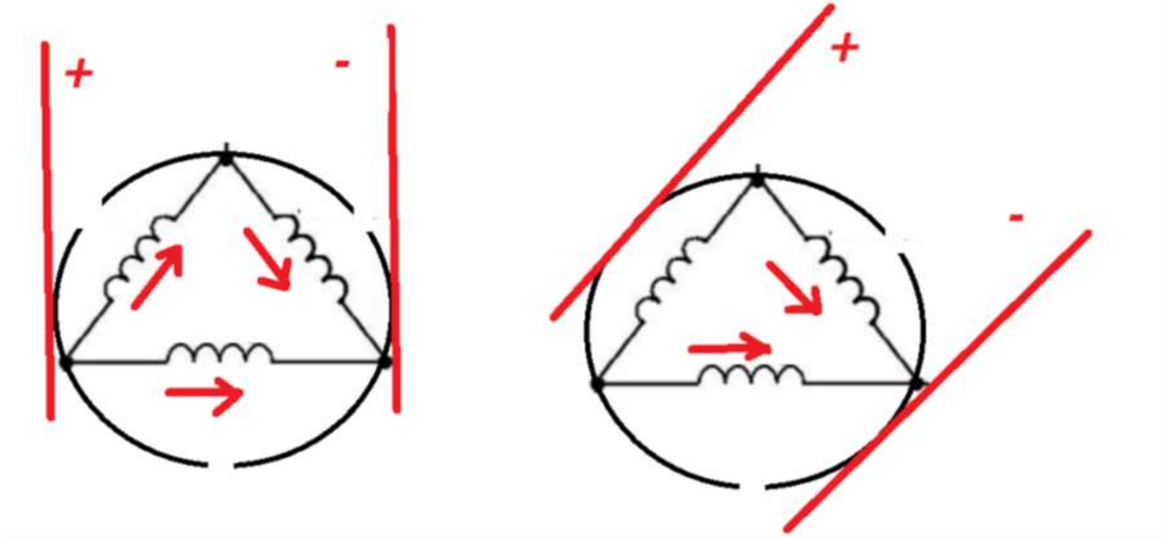
Ferrite chokes are used mainly to filter noise on power supply adapters

11.14 APPLICATIONS-Motors



DC MOTOR TEARDOWN



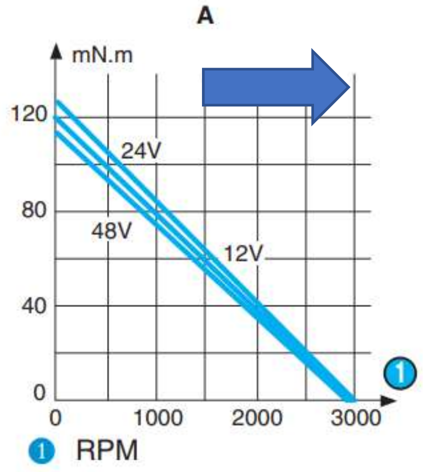


DC Motor Equivalent Circuit

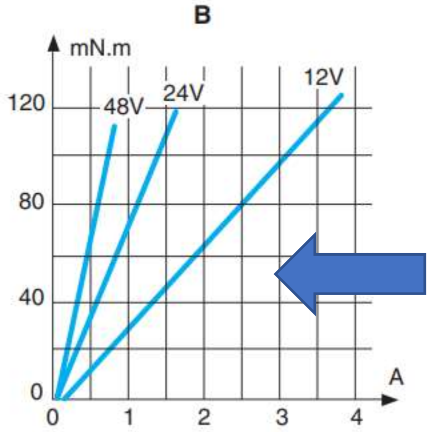
Curves

A - Torque/Speed curves
B - Torque/Current curves

82 810 0

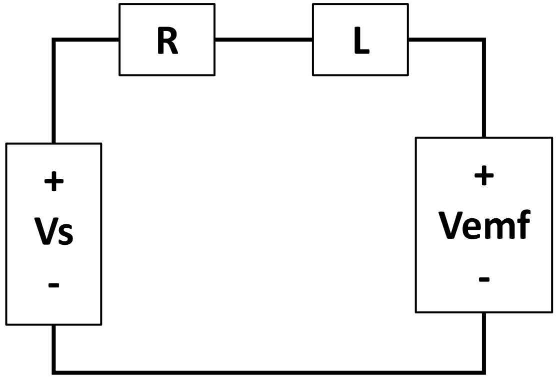


82 810 0



Specifications

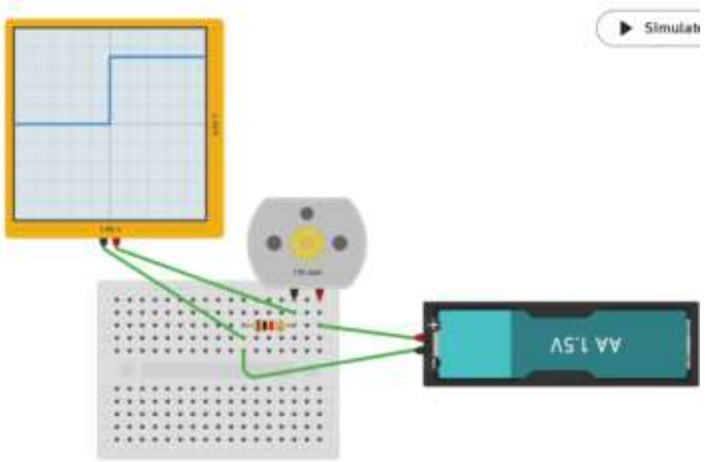
	10 Watts
Type	82 810 0
Voltage	12 V
Part numbers	**82 810 017**
No-load characteristics	
Speed of rotation (rpm)	2850
Absorbed power (W)	4.8
Absorbed current (A)	0.4
Nominal characteristics	
Speed (rpm)	2000
Torque (mN.m)	45
Usable power (W)	9.4
Absorbed power (W)	20.4
Absorbed current (A)	1.7
Gearbox case temperature rise (°C)	45
Efficiency (%)	46
General characteristics	
Insulation class (conforming to IEC 85)	F (155 °C)
Protection (IEC 529) Housing	IP20
Max. output (W)	10.3
Start torque (mN.m)	127
Starting current (A)	4
Resistance (Ω)	3.1
Inductance (mH)	2.5
Torque constant (Nm/A)	0.035
Electrical time constant (ms)	0.8
Mechanical time constant (ms)	19
Thermal time constant (min)	10
Inertia ($g.cm^2$)	80
Weight (g)	310
No of segments	8
Service life (h)	3000
Sintered bronze bearings	✓
Replaceable brushes (mm)	✓

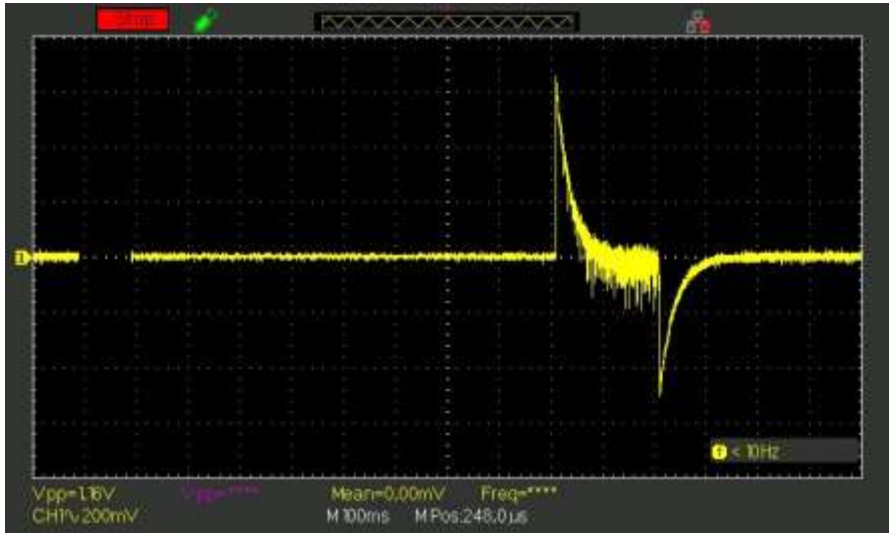


DC motor Equations:
Torque=Kt.I
Vemf=Kt.rpm. 2pi/60
Vs=I.R + Vemf

Example:
2A,→ 60mNm
60mNm→1500rpm
12=2x3 + Vemf
Vemf=6V

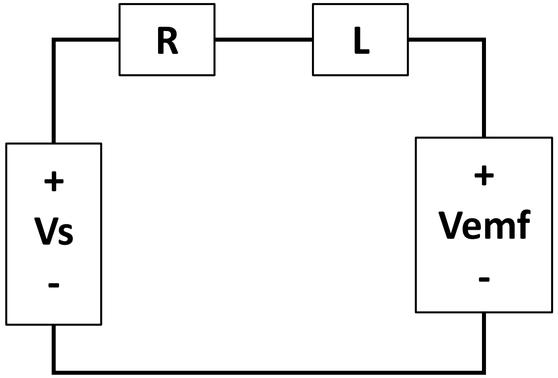
DC Motor Test





Vs=3V
R=3ohm

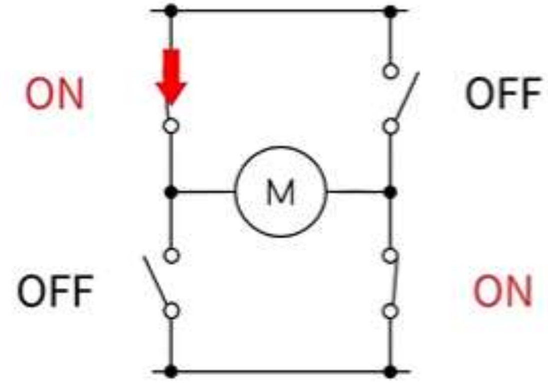
I=500mA
Vems=Vs-IR=3-0.5x3
Vems=1.5V



DC motor Equations:
Torque=Kt.I
Vemf=Kt.rpm. 2pi/60
Vs=I.R + Vemf

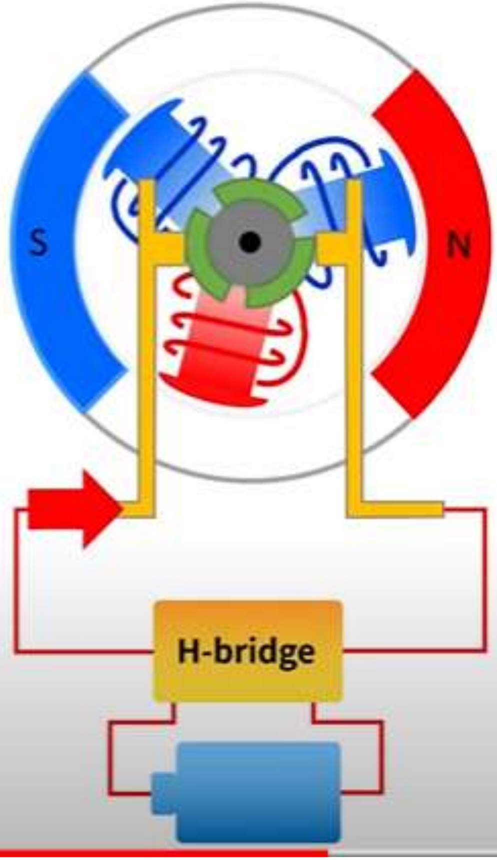
How to control a brushed DC motor

Rotating direction control



H-bridge circuit

2 switches are ON, others are OFF
Forward



Capacitors

10

Objectives

- *Become familiar with the basic construction of a capacitor and the factors that determine how much charge will be deposited on the plates.*
- *Understand how charge is deposited on the plates of a capacitor and how the insertion of an insulator (of a particular type) will affect the amount of charge deposited on the plates.*
- *Become familiar with the wide variety of capacitors available, their basic construction and a few areas of application.*
- *Be able to determine the transient (time-varying) response of a capacitive network due to the application of a dc voltage.*
- *Understand the impact of combining capacitors in series or parallel and how it affects the transient behavior of the network.*

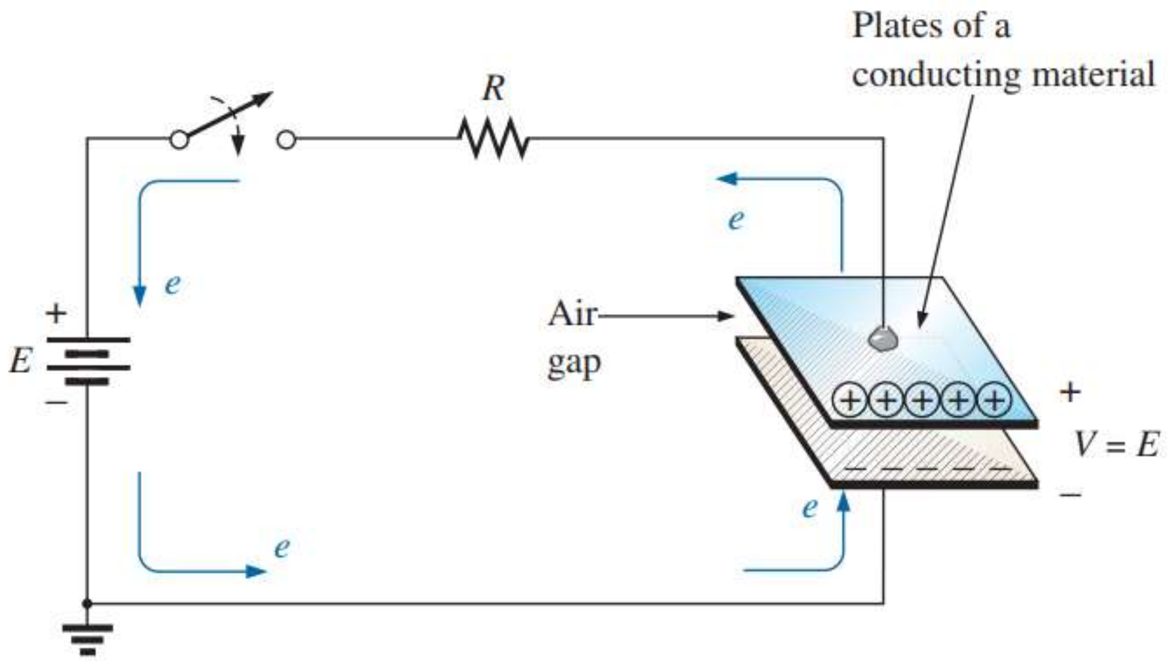


FIG. 10.4
Fundamental charging circuit.

- The instant the switch is closed, however, electrons are drawn from the upper plate through the resistor to the positive terminal of the battery.
- There will be a surge of current at first, limited in magnitude by the resistance present. The level of flow then declines, as will be demonstrated in the sections to follow. This action creates a net positive charge on the top plate.
- Electrons are being repelled by the negative terminal through the lower conductor to the bottom plate at the same rate they are being drawn to the positive terminal.
- This transfer of electrons continues until the potential difference across the parallel plates is exactly equal to the battery voltage.

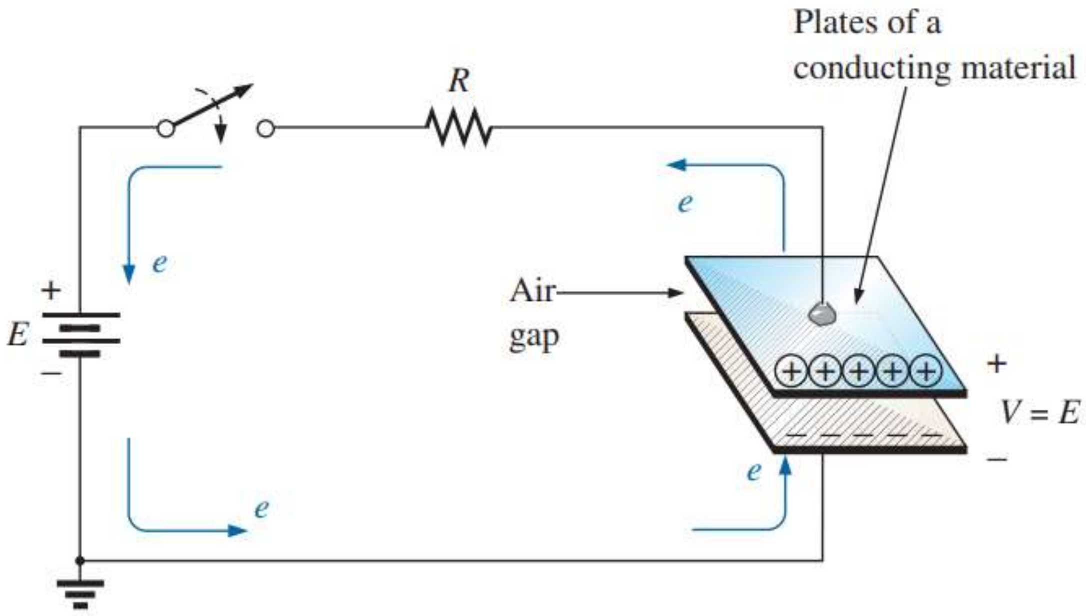


FIG. 10.4
Fundamental charging circuit.

Capacitance is a measure of a capacitor's ability to store charge on its plates—in other words, its storage capacity.

In addition,

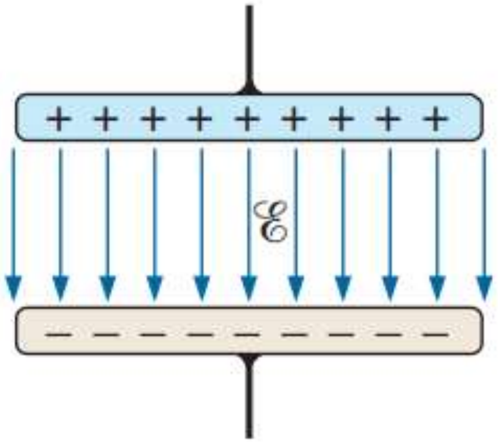
the higher the capacitance of a capacitor, the greater is the amount of charge stored on the plates for the same applied voltage.

The unit of measure applied to capacitors is the farad (F), named after an English scientist, Michael Faraday, who did extensive research in the field (Fig. 10.5). In particular,

a capacitor has a capacitance of 1 F if 1 C of charge (6.242×10^{18} electrons) is deposited on the plates by a potential difference of 1 V across its plates.

$$\boxed{C = \frac{Q}{V}} \qquad \begin{aligned} C &= \text{farads (F)} \\ Q &= \text{coulombs (C)} \\ V &= \text{volts (V)} \end{aligned} \tag{10.5}$$

$$\boxed{Q = CV} \qquad \text{(coulombs, C)} \tag{10.6}$$



(b)

FIG. 10.6

Electric flux distribution between the plates of a capacitor: (a) including fringing; (b) ideal.

The **electric field strength** between the plates is determined by the
ɔss the plates and the distance between the plates as follows:

$$\boxed{\mathscr{E} = \frac{V}{d}} \qquad \begin{aligned} \mathscr{E} &= \text{volts/m (V/m)} \\ V &= \text{volts (V)} \\ d &= \text{meters (m)} \end{aligned} \qquad \textbf{(10.7)}$$

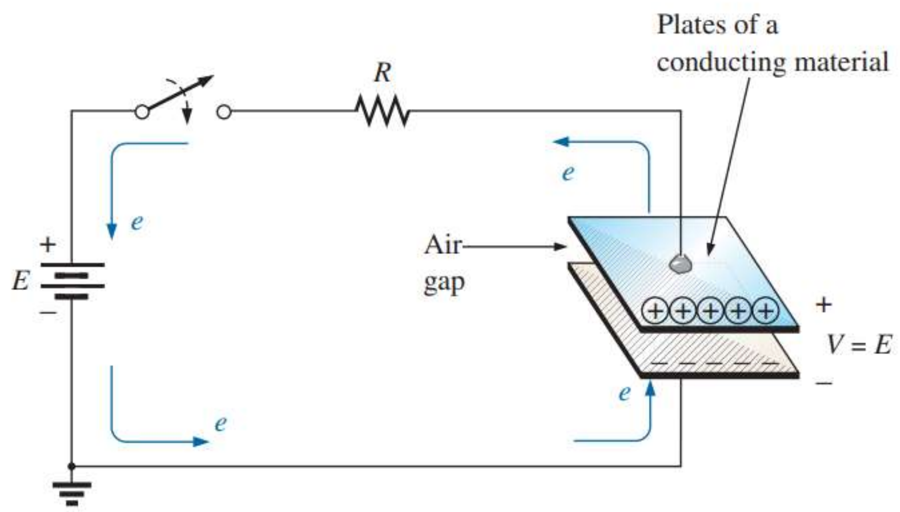


TABLE 10.1

Relative permittivity (dielectric constant) ε_r of various dielectrics.

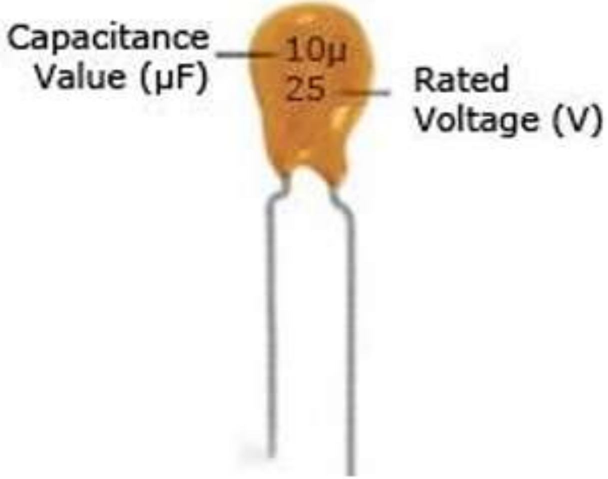
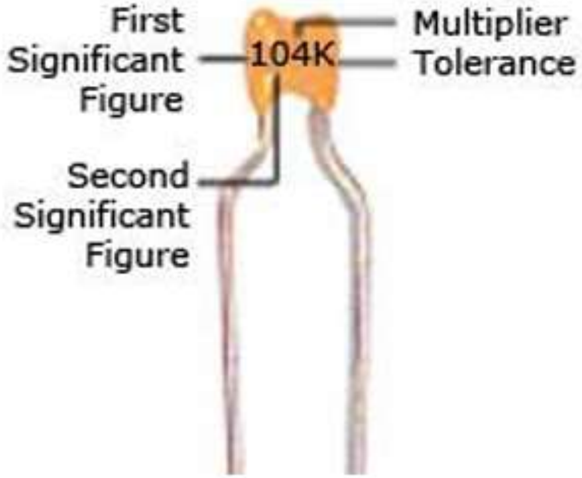
Dielectric	ε_r (Average Values)
Vacuum	1.0
Air	1.0006
Teflon®	2.0
Paper, paraffined	2.5
Rubber	3.0
Polystyrene	3.0
Oil	4.0
Mica	5.0
Porcelain	6.0
Bakelite®	7.0
Aluminum oxide	7
Glass	7.5
Tantalum oxide	30
Ceramics	20–7500
Barium-strontium titanite (ceramic)	7500.0

If we substitute Eq. (10.8) for the permittivity of the material, we obtain the following equation for the capacitance:

$$\boxed{C = \varepsilon_o \varepsilon_r \frac{A}{d}} \quad \text{(farads, F)} \qquad \textbf{(10.10)}$$

or if we substitute the known value for the permittivity of air, we obtain the following useful equation:

$$\boxed{C = 8.85 \times 10^{-12} \varepsilon_r \frac{A}{d}} \quad \text{(farads, F)} \qquad \textbf{(10.11)}$$

Electrolytic Capacitor	Tantalum Capacitor	Monolithic Capacitor
		
These polarity-sensitive capacitors are the easiest to decipher because their value and maximum voltage ratings are listed directly on the metal component "can". The negative side (-) is usually clearly marked with the negative side being the shorter lead and the positive side (+) being the longer lead.	These brightly colored "gumdrop" capacitors are polarity-sensitive, where the positive lead (+) is longer than the negative (-). Tantalum capacitors usually have the capacitance value, maximum voltage rating and polarity printed right on the component.	These non-polar capacitors have equal length leads that can be installed in either direction and come in many colors. The chart illustrates how to determine their value using the three-number and letter code found on most monolithic capacitors.

General Capacitor Codebreaker

Common Capacitor Code	PicoFarad (pF)	NanoFarad (nF)	MicroFarad (mF/.μF/mfd)
102	1000	1 or 1n	0.001
152	1500	1.5 or 1n5	0.0015
222	2200	2.2 or 2n2	0.0022
332	3300	3.3 or 3n3	0.0033
472	4700	4.7 or 4n7	0.0047
682	6800	6.8 or 6n8	0.0068

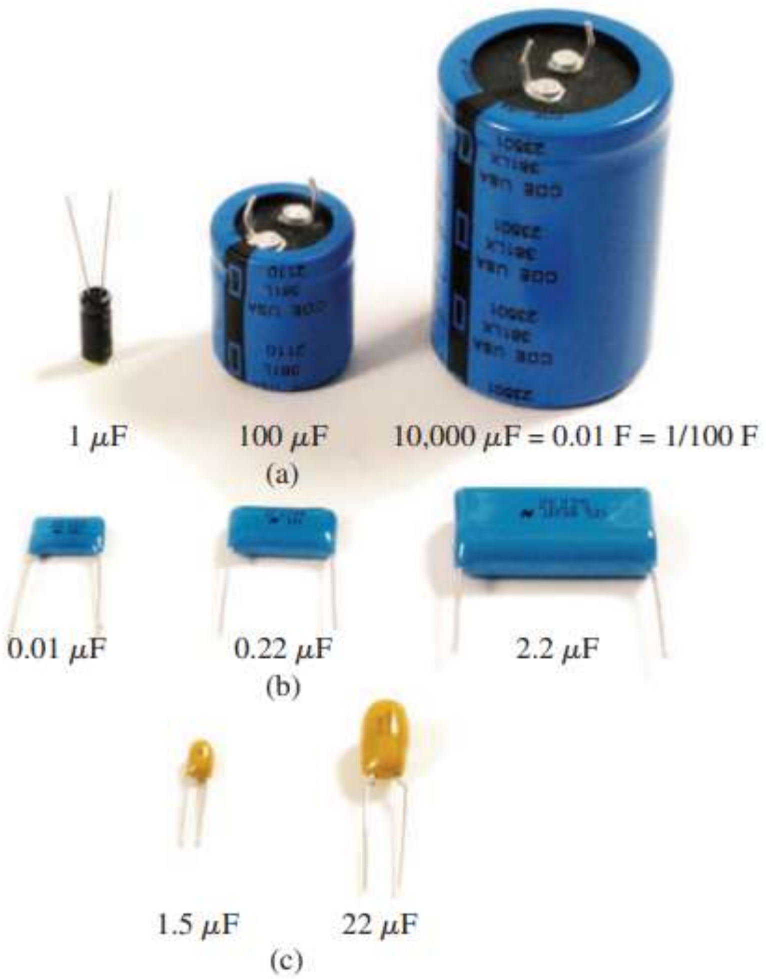


FIG. 10.12
Demonstrating that, in general, for each type of construction, the size of a capacitor increases with the capacitance value: (a) electrolytic; (b) polyester-film; (c) tantalum.

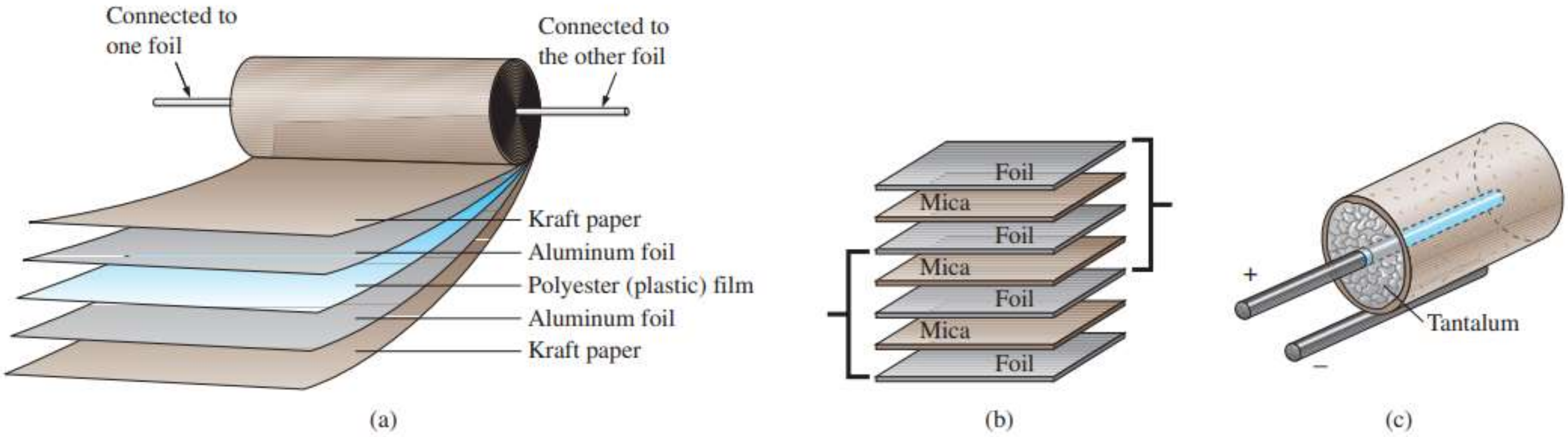


FIG. 10.13

Three ways to increase the area of a capacitor: (a) rolling; (b) stacking; (c) insertion.

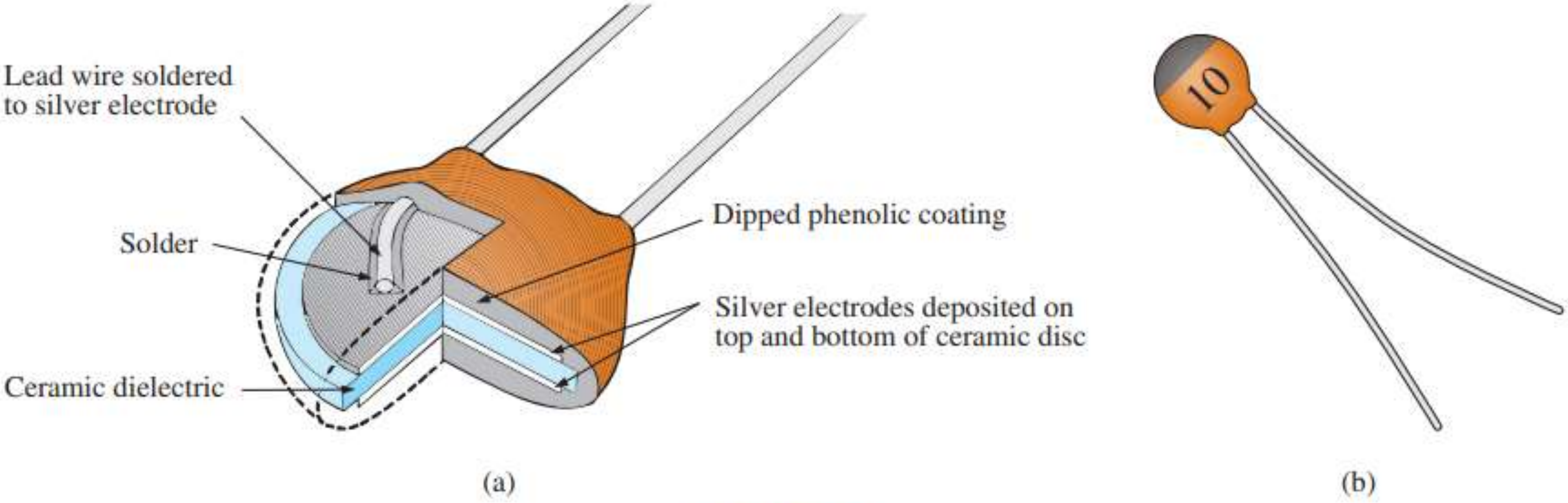


FIG. 10.16
Ceramic (disc) capacitor: (a) construction; (b) appearance.

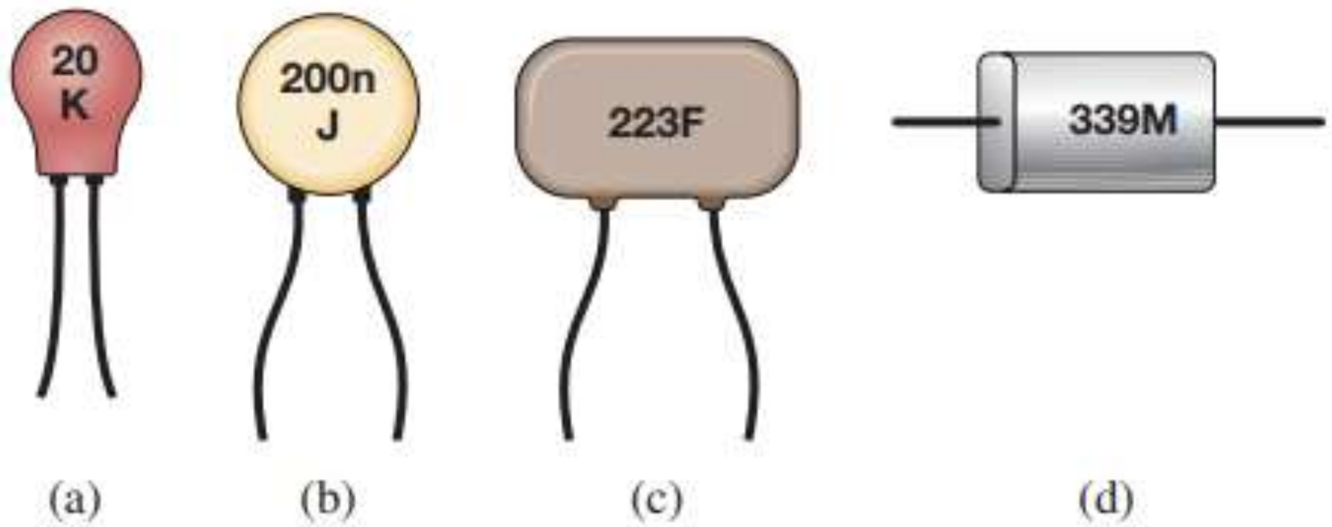


FIG. 10.25

Various marking schemes for small capacitors.

in Fig. 10.25. For very small units such as those in Fig. 10.25(a) with only two numbers, the value is recognized immediately as being in pF with the **K** an indicator of a $\pm$ 10% tolerance level. Too often the K is read as a multiplier of 10^3, and the capacitance is read as 20,000 pF or 20 nF rather than the actual 20 pF.

10.5 TRANSIENTS IN CAPACITIVE NETWORKS: THE CHARGING PHASE

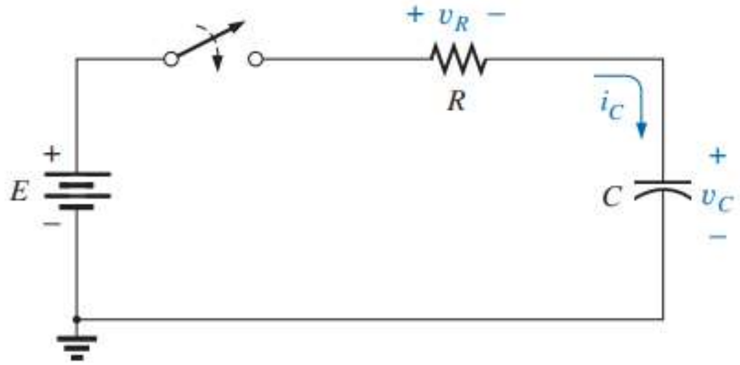


FIG. 10.28
Basic R-C charging network.

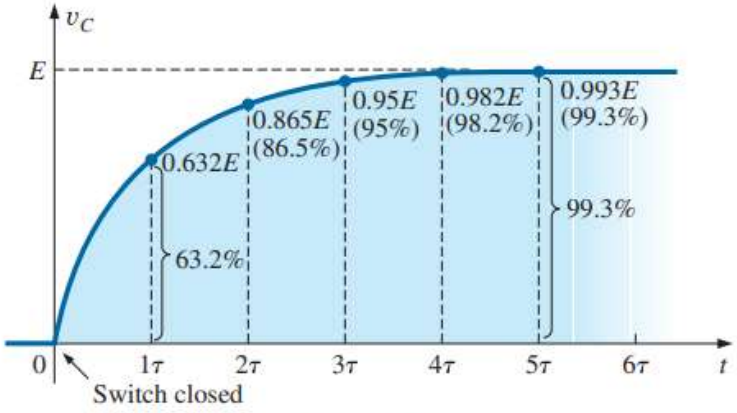


FIG. 10.31
Plotting the equation $v_C = E(1 - e^{-t/\tau})$ versus time (t).

very rapid at first, slowing down as the potential across the plates approaches the applied voltage

$$\boxed{v_C = E(1 - e^{-t/\tau})}_{\text{charging}} \qquad \text{(volts, V)} \qquad \textbf{(10.13)}$$

First note in Eq. (10.13) that

the voltage v_C is written in lowercase (not capital) italic to point out that it is a function that will change with time—it is not a constant.

$$\boxed{\tau = RC} \qquad \text{(time, s)} \qquad \textbf{(10.14)}$$

$$\boxed{i_C = C\frac{dv_C}{dt}} \qquad \textbf{(10.27)}$$

10.5 TRANSIENTS IN CAPACITIVE NETWORKS: THE CHARGING PHASE

$$\boxed{i_C = \frac{E}{R}e^{-t/\tau}}_{\text{charging}} \qquad (\text{amperes, A}) \qquad \textbf{(10.15)}$$

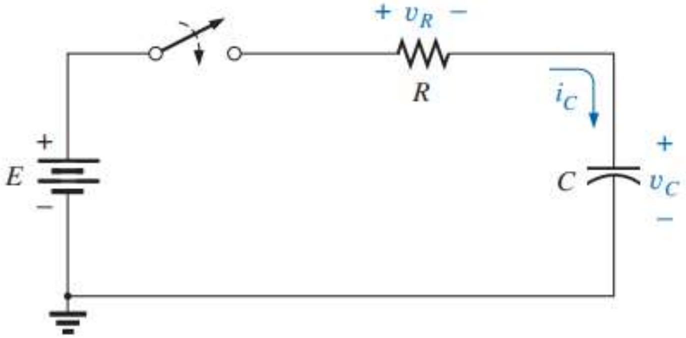


FIG. 10.28
Basic R-C charging network.

the current of a capacitive dc network is essentially zero amperes after five time constants of the charging phase have passed.

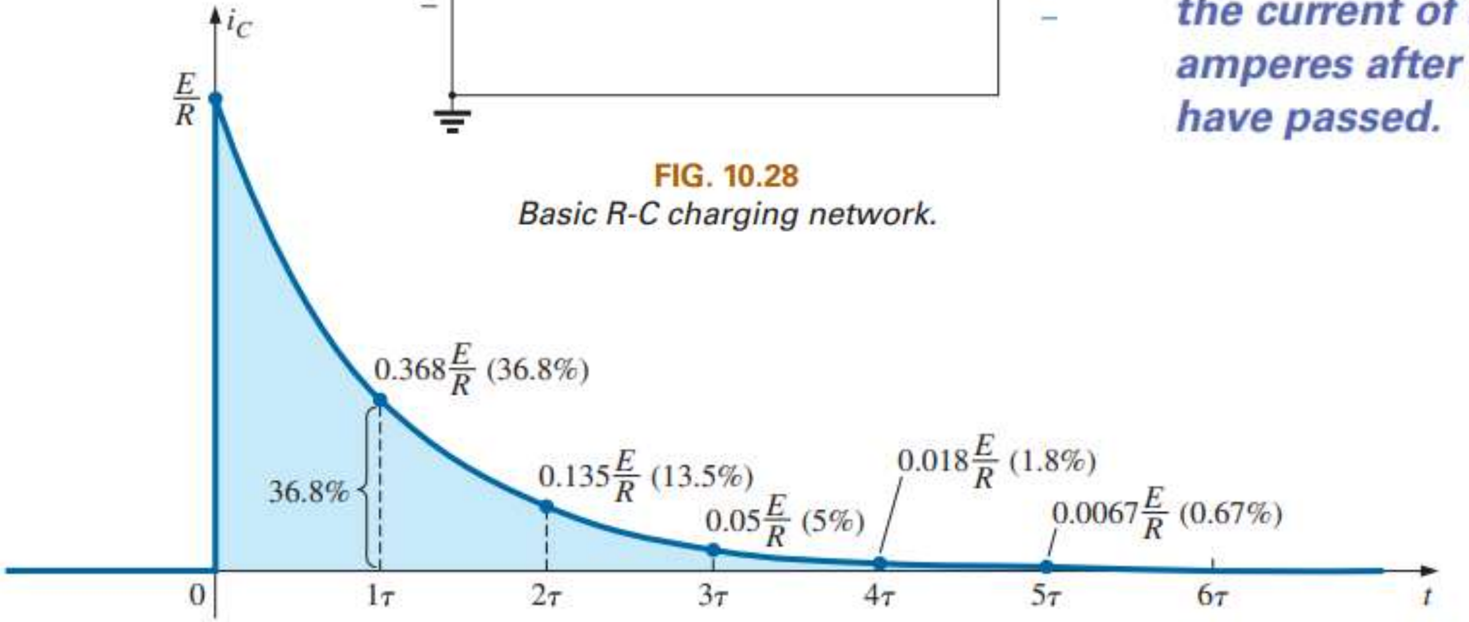


FIG. 10.32
Plotting the equation $i_C = \frac{E}{R}e^{-t/\tau}$ versus time (t).

10.8 DISCHARGE PHASE

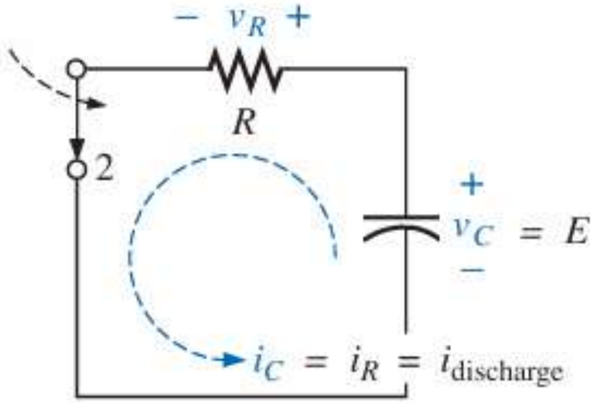
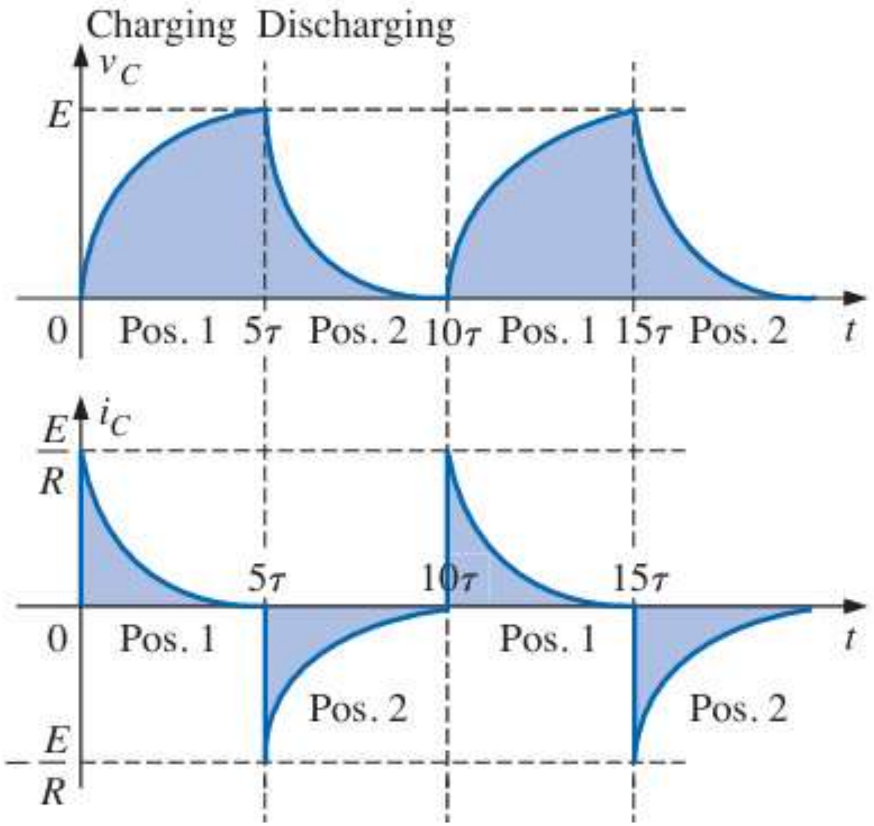


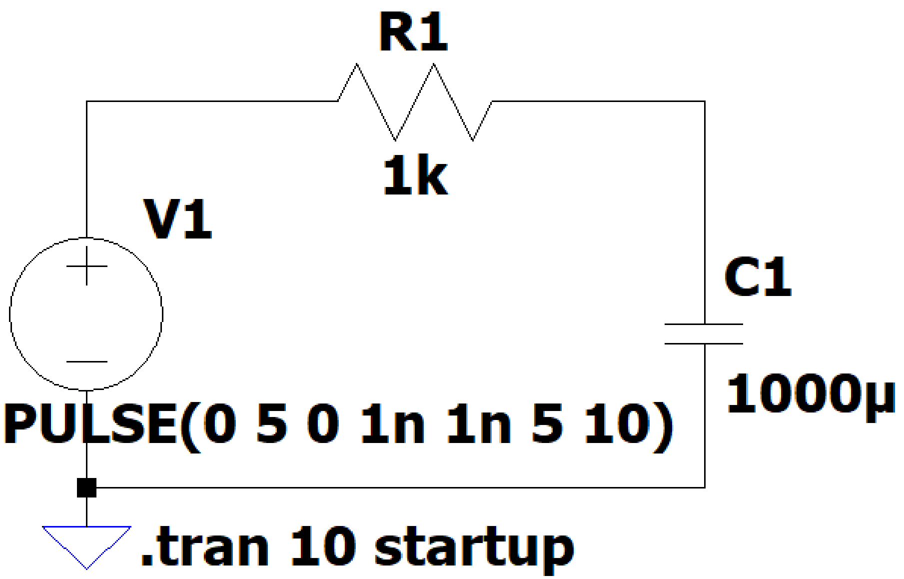
FIG. 10.38
Demonstrating the discharge behavior of a capacitive network.

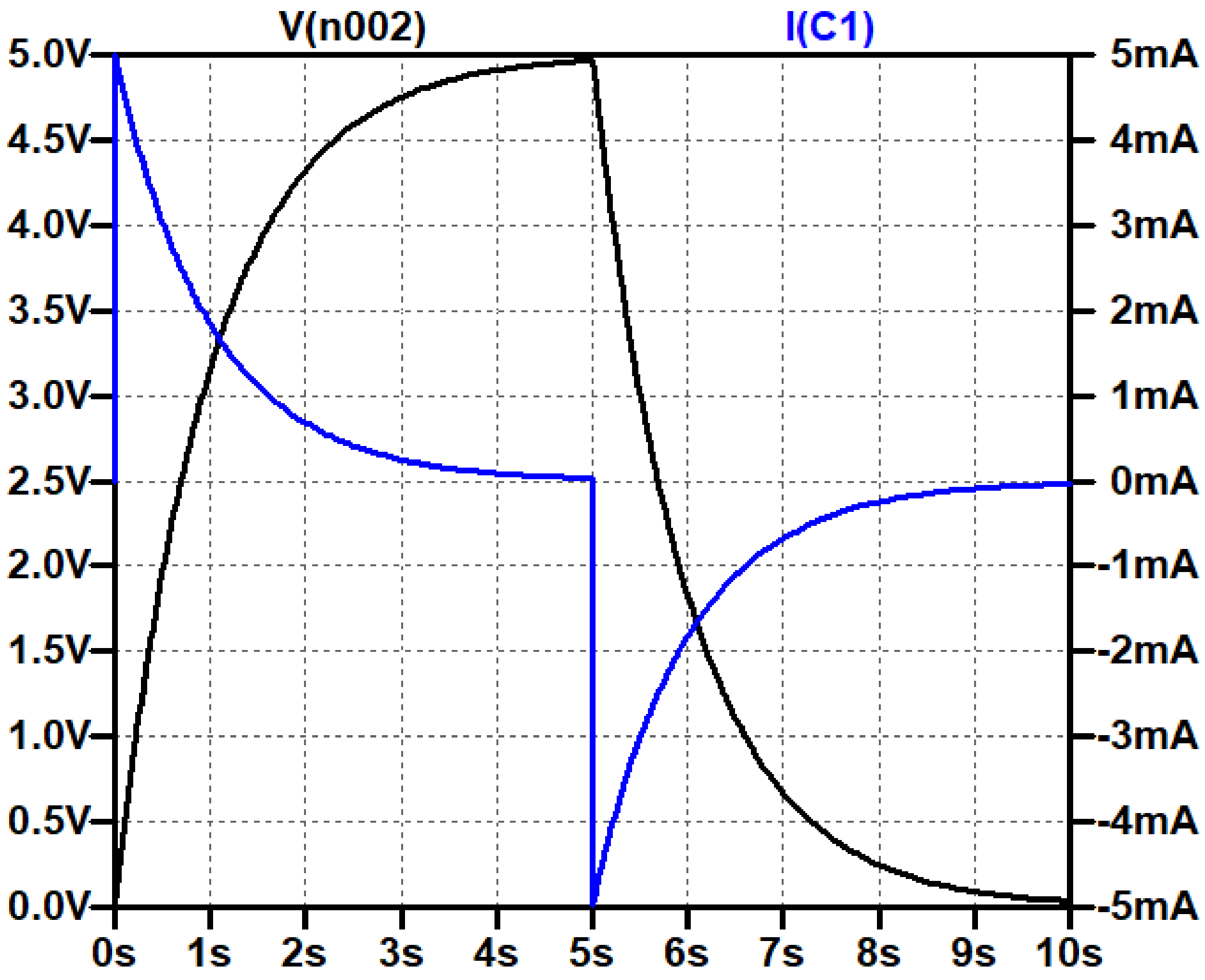


$$\boxed{v_C = Ee^{-t/RC}} \qquad \textit{discharging} \tag{10.18}$$

$$\boxed{i_C = \frac{E}{R}e^{-t/RC}} \qquad \textit{discharging} \tag{10.19}$$

10.8 DISCHARGE PHASE





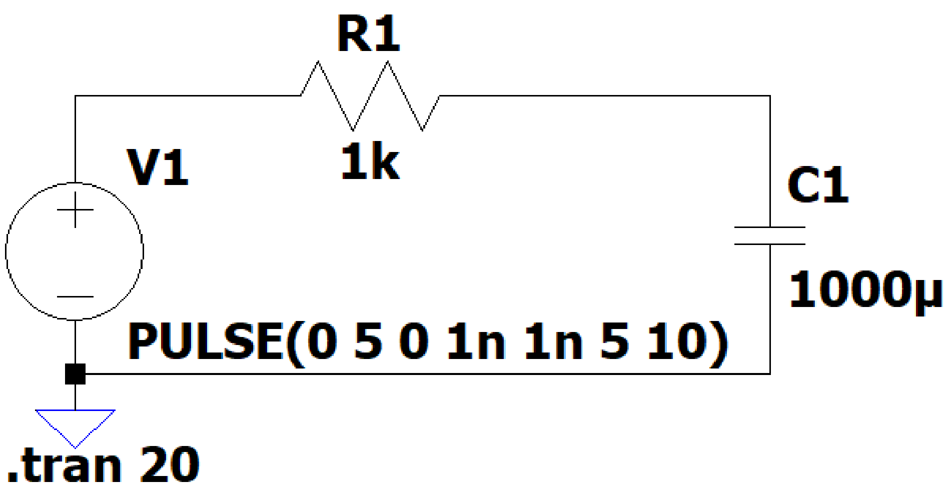
$$\boxed{v_C = E(1 - e^{-t/\tau})}_{\text{charging}} \quad \text{(volts, V)} \tag{10.13}$$

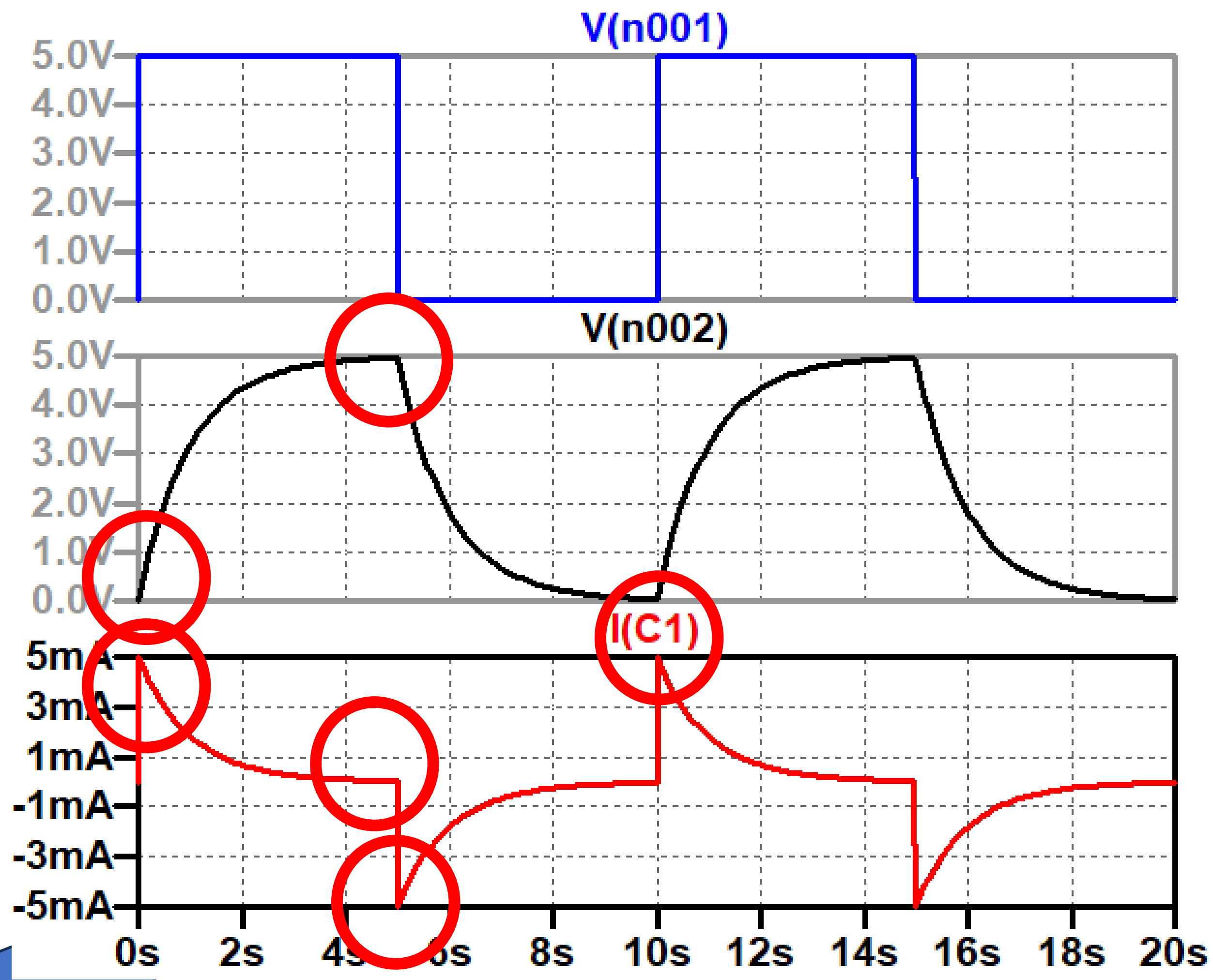
$$\boxed{i_C = \frac{E}{R} e^{-t/\tau}}_{\text{charging}} \quad \text{(amperes, A)} \tag{10.15}$$

$$\boxed{v_C = Ee^{-t/RC}} \quad \textit{discharging} \tag{10.18}$$

$$\boxed{i_C = \frac{E}{R} e^{-t/RC}} \quad \textit{discharging} \tag{10.19}$$

10.8 DISCHARGE PHASE



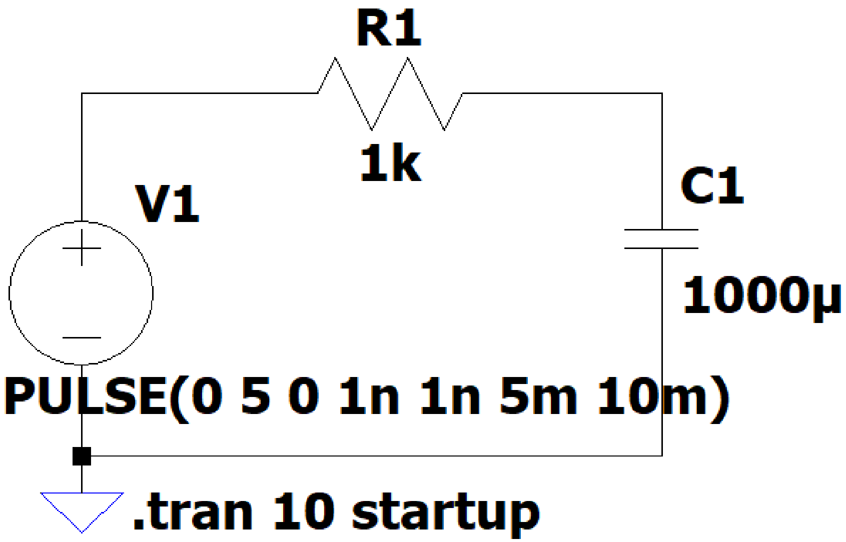


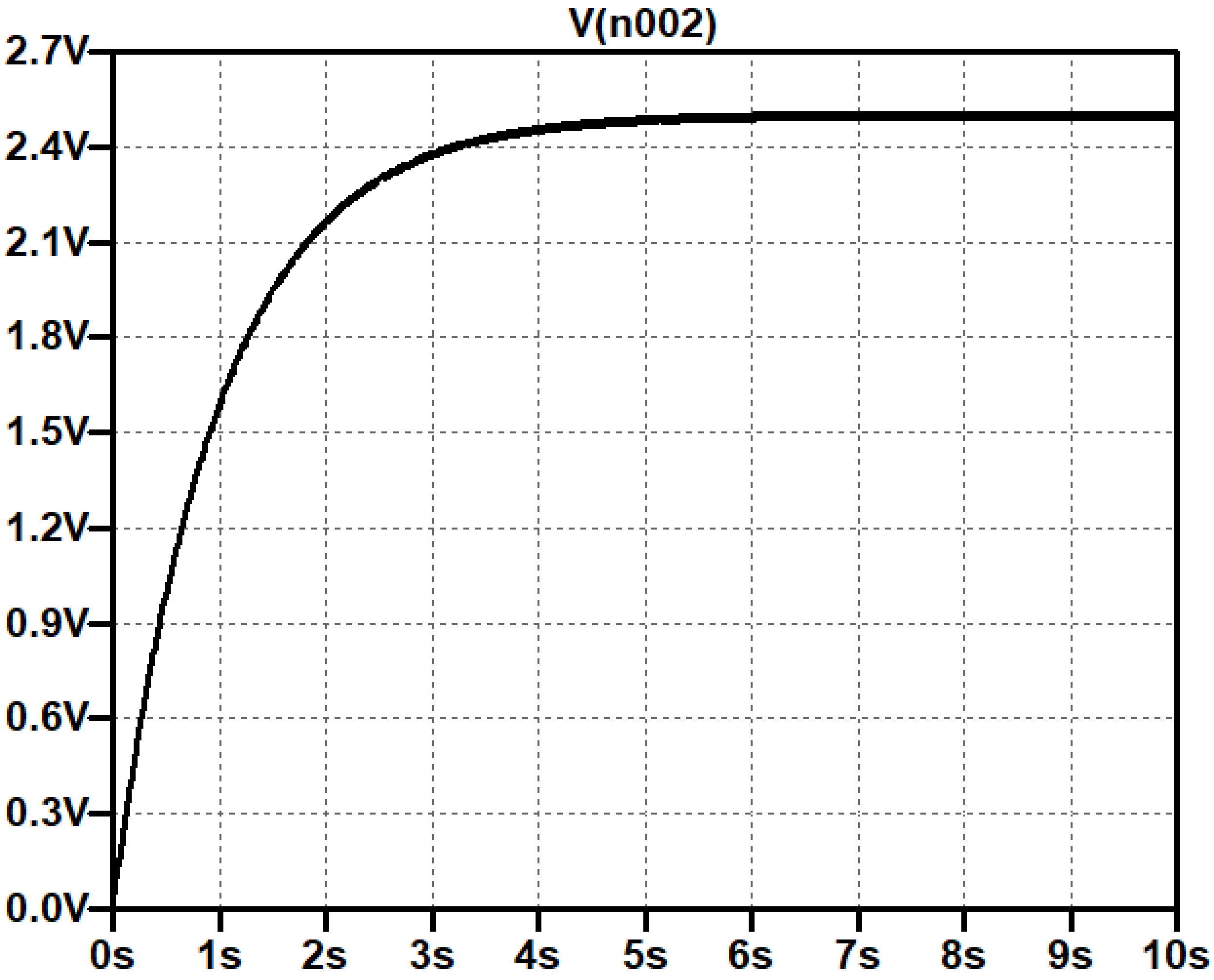
Charging
Vinit = 0, Iinit= V1/R1 = 5V/1K=5mA
Vsteady = V1, Isteady = 0

Discharging
Vinit=5V, Iinit = - V1/R1 = -5mA (negative)
Vsteady = 0, Isteady=0

$$\tau = RC \quad (\text{time, s})$$

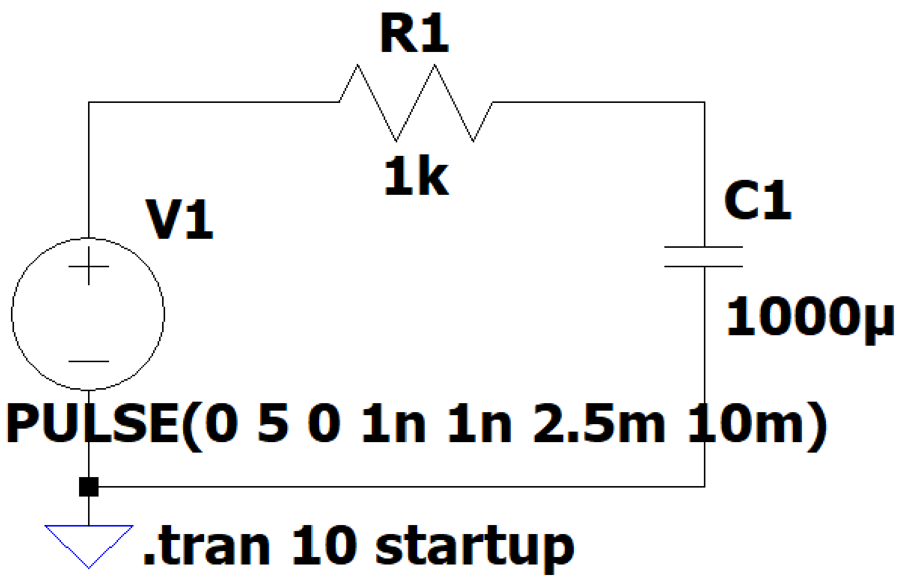
10.8 DISCHARGE PHASE

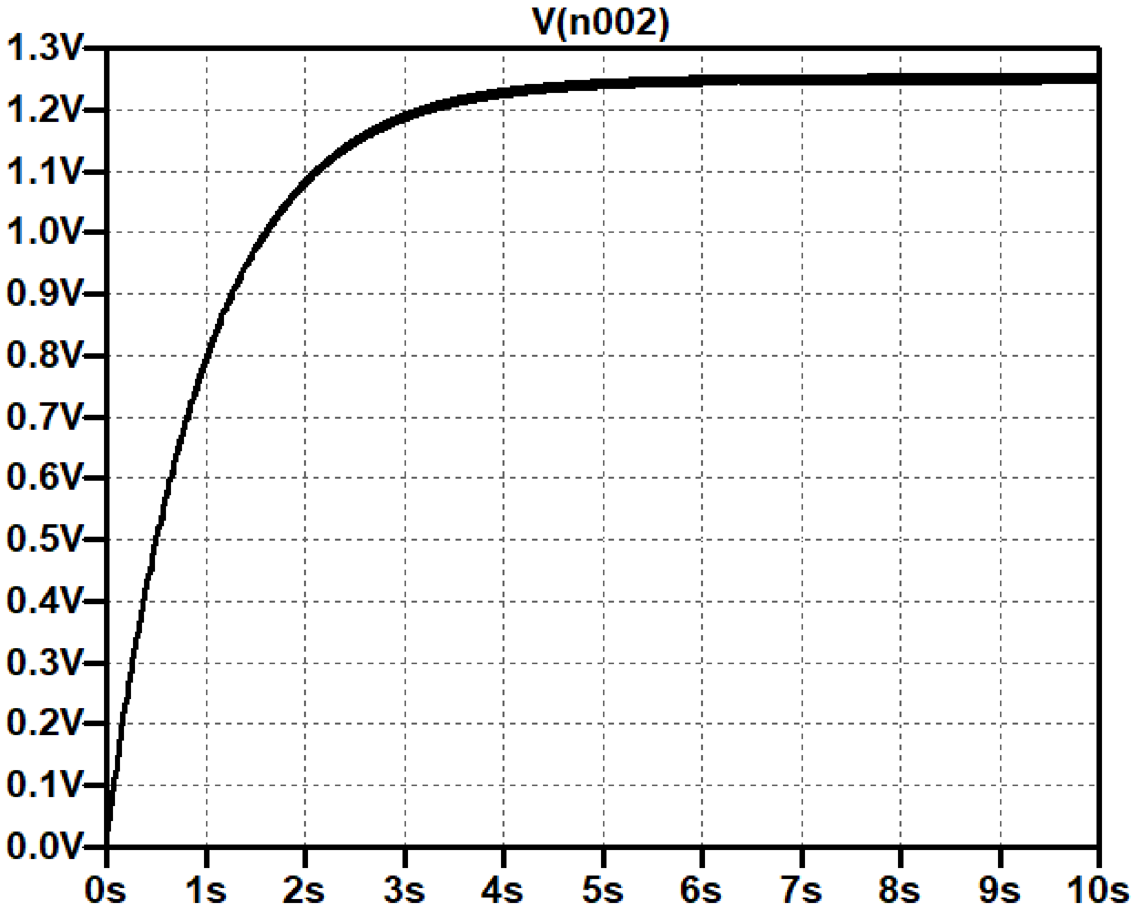




%50 DUTY

10.8 DISCHARGE PHASE





%25 DUTY

10.13 CAPACITORS IN SERIES AND PARALLEL

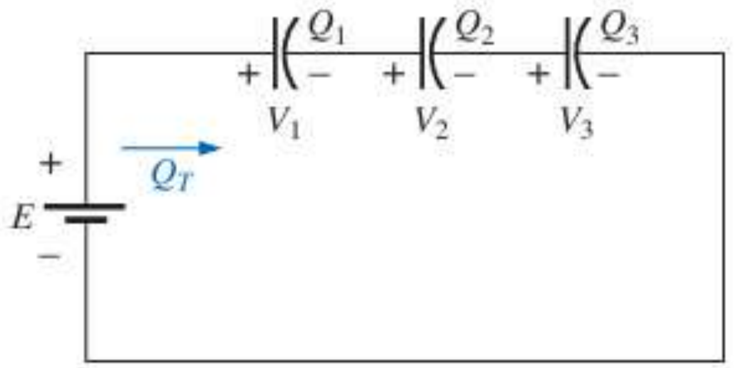


FIG. 10.61
Series capacitors.

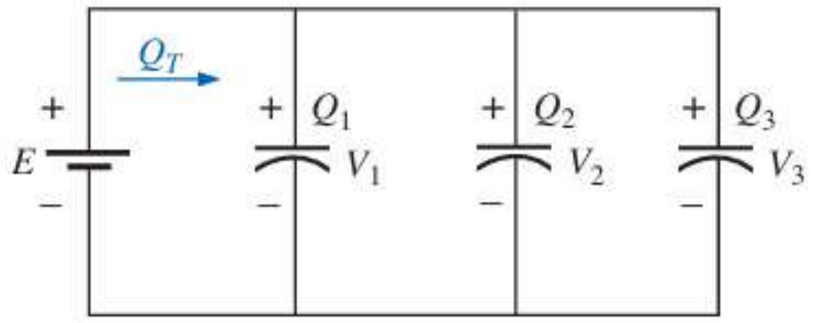


FIG. 10.62
Parallel capacitors.

$$\boxed{\frac{1}{C_T} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

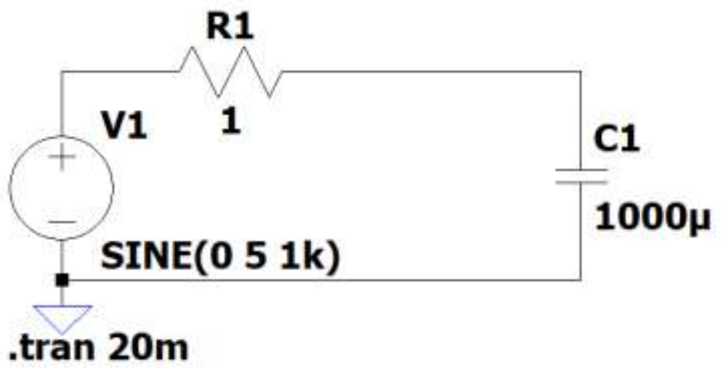
$$\boxed{C_T = C_1 + C_2 + C_3}$$

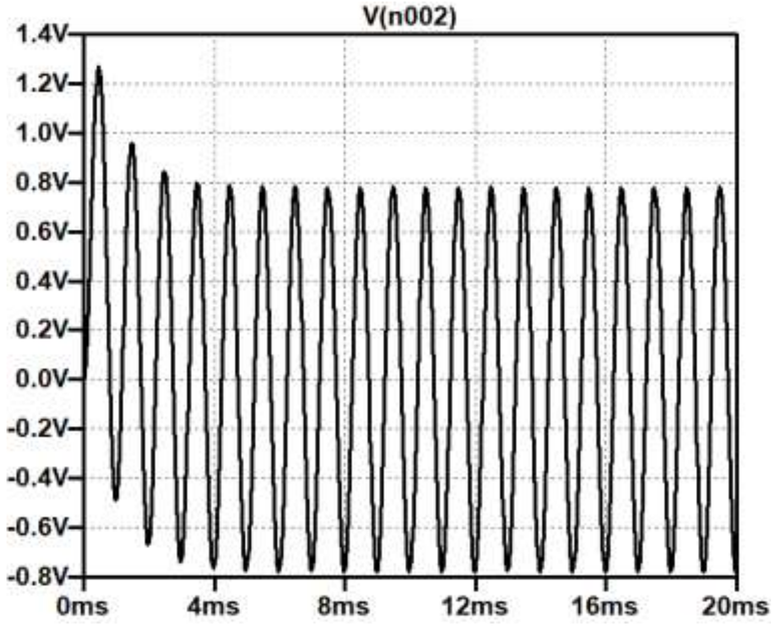
REACTANCE OF CAPACITOR

The quantity $1/\omega C$, called the **reactance** of a capacitor, is symbolically represented by X_C and is measured in ohms; that is,

$$\boxed{X_C = \frac{1}{\omega C}} \qquad \text{(ohms, } \Omega) \qquad \textbf{(14.6)}$$

w=2*pi*f

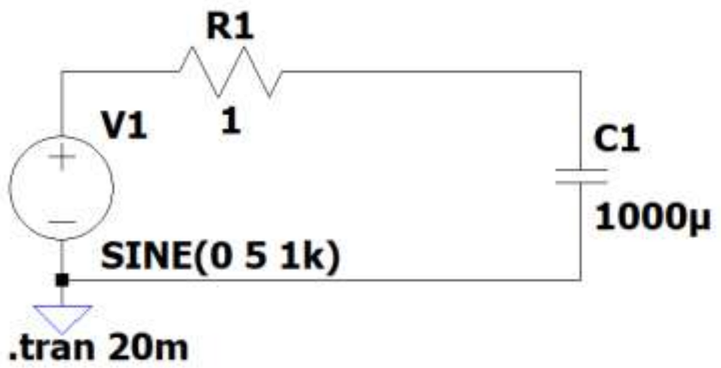




REACTANCE OF CAPACITOR

The quantity $1/\omega C$, called the **reactance** of a capacitor, is symbolically represented by X_C and is measured in ohms; that is,

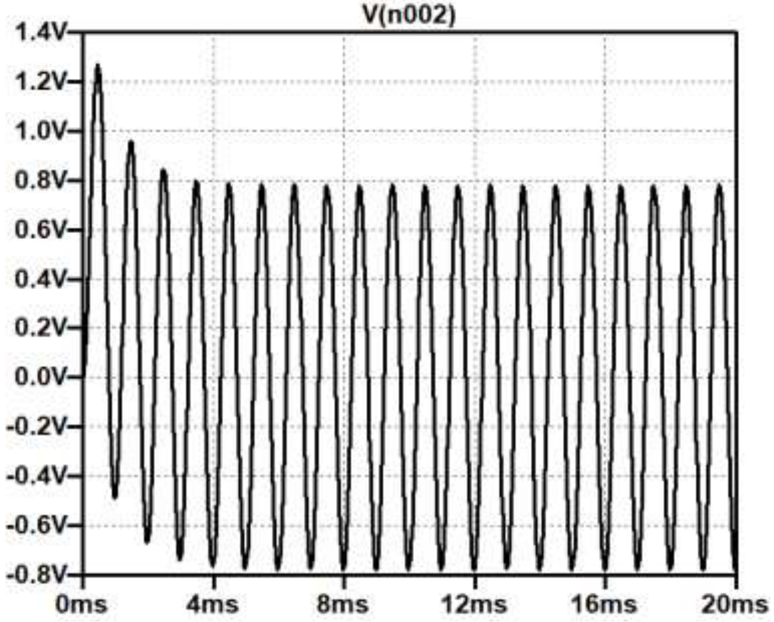
$$\boxed{X_C = \frac{1}{\omega C}} \qquad \text{(ohms, } \Omega) \qquad \textbf{(14.6)}$$



w = 2*pi*f

example = f=1khz
w=2*3.14*1k = 6.28k

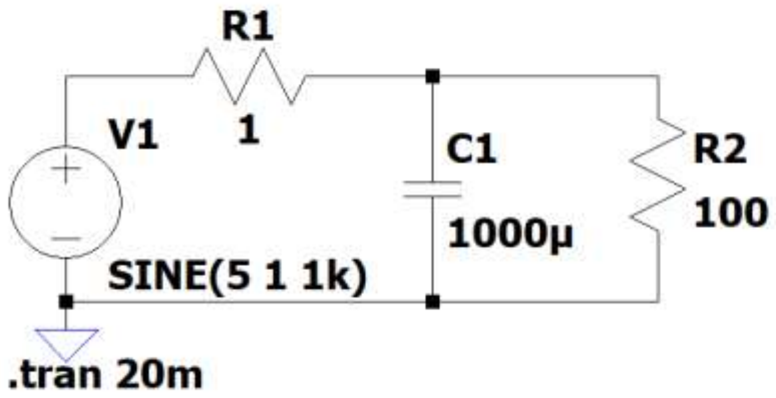
Xc= 1/ (6.28k* 1000 e-6)

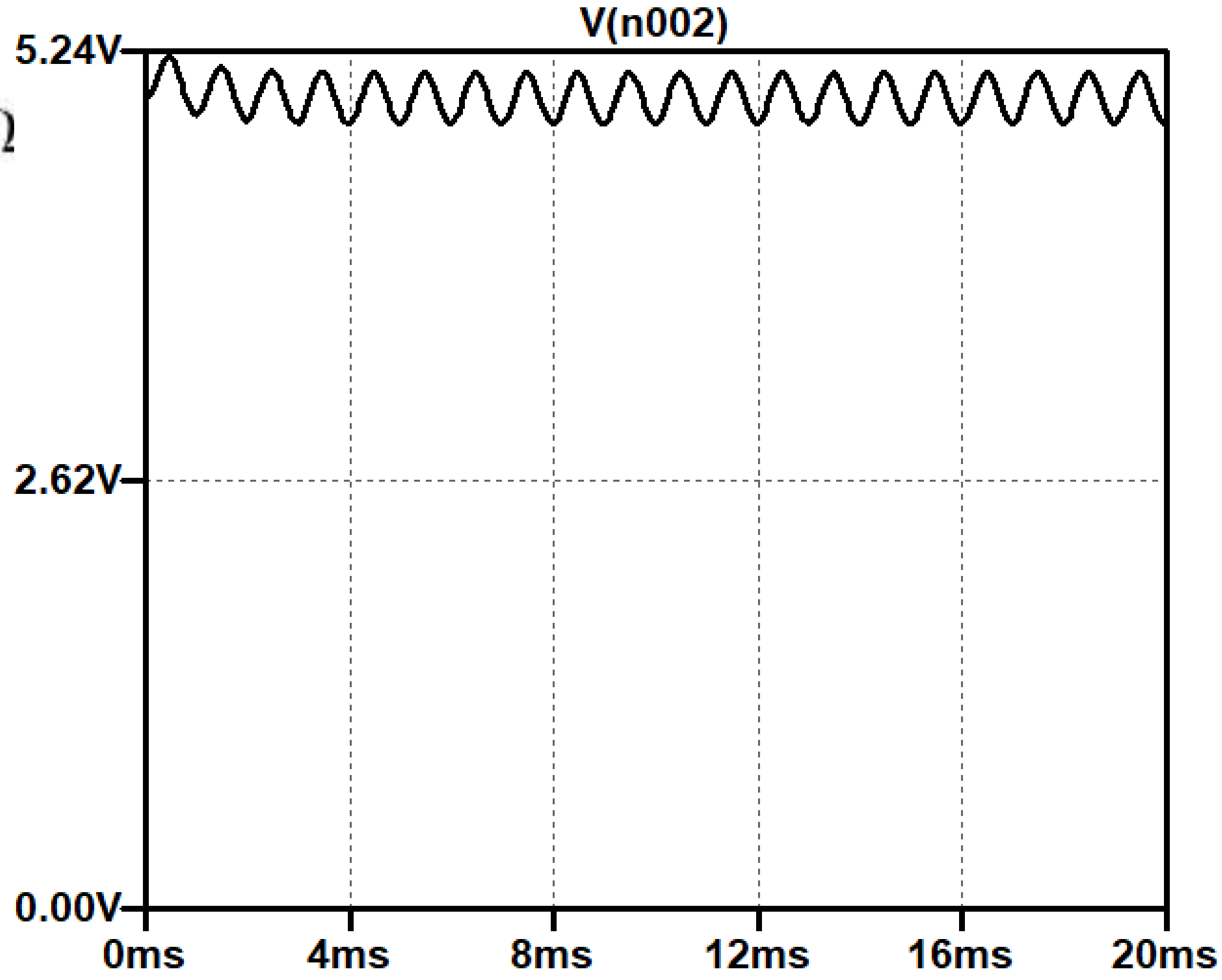


REACTANCE OF CAPACITOR – APPLICATION FILTER

The quantity $1/\omega C$, called the **reactance** of a capacitor, is symbolically represented by X_C and is measured in ohms; that is,

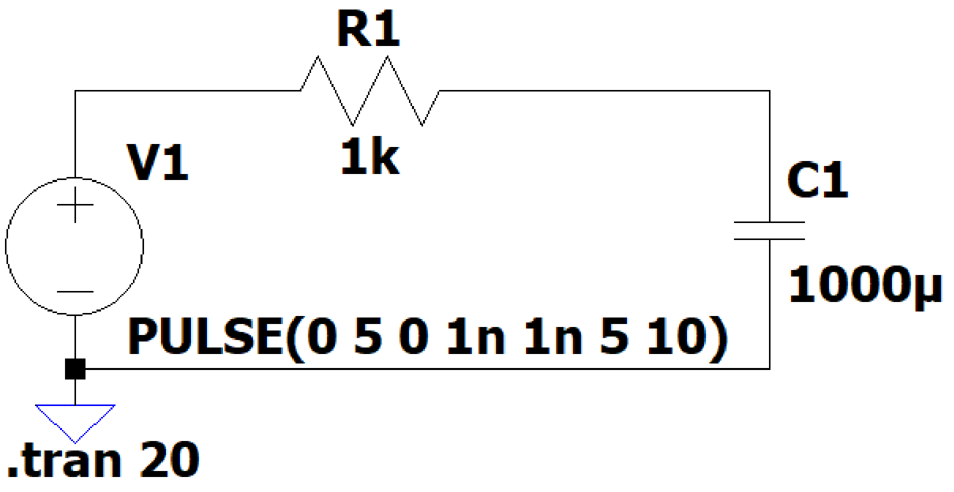
$$\boxed{X_C = \frac{1}{\omega C}} \qquad \text{(ohms, } \Omega$$

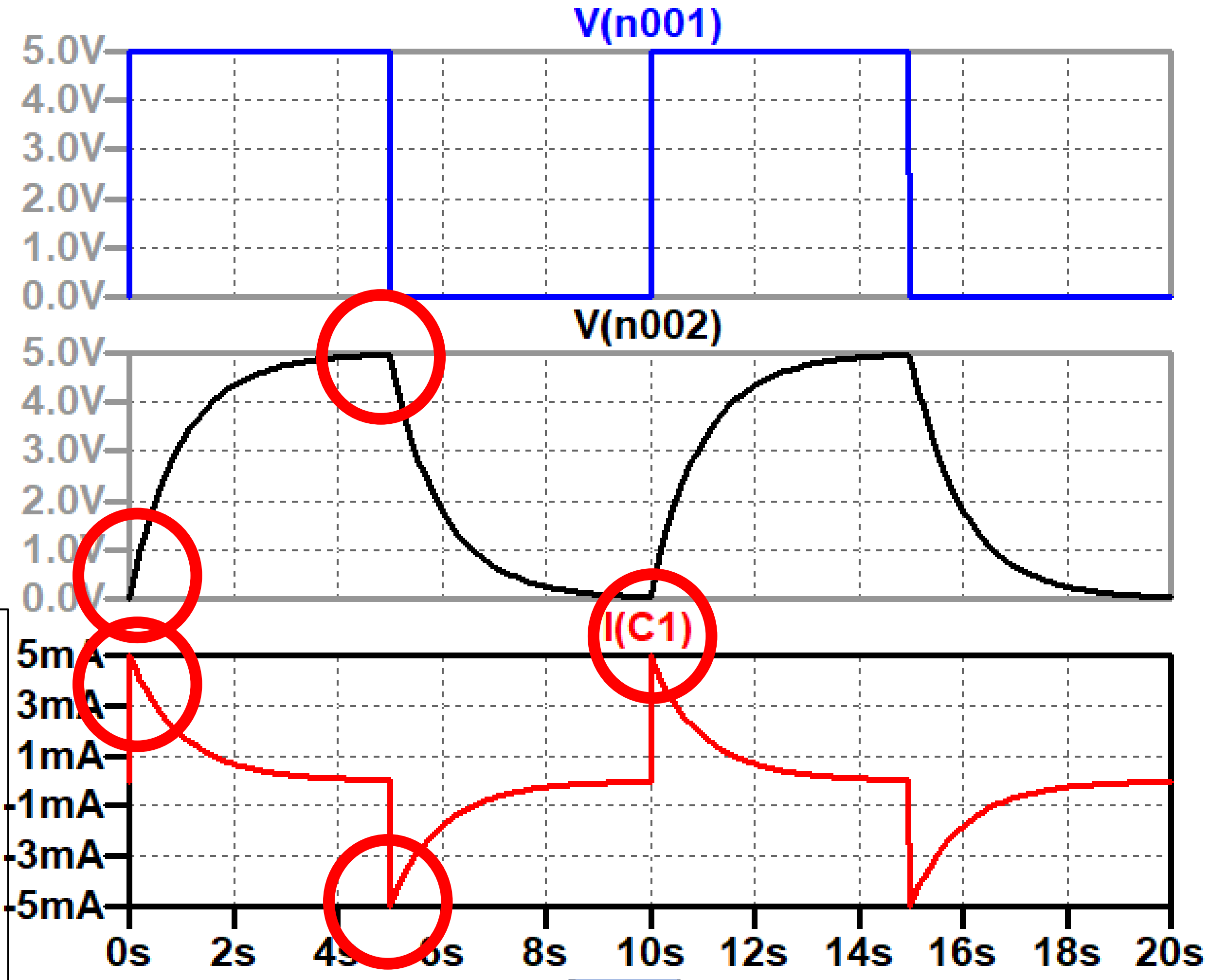




EXERCIZES

10.8 DISCHARGE PHASE





Charging (default)

Vinitial = 0, Iinit= V1/R1 = 5V/1K=5mA

Vsteady = 5V, Isteady = 0

Discharging

Vinit=5V, Iinitial = - V1/R1 = -5mA (negative)

Vsteady = 0, Isteady=0

10.5 TRANSIENTS IN CAPACITIVE NETWORKS: THE CHARGING PHASE

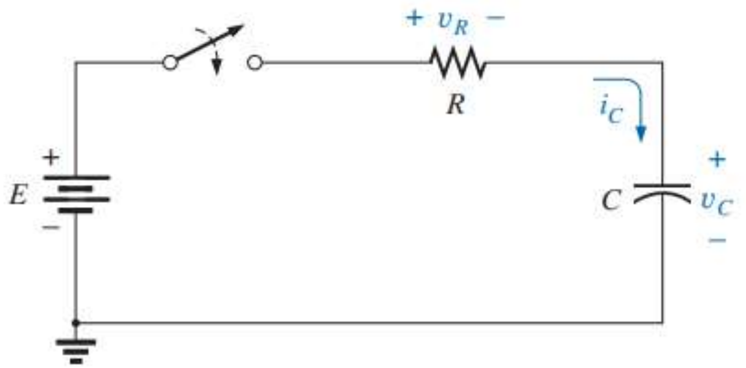


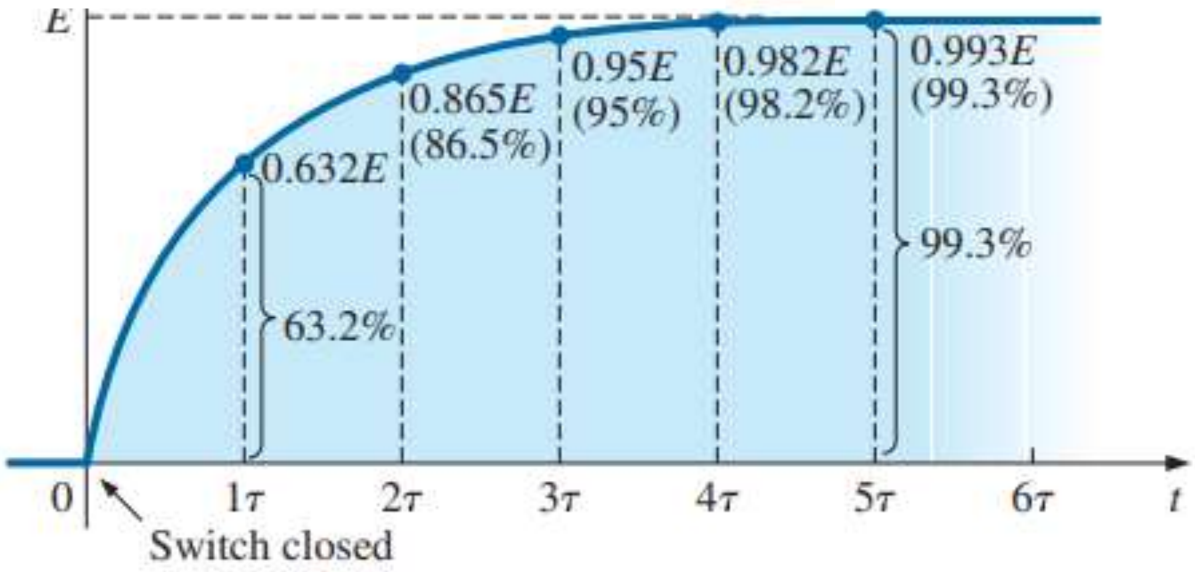
FIG. 10.28
Basic R-C charging network.

very rapid at first, slowing down as the potential across the plates approaches the applied voltage

$$\boxed{v_C = E(1 - e^{-t/\tau})}_{\text{charging}} \qquad (\text{volts, V}) \qquad \textbf{(10.13)}$$

First note in Eq. (10.13) that

the voltage v_C is written in lowercase (not capital) italic to point out that it is a function that will change with time—it is not a constant.



$$\boxed{i_C = C\frac{dv_C}{dt}}$$

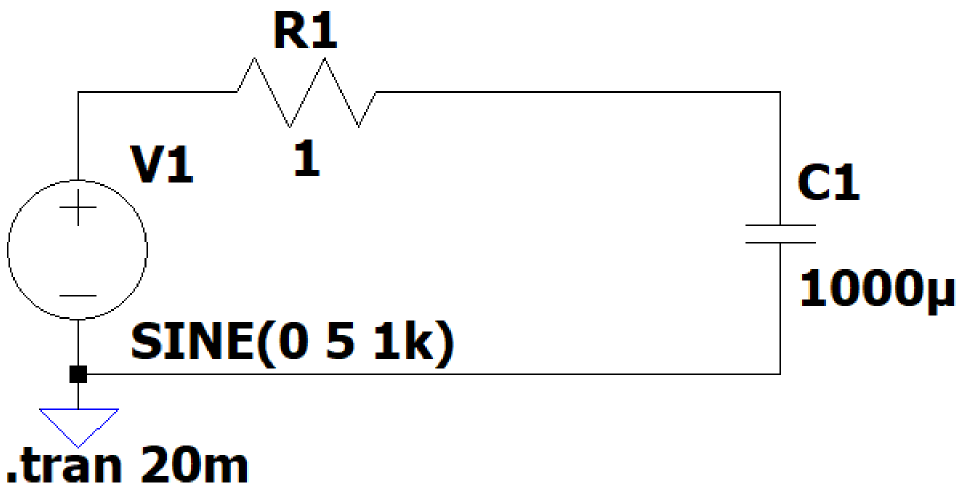
$$\boxed{\tau = RC} \qquad (\text{time, s})$$

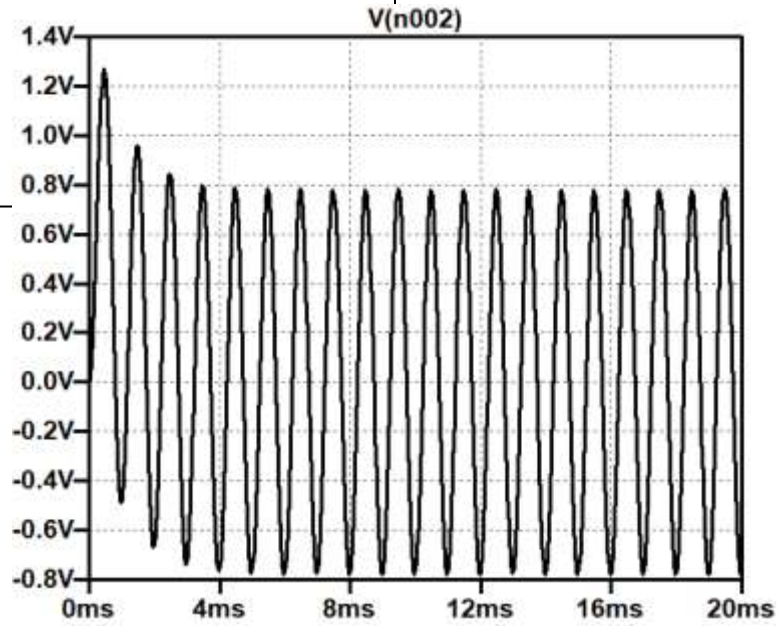
REACTANCE OF CAPACITOR

The quantity $1/\omega C$, called the **reactance** of a capacitor, is symbolically represented by X_C and is measured in ohms; that is,

$$\boxed{X_C = \frac{1}{\omega C}} \qquad \text{(ohms, } \Omega\text{)}$$

w = 2*pi*F





at very HIGH frequencies capacitor becomes SHORT circuit

at very LOW frequencies capacitor becomes OPEN circuit

11.5 RL TRANSIENTS: THE STORAGE PHASE

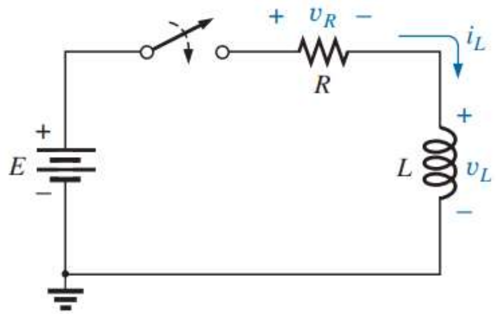


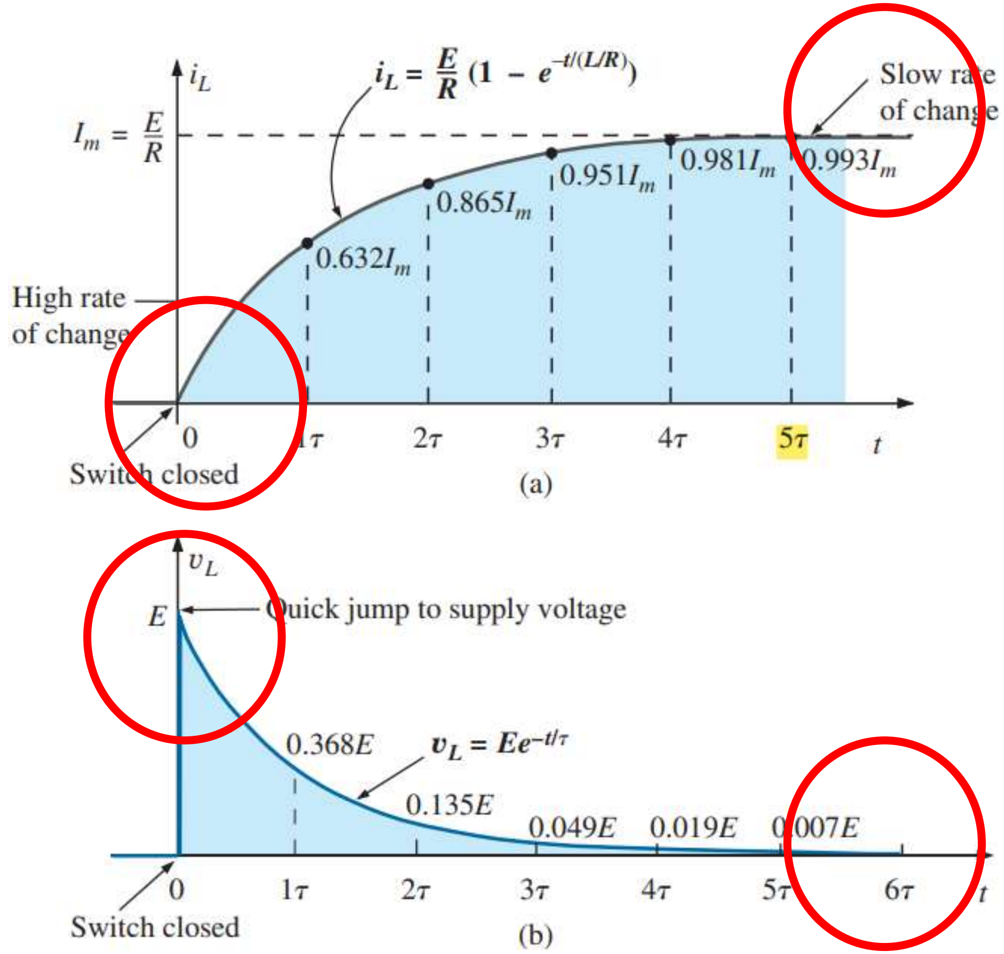
FIG. 11.31
Basic R-L transient network.

$$\boxed{\tau = \frac{L}{R}} \quad \text{(seconds, s)}$$

L is inductance in Henry

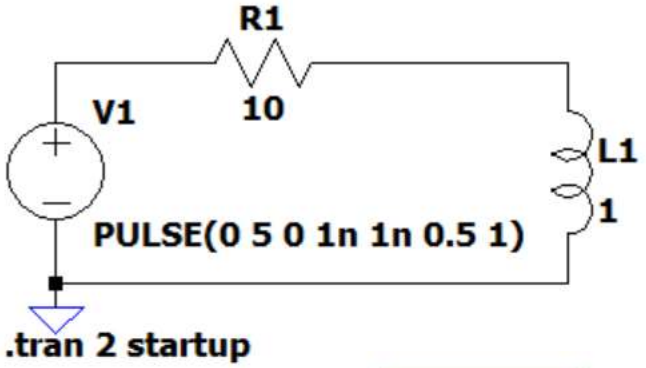
Vinitial=5V, Vsteady state = 0

Iinitial=0, Isteadystate = 5V/R



$$\boxed{v_L = L\frac{di_L}{dt}} \quad \text{(volts, V)}$$

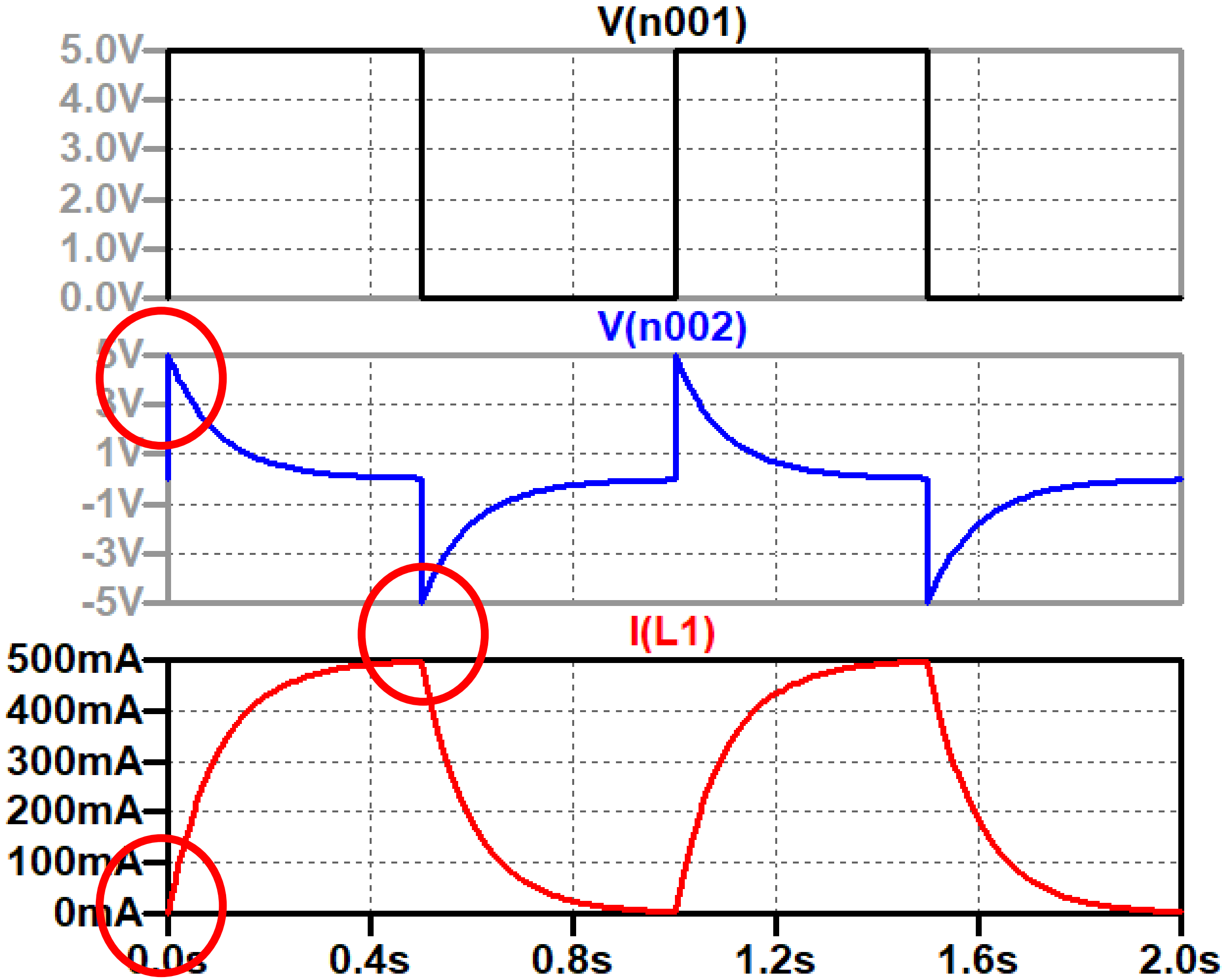
11.5 RL TRANSIENTS: LTSpice



$$\tau = \frac{L}{R} \quad \text{(seconds, s)}$$

T= L/R = 1/10=0.1s
charging
imin = 0A → Vmax=5V
imax=V/R=5/10=500mA → Vmin=0V

discharging
decrease from 500mA to 0
V is flipping start -5V discharging to 0V



$$v_L = L\frac{di_L}{dt} \quad \text{(volts, V)}$$

14.2 RESPONSE OF BASIC R, L, AND C ELEMENTS TO A SINUSOIDAL VOLTAGE OR CURRENT

The quantity ωL, called the **reactance** (from the word *reaction*) of an inductor, is symbolically represented by X_L and is measured in ohms; that is,

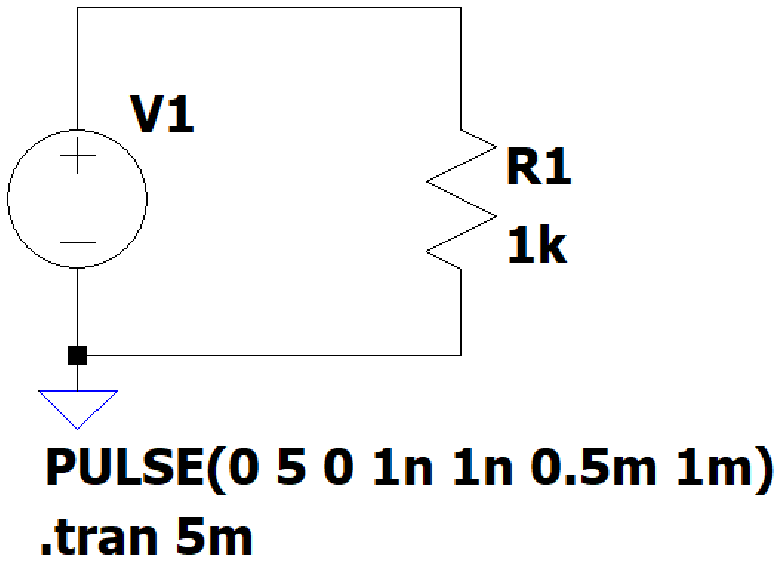
$$\boxed{X_L = \omega L} \quad (\text{ohms}, \Omega) \qquad \textbf{(14.4)}$$

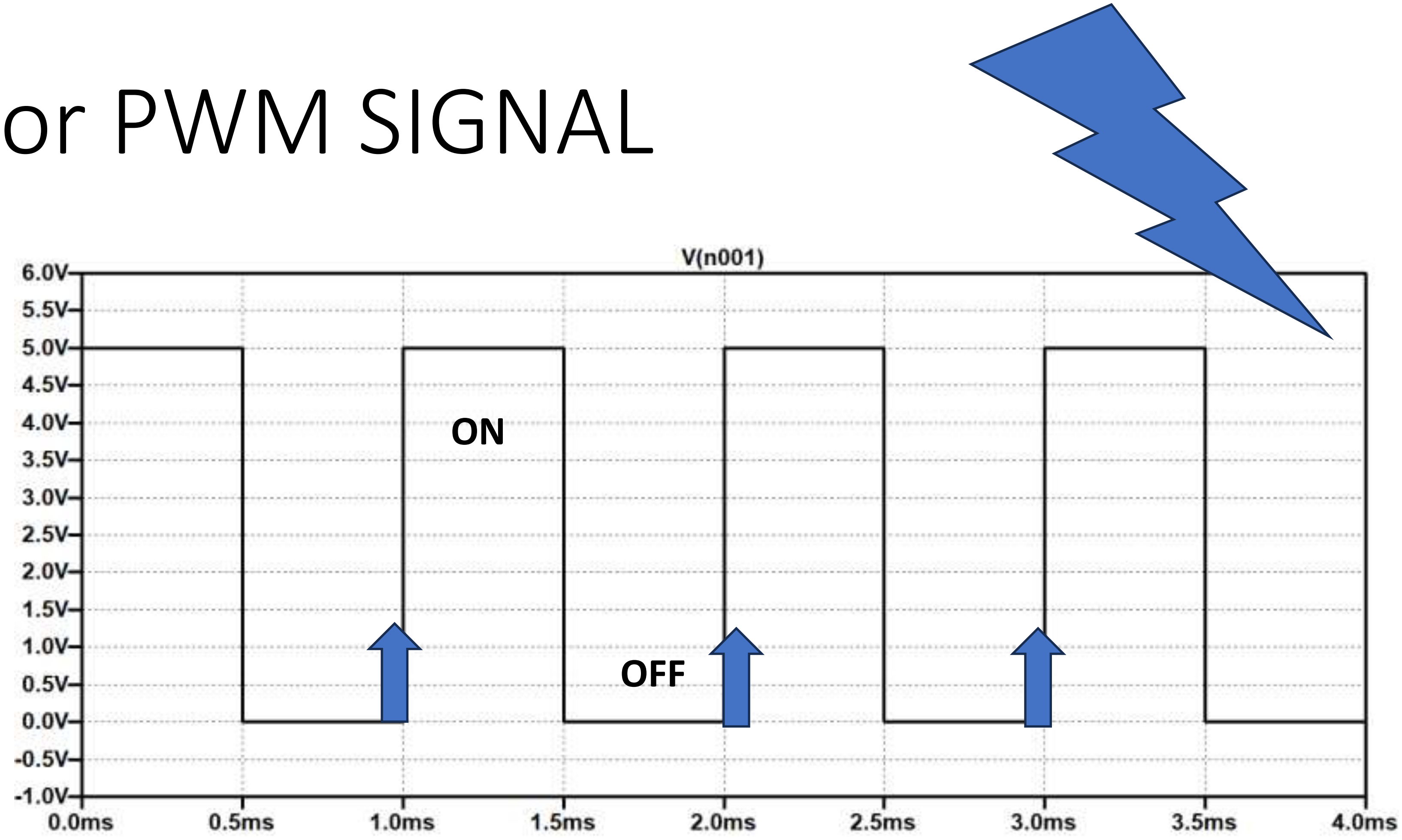
w = 2 * pi * f

at very HIGH frequencies inductor becomes OPEN circuit

at very LOW frequencies inductor becomes SHORT circuit

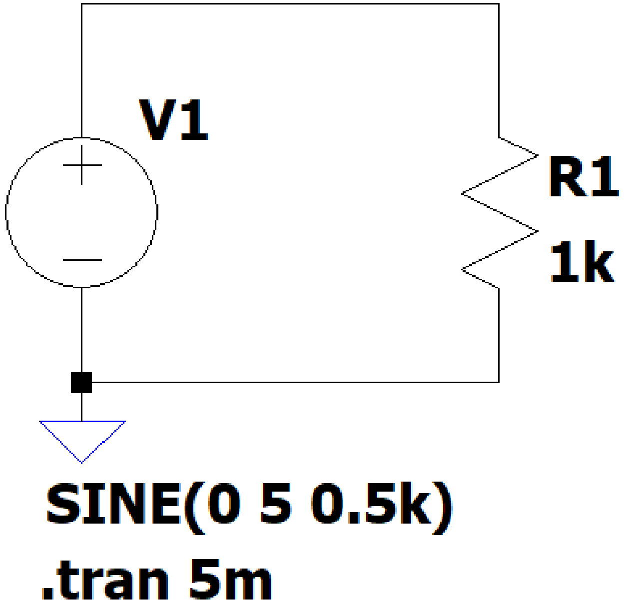
SQUARE WAVE or PWM SIGNAL

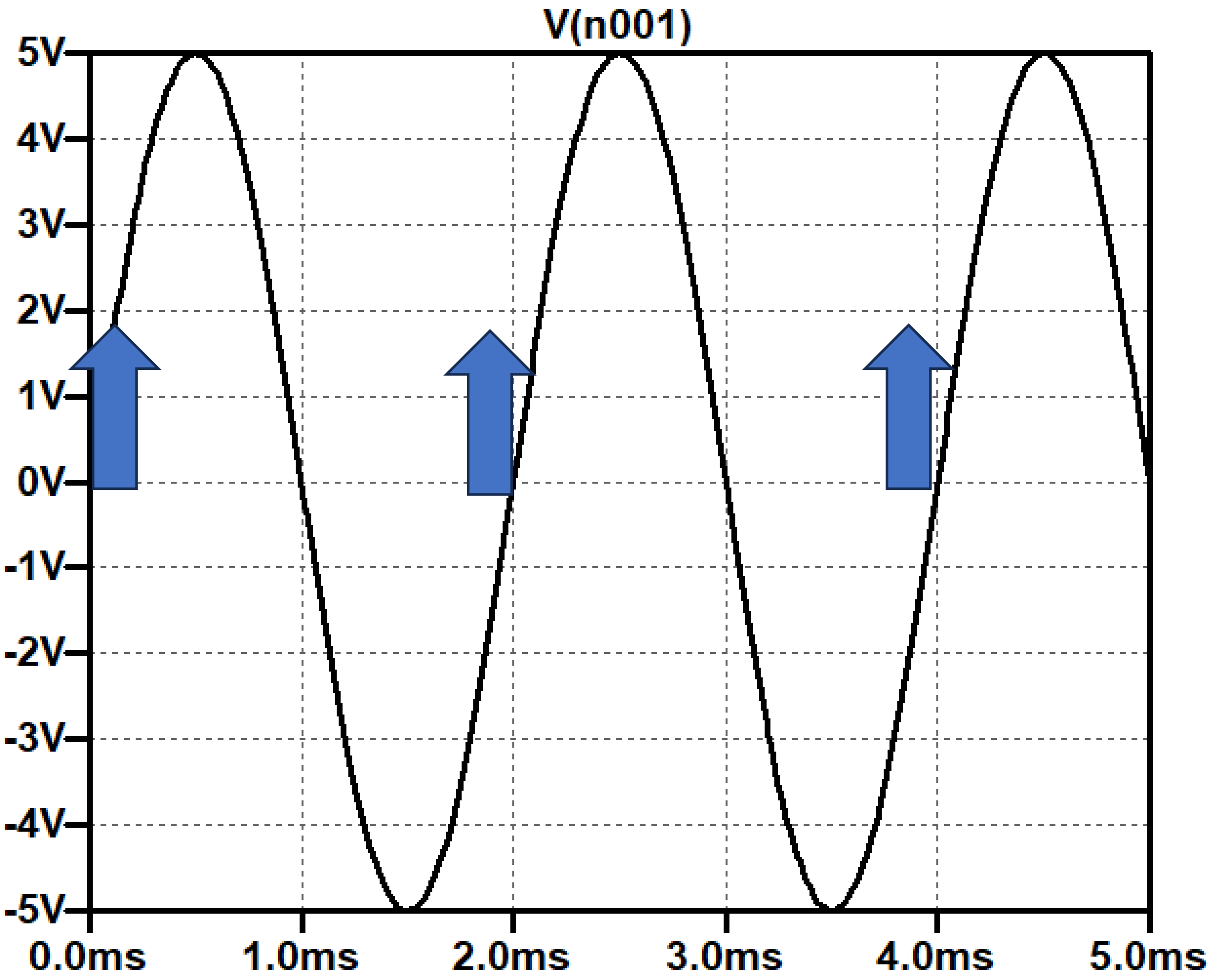




Period: calculate rising edge to rising edge T= 1.5 – 0.5 =1ms
Frequency = 1/Period = 1/1ms = 1000 Hz = 1KHz
Duty Cycle = % Ontime/Period, D=0.5ms / 1ms = 0.5 in percentage 50%

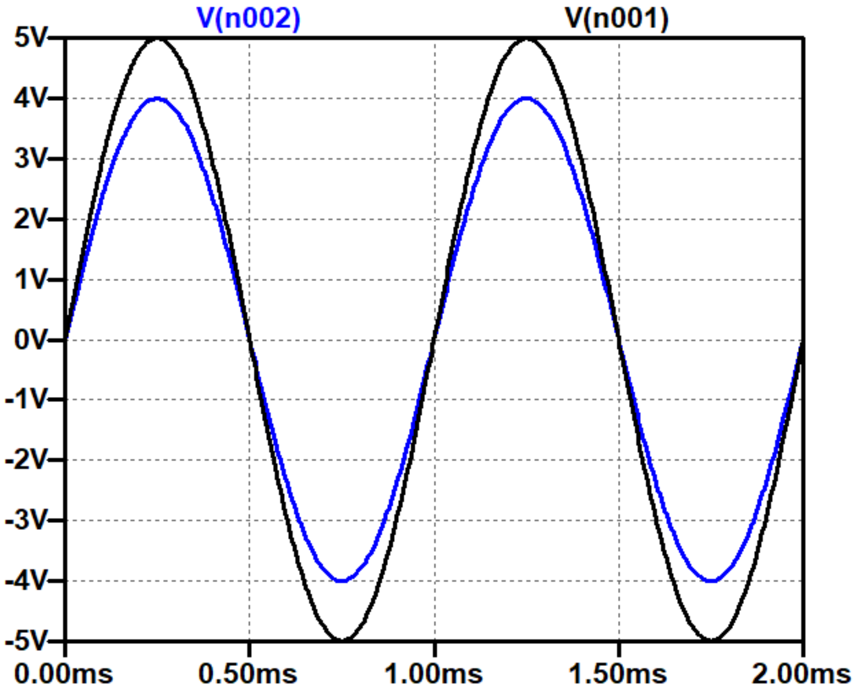
Sinusoidal



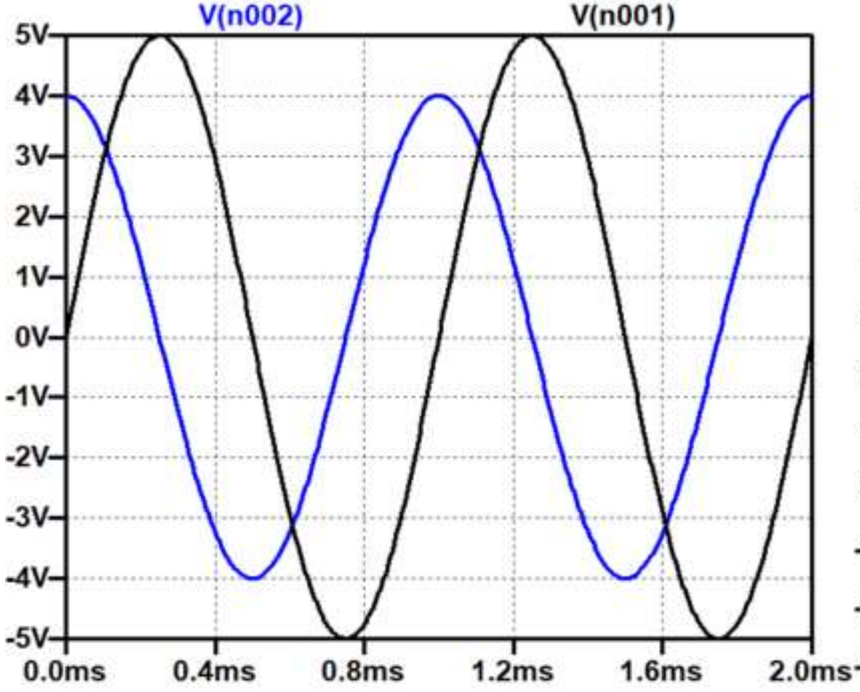


Period : rising edge to rising edge = T = 4-2 = 2ms,
Frequency F = 1/Period = 1/2ms = 500 Hz = 0.5 KHz
Amplitude, Peak 5V
Peak-to-Peak = 10V

Sinusoidal-Phase-Difference

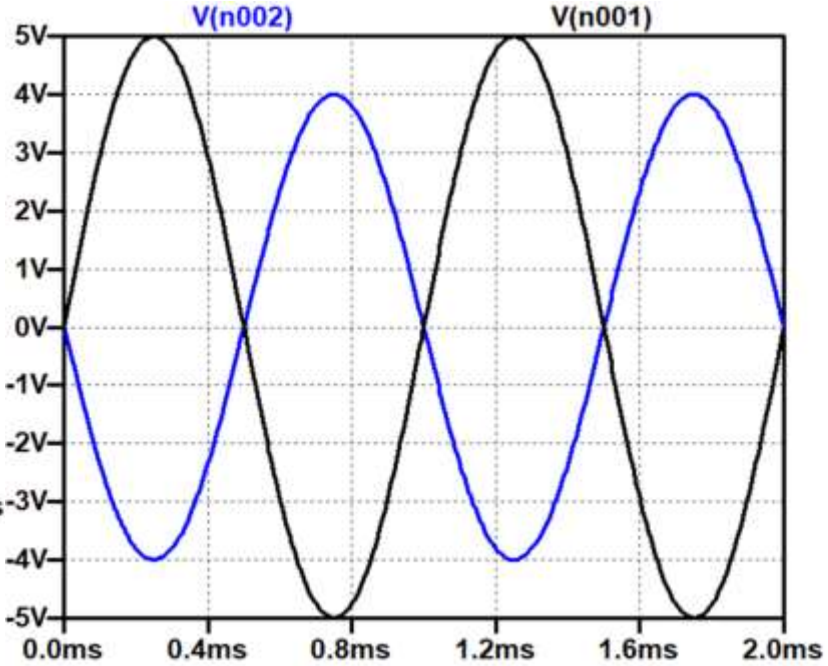


Phase Difference = 0 deg
V1=5*sin(wt)
V2=4*sin(wt)



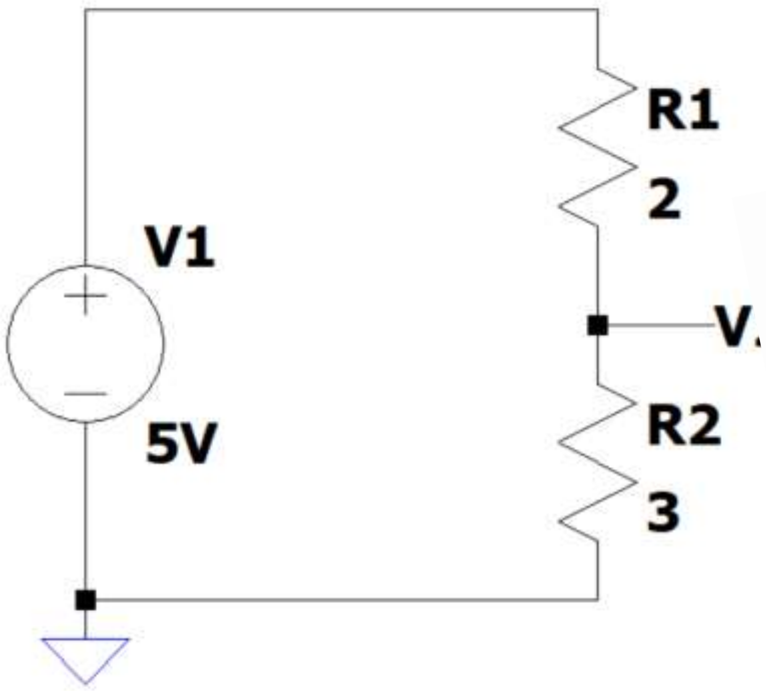
Phase Difference = 90 deg
V1=5*sin(wt)
V2=4*sin(wt + 90deg)

Dt/T=Phase/360



Phase Difference = 180 deg
V1=5*sin(wt)
V2=4*sin(wt + 180deg)

Voltage Divider



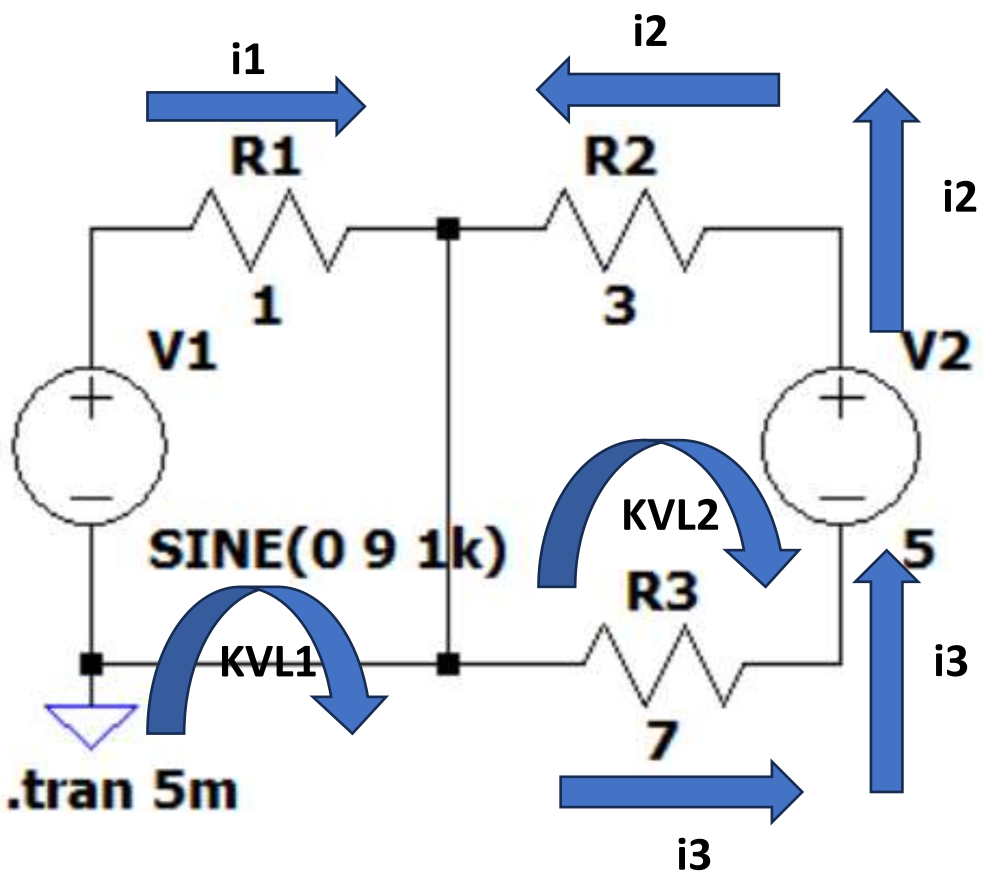
V2= V1 * R2 / (R2 + R1)

ex1:
V2 = 5 * 3 / (3+2) = 3V

ex2: R1+R2 = 500
to have V2=3V calculate R2 ?

V2 = V1 * R2 / (R2+R1)
3 = 5 * R2 / 500
R2 = 300 ohm
remember that R1+R2=500 ohm
so R1 =200 ohm

KVL vs Superposition



V1= 9sin(wt), V2=5V,
calculate i1 and i2 ?

KVL1
-9sin(wt) +i1.1 = 0
i1= 9*sin(wt) AC ampere

KVL2:
i2=i3
-i2*3 + 5 –i2*7 = 0
-10*i2 + 5 = 0
i2 = 5/10 = 0.5A = 500mA   DC

- **1.** RESISTOR COLOR CODE, TOLERANCE
- **2.** OHM'S LAW
- **3.** VERIFICATION OF KVL AND KCL
- **4.** MESH ANALYSIS
- **5.** NODAL ANALYSIS
- **6. SUPERPOSITION & THEVENIN'S THEOREMS**
- **7. NETWORK THEOREMS**
- **8. AVERAGE AND RMS VALUES**
- **9. NETWORK THEOREMS WITH AC**
- 10. INVERTING OPERATIONAL AMPLIFIER CIRCUITS
- 11. SUMMING AMPLIFIER CIRCUIT
- 12. DIFFERENTIATOR/INTEGRATOR AMPLIFIER CIRCUIT
- 13. DIFFERENTIATOR/INTEGRATOR AMPLIFIER CIRCUIT

12.10.2023	19.10.2023	26.10.2023	2.11.2023	MIDTERM	16.11.2023	23.11.2023	30.11.2023	7.11.2023
GROUP 1, 2, 3, 4, 5	GROUP 6, 7, 8, 9, 10	GROUP 1, 2, 3, 4, 5	GROUP 6, 7, 8, 9, 10		GROUP 1, 2, 3, 4, 5	GROUP 6, 7, 8, 9, 10	GROUP 1, 2, 3, 4, 5	GROUP 6, 7, 8, 9, 10
EXP. 1, 2	EXP. 1, 2	EXP. 3, 4	EXP. 3, 4		EXP. 5, 6	EXP. 5, 6	EXP. 7, 8	EXP. 7, 8