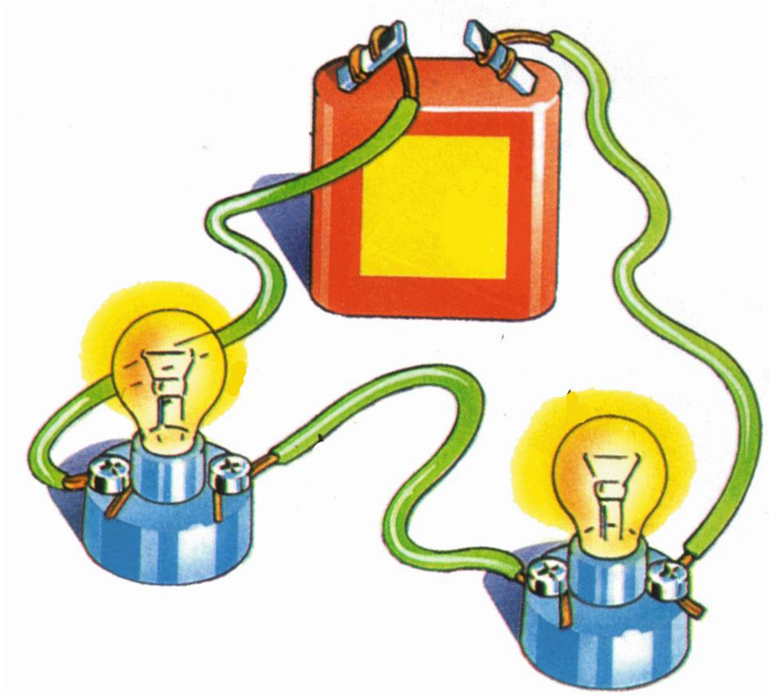
Types of Electrical Circuits

1) ***Series circuits***
2) ***Parallel circuits***
3) ***Series-Parallel circuits***

Series dc Circuits



Life isn't about finding yourself. Life is about creating yourself

> A **branch** represents a single element such as a voltage source or a resistor.

In other words, a branch represents any two-terminal element. The circuit in Fig. 2.10 has five branches, namely, the 10-V voltage source the 2-A current source, and the three resistors.

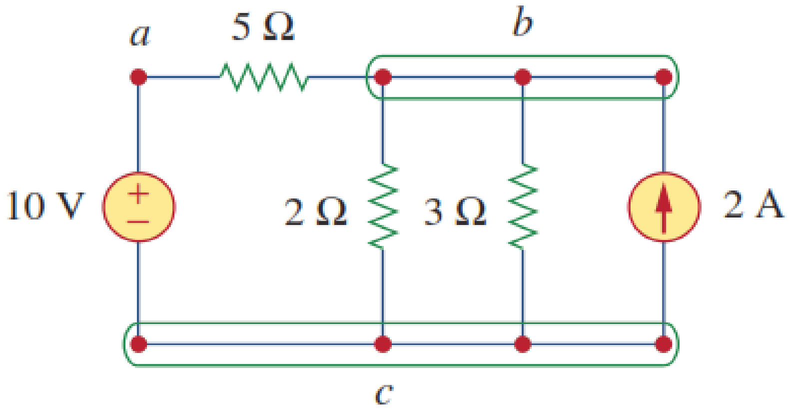


Figure 2.10
Nodes, branches, and loops.

> A **node** is the point of connection between two or more branches.

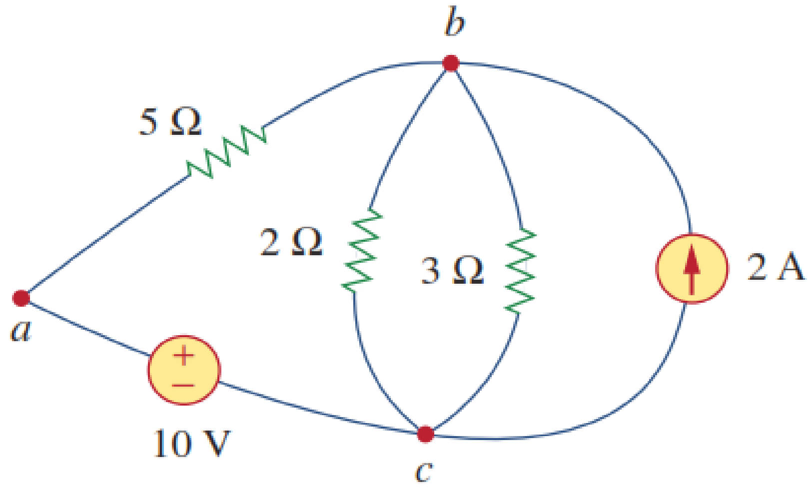


Figure 2.11
The three-node circuit of Fig. 2.10 is redrawn.

> A **loop** is any closed path in a circuit.

A loop is a closed path formed by starting at a node, passing through a set of nodes, and returning to the starting node without passing through any node more than once. A loop is said to be *independent* if it contains

Two or more elements are in **series** if they exclusively share a single node and consequently carry the same current.

Two or more elements are in **parallel** if they are connected to the same two nodes and consequently have the same voltage across them.

Determine the number of branches and nodes in the circuit shown in Fig. 2.12. Identify which elements are in series and which are in parallel.

Solution:

Since there are four elements in the circuit, the circuit has four branches: 10 V, 5 Ω, 6 Ω, and 2 A. The circuit has three nodes as identified in Fig. 2.13. The 5-Ω resistor is in series with the 10-V voltage source because the same current would flow in both. The 6-Ω resistor is in parallel with the 2-A current source because both are connected to the same nodes 2 and 3.

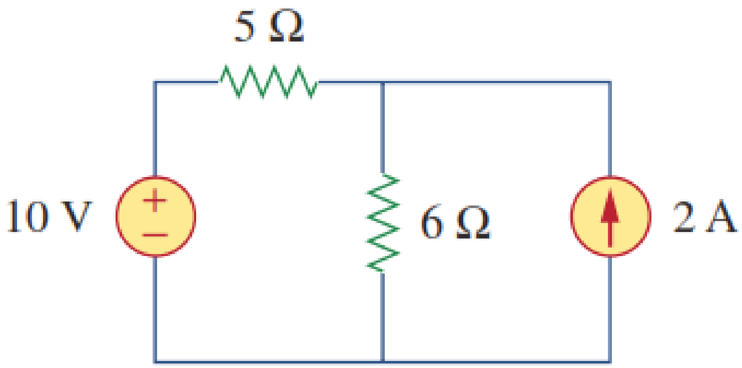


Figure 2.12
For Example 2.4.

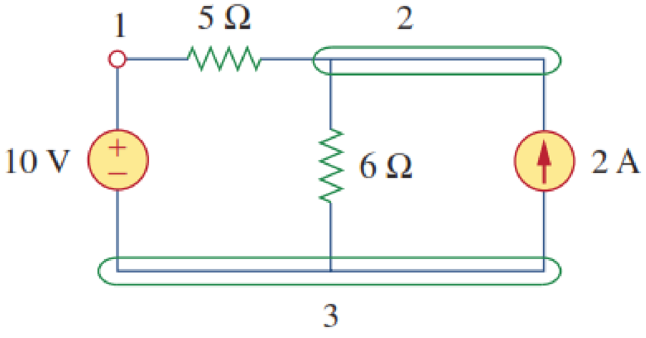


Figure 2.13
The three nodes in the circuit of Fig. 2.12.

How many branches and nodes does the circuit in Fig. 2.14 have? Identify the elements that are in series and in parallel.

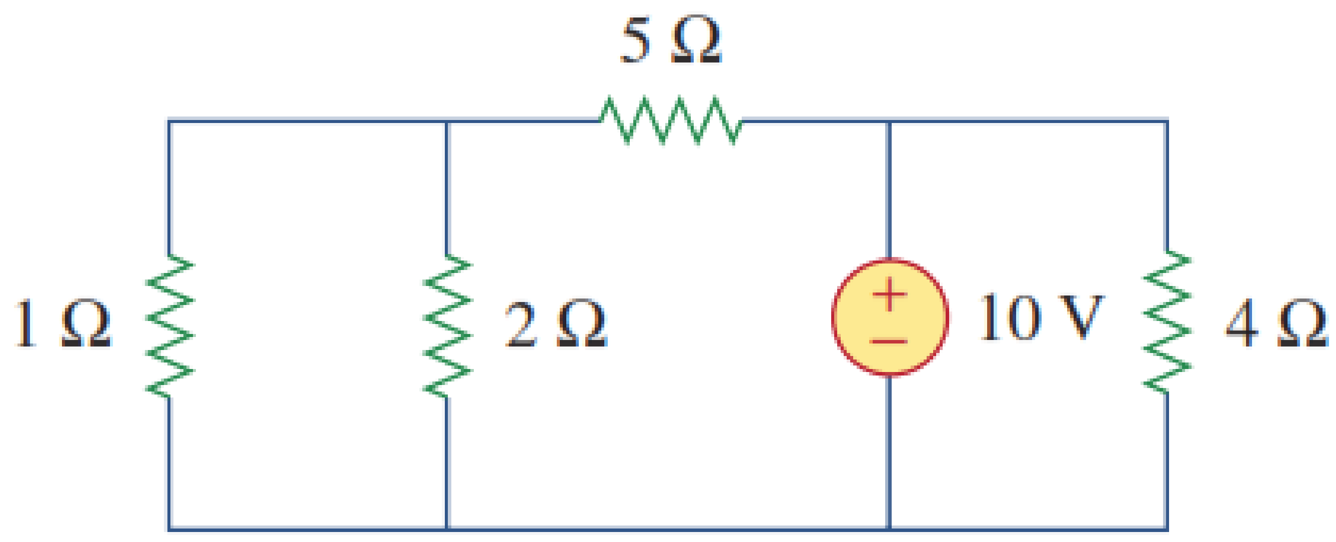


Figure 2.14
For Practice Prob. 2.4.

Answer: Five branches and three nodes are identified in Fig. 2.15. The 1-Ω and 2-Ω resistors are in parallel. The 4-Ω resistor and 10-V source are also in parallel.

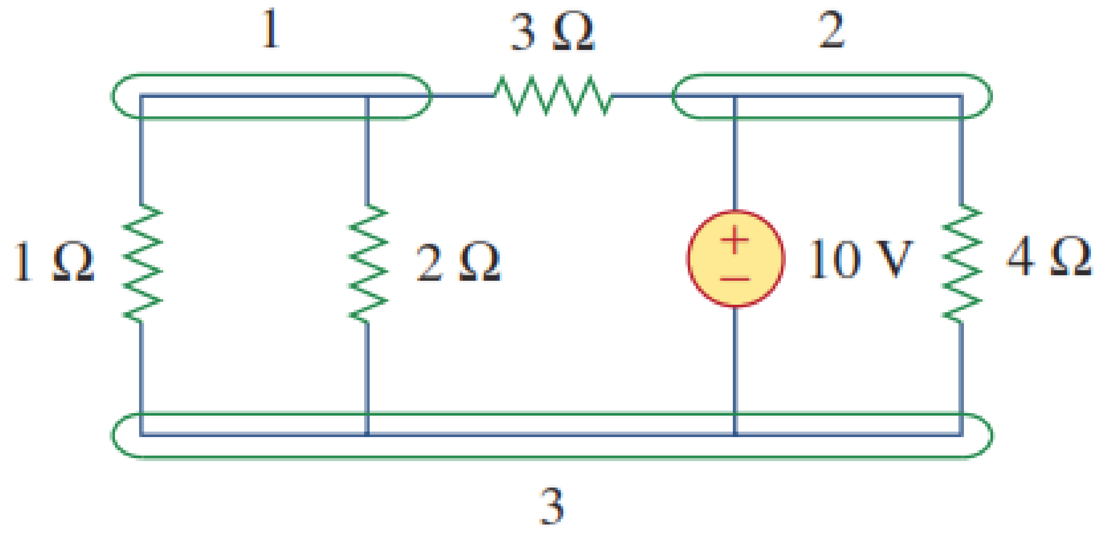


Figure 2.15
Answer for Practice Prob. 2.4.

SERIES CIRCUITS

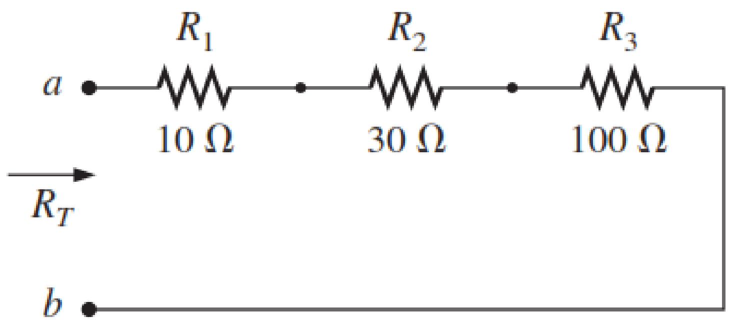


FIG. 5.4
Series connection of resistors.

the total resistance of a series configuration is the sum of the resistance levels.

In equation form for any number (N) of resistors,

$$\boxed{R_T = R_1 + R_2 + R_3 + R_4 + \cdots + R_N} \tag{5.1}$$

A result of Eq. (5.1) is that

the more resistors we add in series, the greater the resistance, no matter what their value.

Further,

the largest resistor in a series combination will have the most impact on the total resistance.

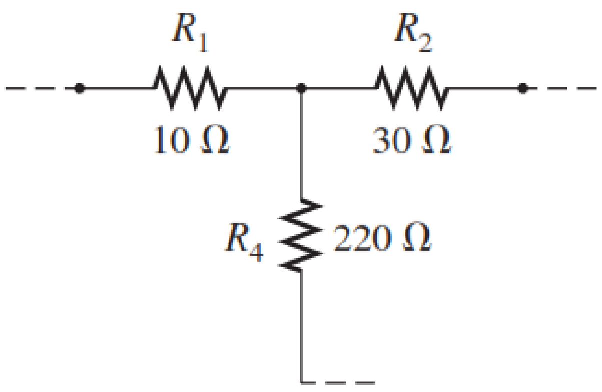


FIG. 5.5
Configuration in which none of the resistors are in series.

EXAMPLE 5.1 Determine the total resistance of the series connection in Fig. 5.6. Note that all the resistors appearing in this network are standard values.

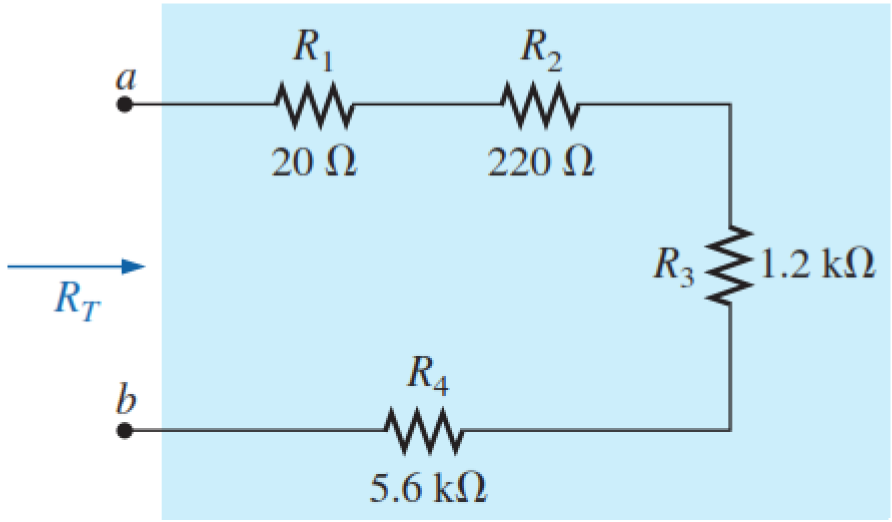


FIG. 5.6
Series connection of resistors for Example 5.1.

For the special case where resistors are the *same value,* Eq. (5.1) can be modified as follows:

$$\boxed{R_T = NR} \tag{5.2}$$

where N is the number of resistors in series of value R.

EXAMPLE 5.2 Find the total resistance of the series resistors in Fig. 5.7. Again, recognize 3.3 kΩ as a standard value.

Solution: Again, don't be concerned about the change in configuration. Neighboring resistors are connected only at one point, satisfying the definition of series elements.

Eq. (5.2): $\quad R_T = NR$

$$= (4)(3.3\ \text{k}\Omega) = \mathbf{13.2\ k\Omega}$$

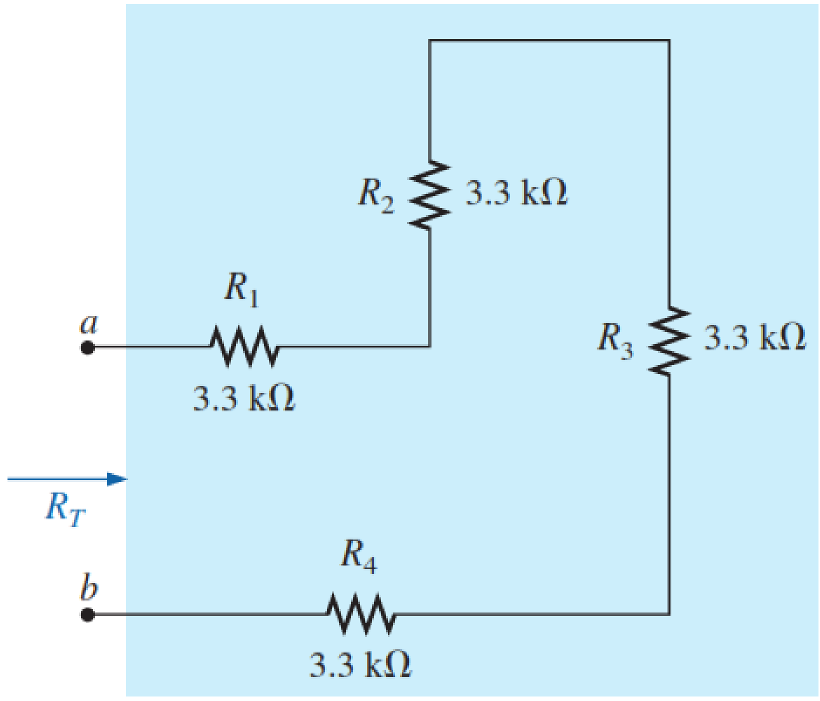
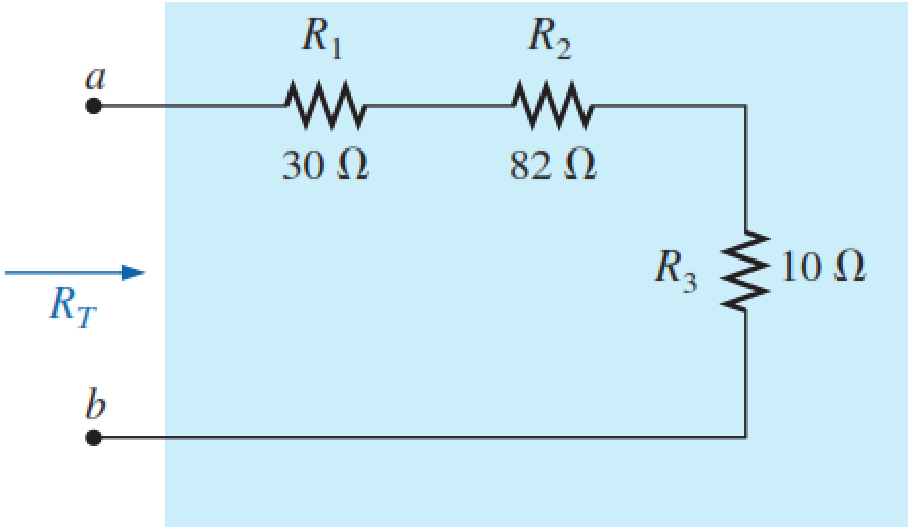


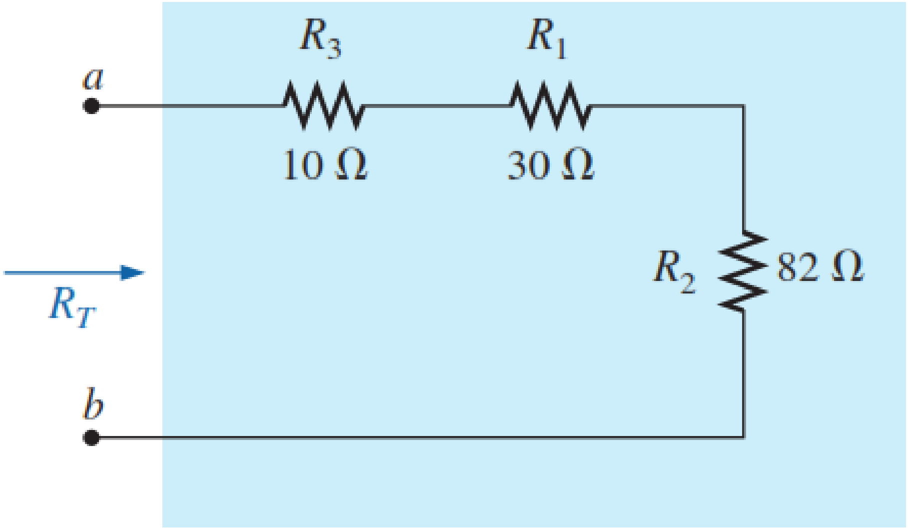
FIG. 5.7
Series connection of four resistors of the same value (Example 5.2).

It is important to realize that since the parameters of Eq. (5.1) can be put in any order,

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



(a)



(b)

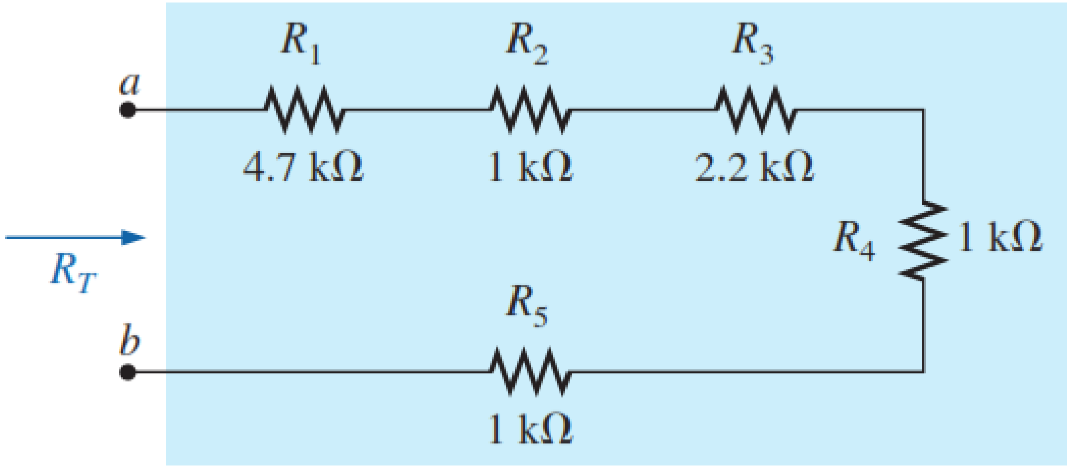


FIG. 5.9
Series combination of resistors for Example 5.3.

EXAMPLE 5.3 Determine the total resistance for the series resistors (standard values) in Fig. 5.9.

Solution: First, the order of the resistors is changed as shown in Fig. 5.10 to permit the use of Eq. (5.2). The total resistance is then

$$R_T = R_1 + R_3 + NR_2$$
$$= 4.7\ \text{k}\Omega + 2.2\ \text{k}\Omega + (3)(1\ \text{k}\Omega) = \mathbf{9.9\ k\Omega}$$

The total resistance of any configuration can be measured by simply connecting an ohmmeter across the access terminals as shown in Fig. 5.11 for the circuit in Fig. 5.4. *Since there is no polarity associated with resistance,* either lead can be connected to point *a,* with the other lead connected to point *b.* Choose a scale that will exceed the total resistance of the circuit,

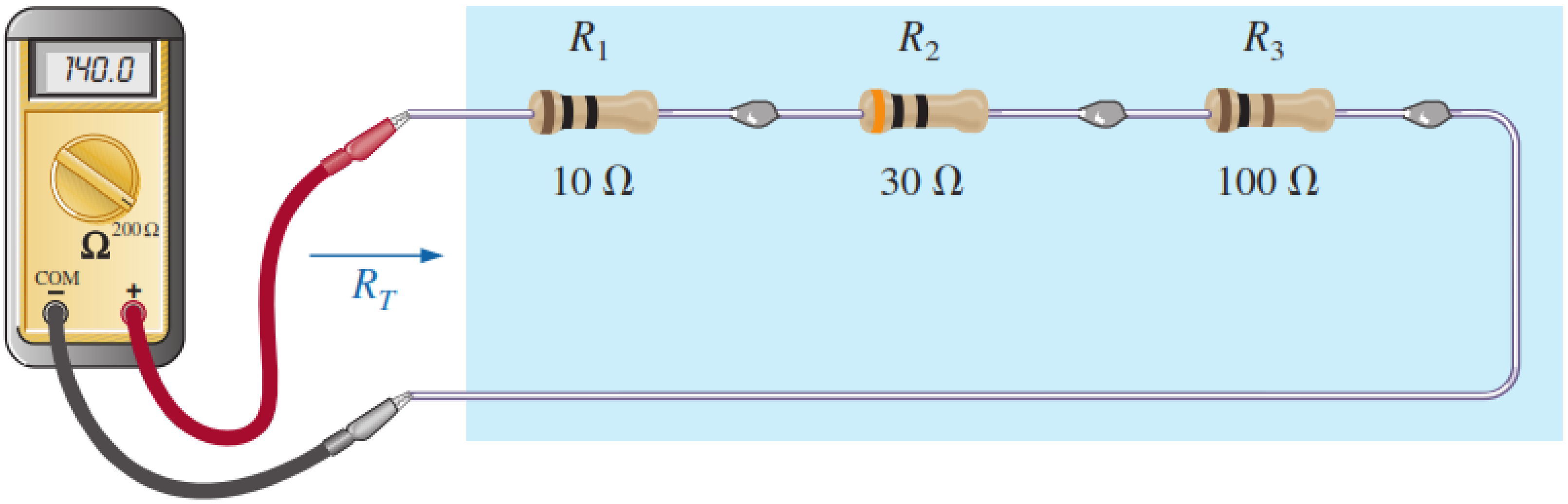


FIG. 5.11

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


SIGMA 33A TRMS
DIGITAL MULTIMETER
AUTO
DC
0.000
V
Hz/DUTY
SELECT
RANGE
REL
HOLD
AUTO
POWER
OFF
Ω
hFE
Hz
℃/℉
µA
mA
A
OFF
V
V~
mV
OFF
TRUE RMS
hFE
10A
mA
COM
VΩHz
TEMP
MAX
400mA
FUSED
10sec MAX
10A
FUSED
CAT Ⅳ 600V
MAX
1000V DC
750V AC


AUTO
POWER
OFF
OFF
mV
V~
V
Ω
Hz
hFE
°C/°F
µA
mA
A
OFF


TRUE RMS
hFE
10A
mA
COM
VΩHz
TEMP
10sec MAX
10A
FUSED
MAX
400mA
FUSED
CAT IV 600V
MAX
1000V DC
750V AC

DC POWER SUPPLY HY3005F-3
5.00
AMP
30.0
VOLT
5.00
AMP
30.0
VOLT
CURRENT
VOLTAGE
CURRENT
VOLTAGE
SERIES
CC
CV
CC
CV
CE
SLAVE
TRACKING
MASTER
ON
OFF
FIXED 3A
POWER

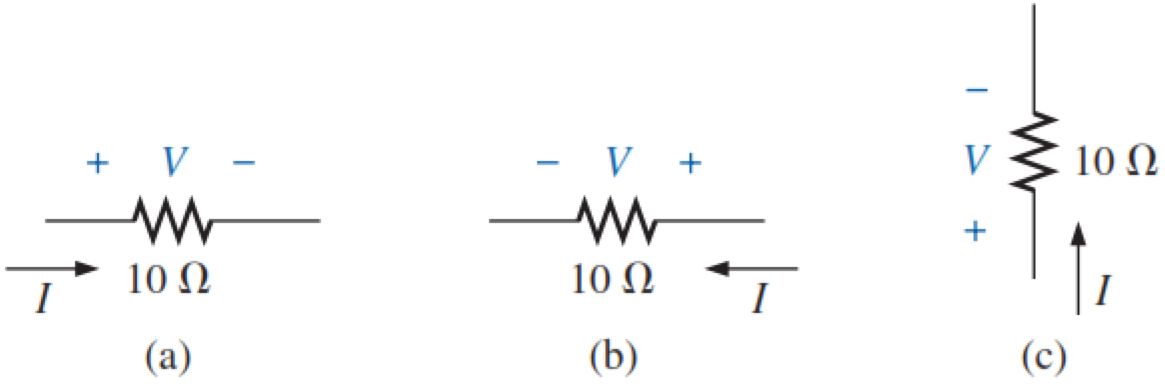


FIG. 5.14
Inserting the polarities across a resistor as determined by the direction of the current.

EXAMPLE 5.4 For the series circuit in Fig. 5.15:

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

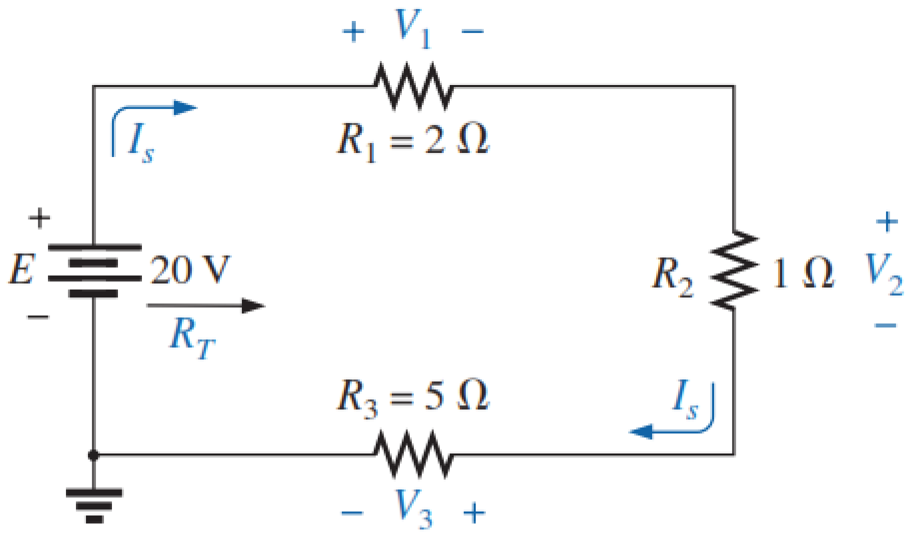


FIG. 5.15
Series circuit to be investigated in Example 5.4.

Solutions:

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

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

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

EXAMPLE 5.6 Given R_T and I_3, calculate R_1 and E for the circuit in Fig. 5.18.

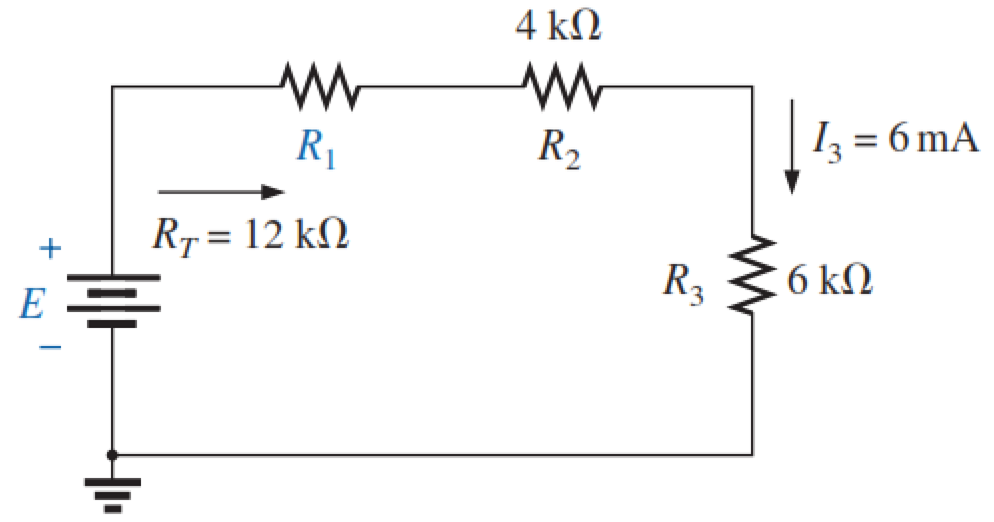


FIG. 5.18
Series circuit to be analyzed in Example 5.6.

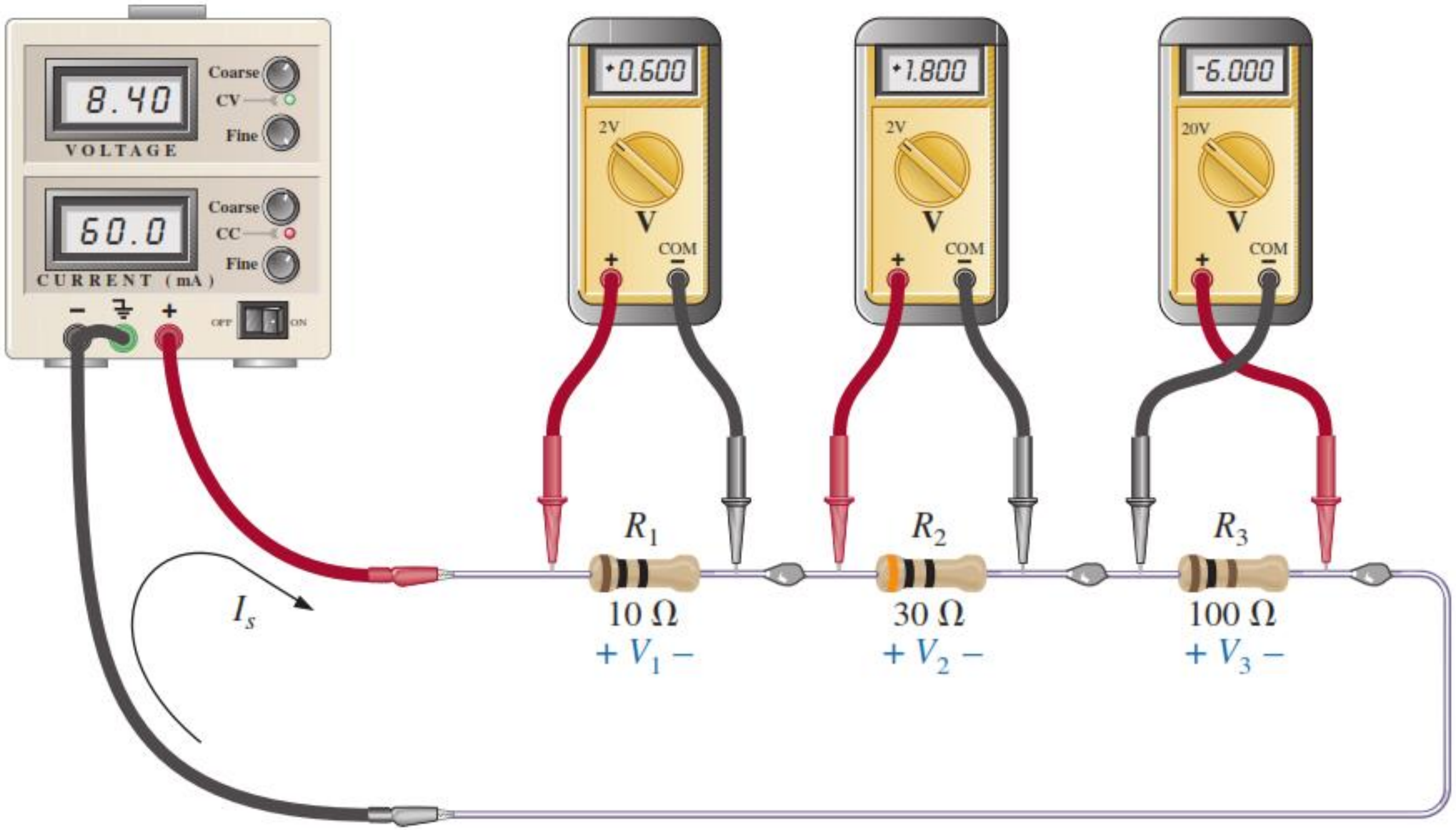


FIG. 5.19

Further, it is particularly helpful in the laboratory to realize that

the voltages of a circuit can be measured without disturbing (breaking the connections in) the circuit.

using an ammeter to measure the current of a circuit requires that the circuit be broken at some point and the meter inserted in series with the branch in which the current is to be determined.

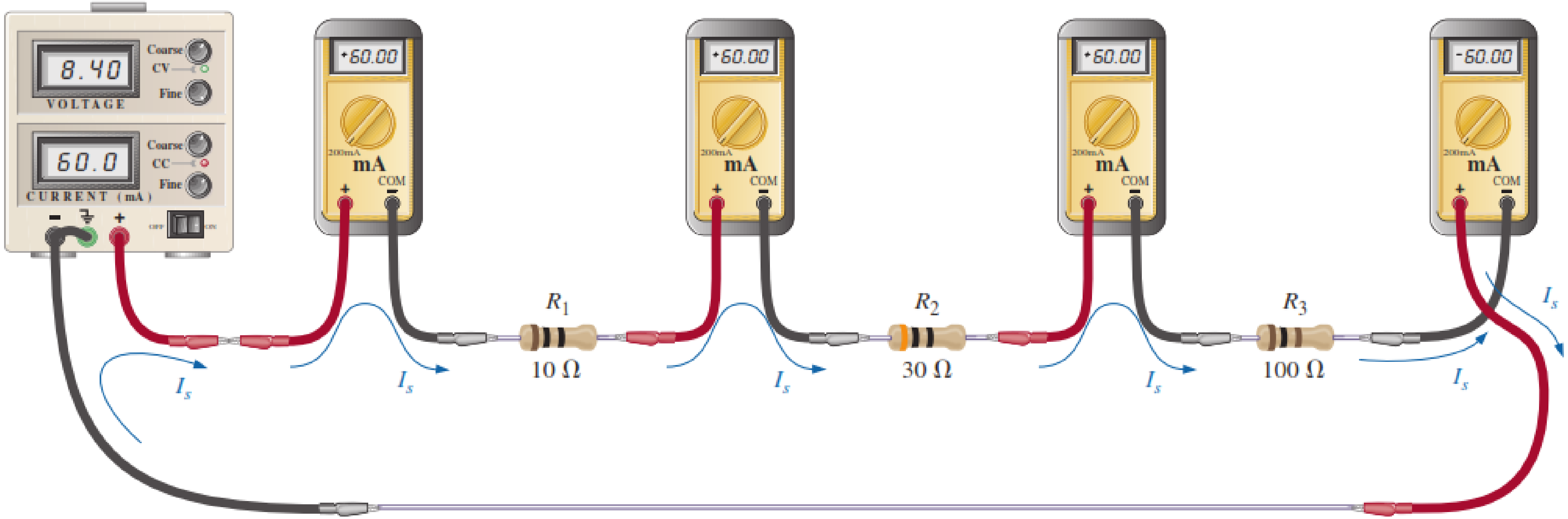


FIG. 5.20

Measuring the current throughout the series circuit in Fig. 5.12.

For instance, to measure the current leaving the positive terminal of the supply, the connection to the positive terminal must be removed to create an open circuit between the supply and resistor R_1. The ammeter is then inserted between these two points to form a bridge between the supply and the first resistor, as shown in Fig. 5.20. The ammeter is now in series

The power delivered by the supply can be determined using

$$\boxed{P_E = EI_s} \qquad \text{(watts, W)} \tag{5.6}$$

The power dissipated by the resistive elements can be determined by any of the following forms (shown for resistor R_1 only):

$$\boxed{P_1 = V_1 I_1 = I_1^2 R_1 = \frac{V_1^2}{R_1}} \qquad \text{(watts, W)} \tag{5.7}$$

Since the current is the same through series elements, you will find in the following examples that

in a series configuration, maximum power is delivered to the largest resistor.

EXAMPLE 5.7 For the series circuit in Fig. 5.22 (all standard values):

a. Determine the total resistance R_T.
b. Calculate the current I_s.
c. Determine the voltage across each resistor.
d. Find the power supplied by the battery.
e. Determine the power dissipated by each resistor.
f. Comment on whether the total power supplied equals the total power dissipated.

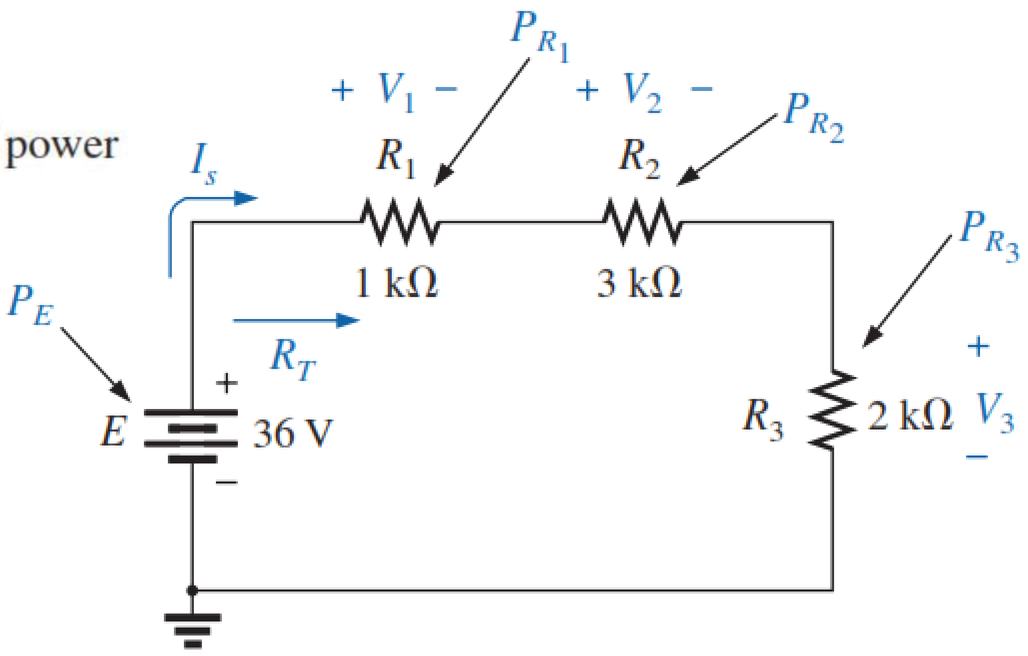


FIG. 5.22
Series circuit to be investigated in Example 5.7.

Solutions:

a. $R_T = R_1 + R_2 + R_3$
$= 1\text{ k}\Omega + 3\text{ k}\Omega + 2\text{ k}\Omega$
$R_T = \mathbf{6\text{ k}\Omega}$

b. $I_s = \dfrac{E}{R_T} = \dfrac{36\text{ V}}{6\text{ k}\Omega} = \mathbf{6\text{ mA}}$

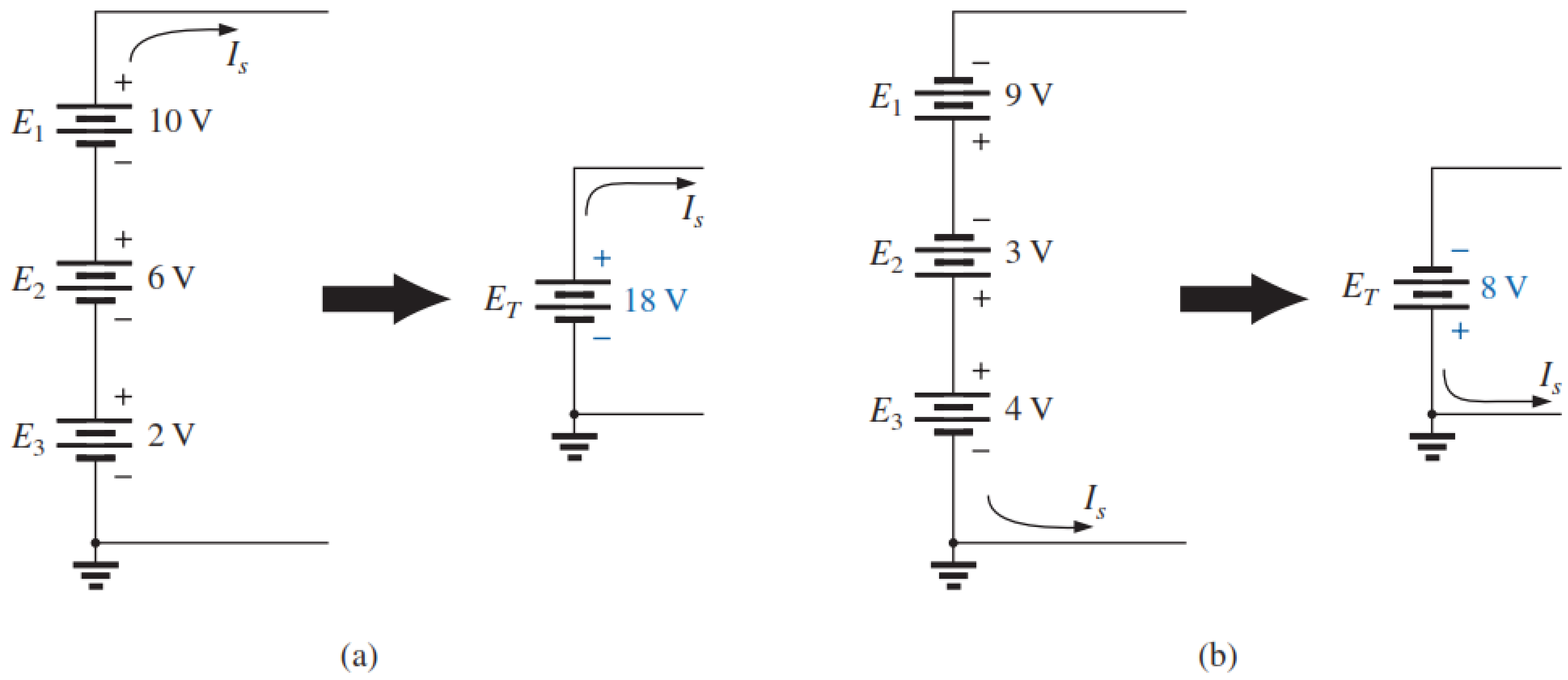
c. $V_1 = I_1R_1 = I_sR_1 = (6\text{ mA})(1\text{ k}\Omega) = \mathbf{6\text{ V}}$
$V_2 = I_2R_2 = I_sR_2 = (6\text{ mA})(3\text{ k}\Omega) = \mathbf{18\text{ V}}$
$V_3 = I_3R_3 = I_sR_3 = (6\text{ mA})(2\text{ k}\Omega) = \mathbf{12\text{ V}}$

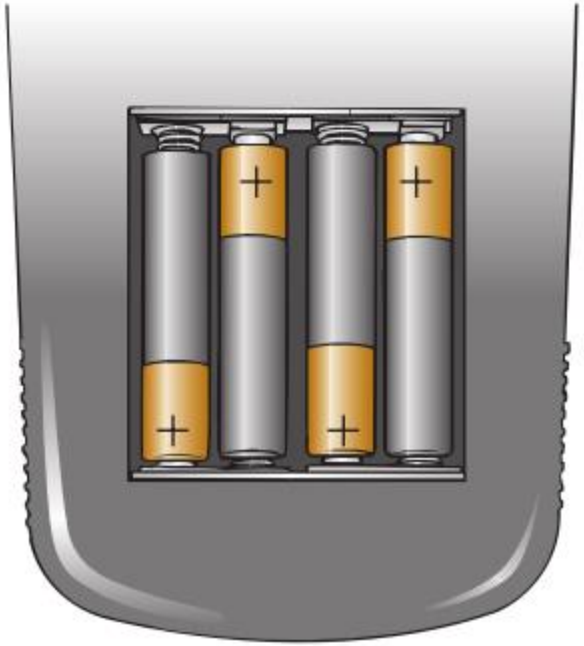
d. $P_E = EI_s = (36\text{ V})(6\text{ mA}) = \mathbf{216\text{ mW}}$

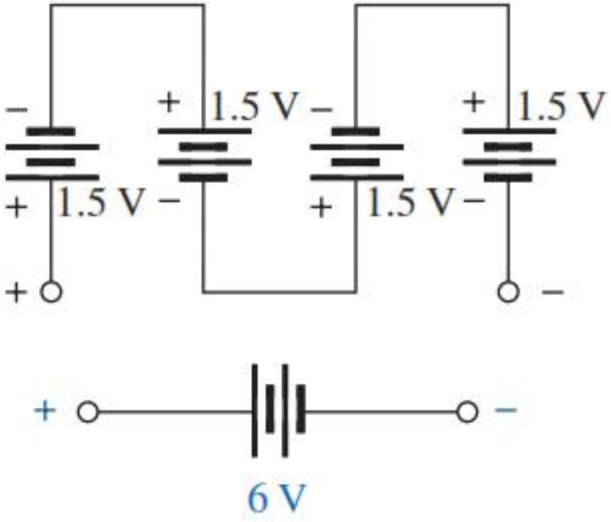
e. $P_1 = V_1I_1 = (6\text{ V})(6\text{ mA}) = \mathbf{36\text{ mW}}$
$P_2 = I_2^2R_2 = (6\text{ mA})^2(3\text{ k}\Omega) = \mathbf{108\text{ mW}}$
$P_3 = \dfrac{V_3^2}{R_3} = \dfrac{(12\text{ V})^2}{2\text{ k}\Omega} = \mathbf{72\text{ mW}}$

f. $P_E = P_{R_1} + P_{R_2} + P_{R_3}$
$216\text{ mW} = 36\text{ mW} + 108\text{ mW} + 72\text{ mW} = \mathbf{216\text{ mW}}$ (checks)

5.5 VOLTAGE SOURCES IN SERIES







1.5 V
1.5 V
1.5 V
1.5 V
6 V

5.12 PROTOBOARDS (BREADBOARDS)

At some point in the design of any electrical/electronic system, a prototype must be built and tested. One of the most effective ways to build a testing model is to use the **protoboard** (in the past most commonly called a **breadboard**)

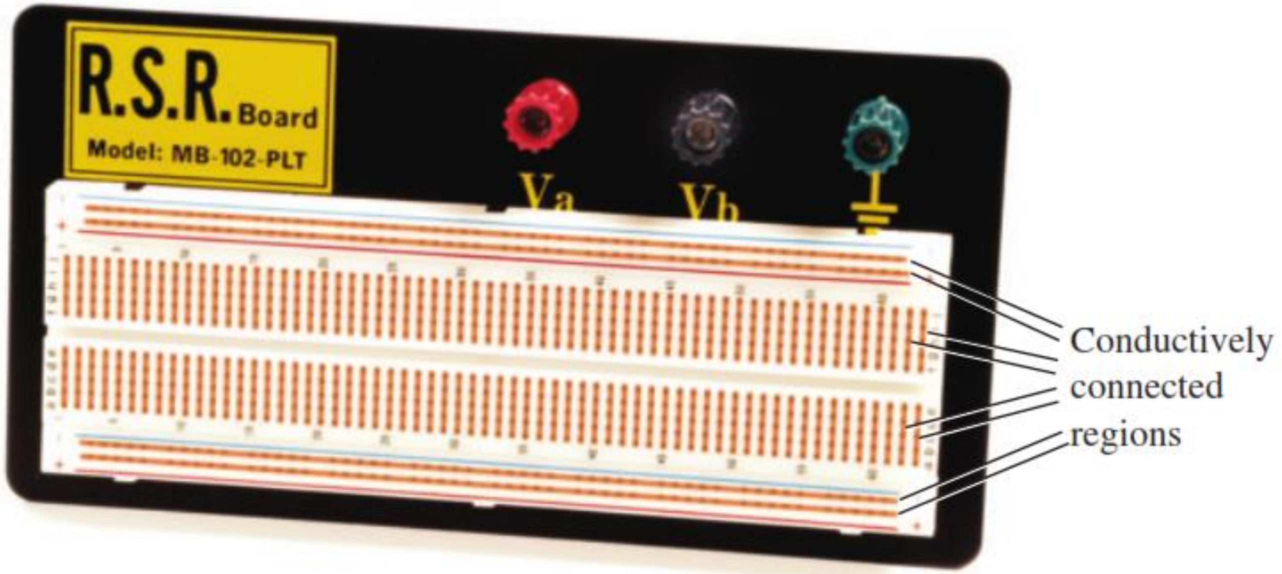
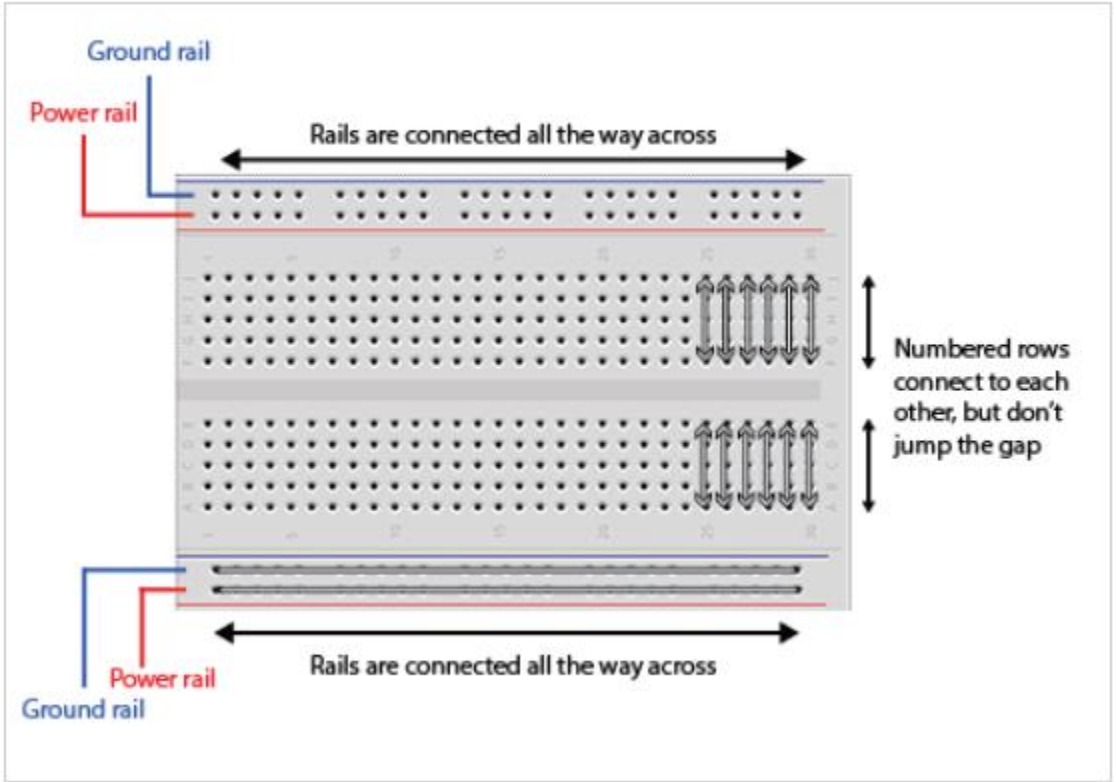
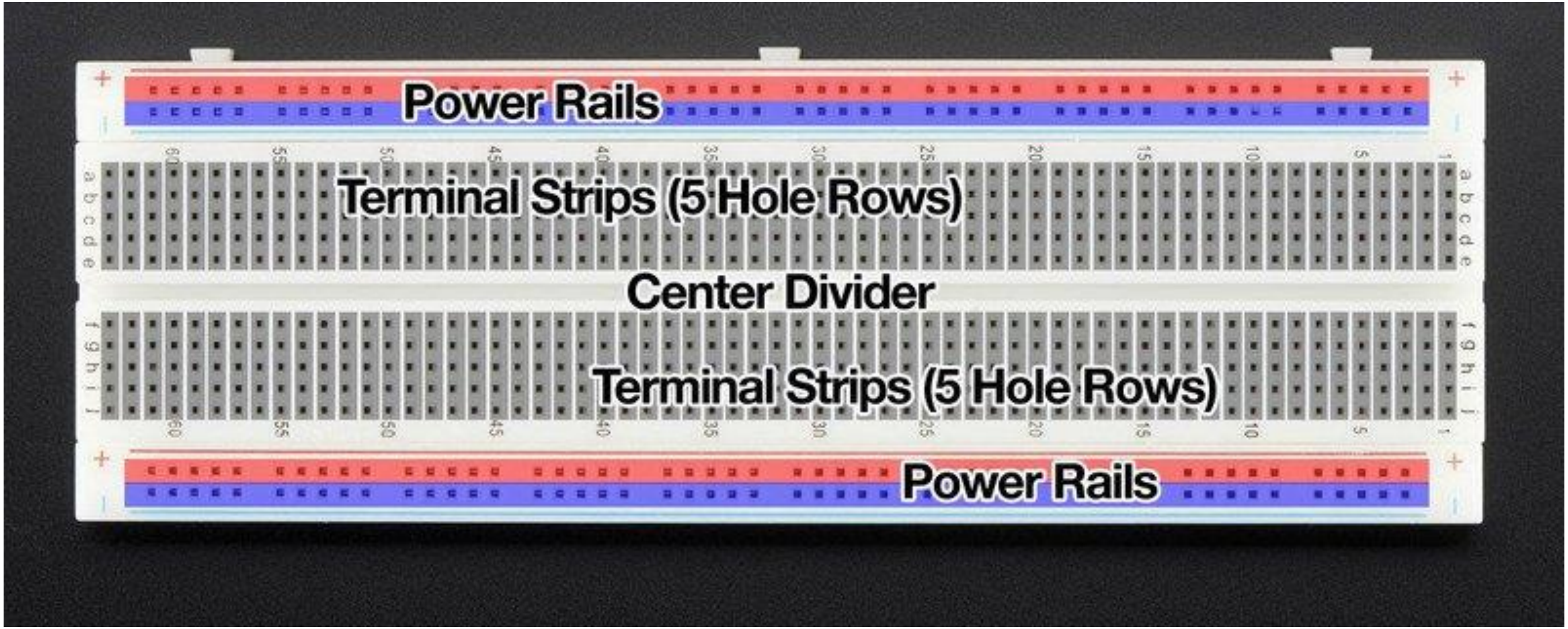
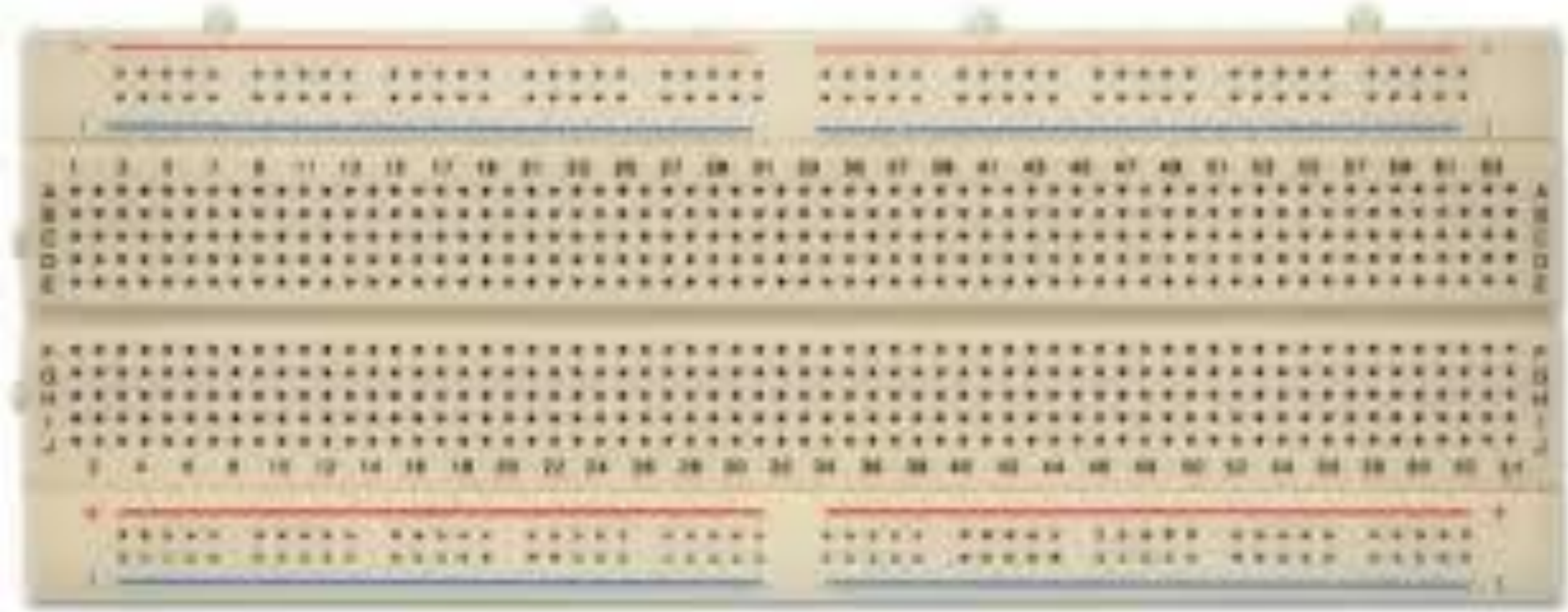


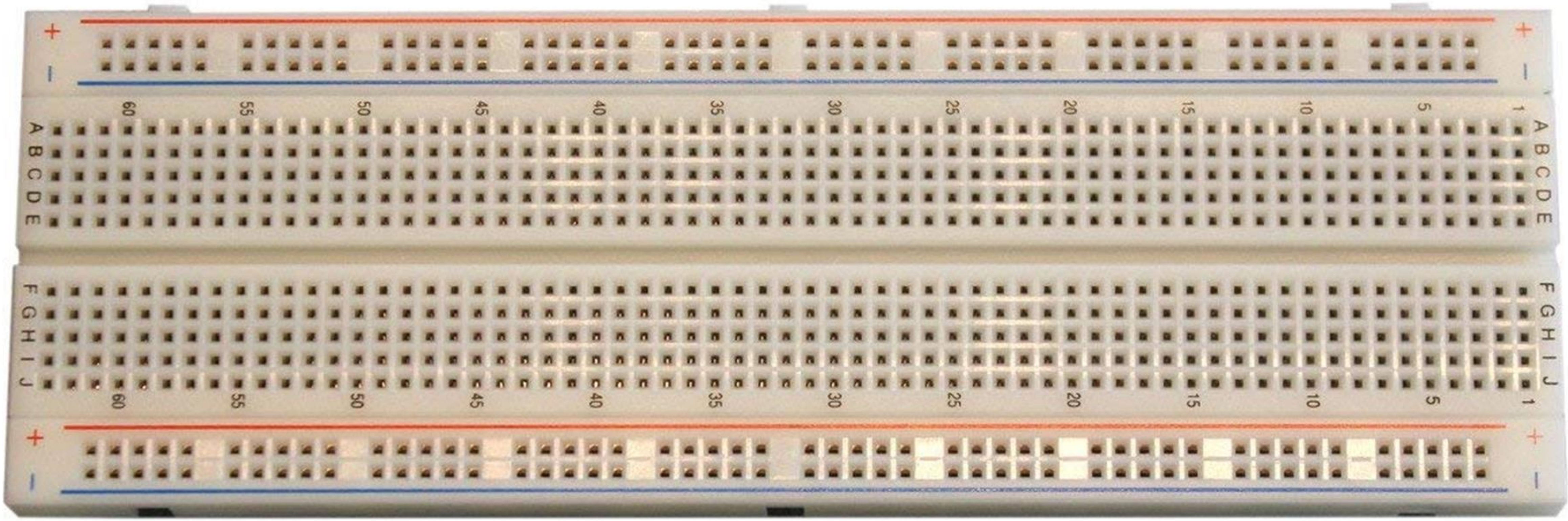
FIG. 5.75
Protoboard with areas of conductivity defined using two different approaches.

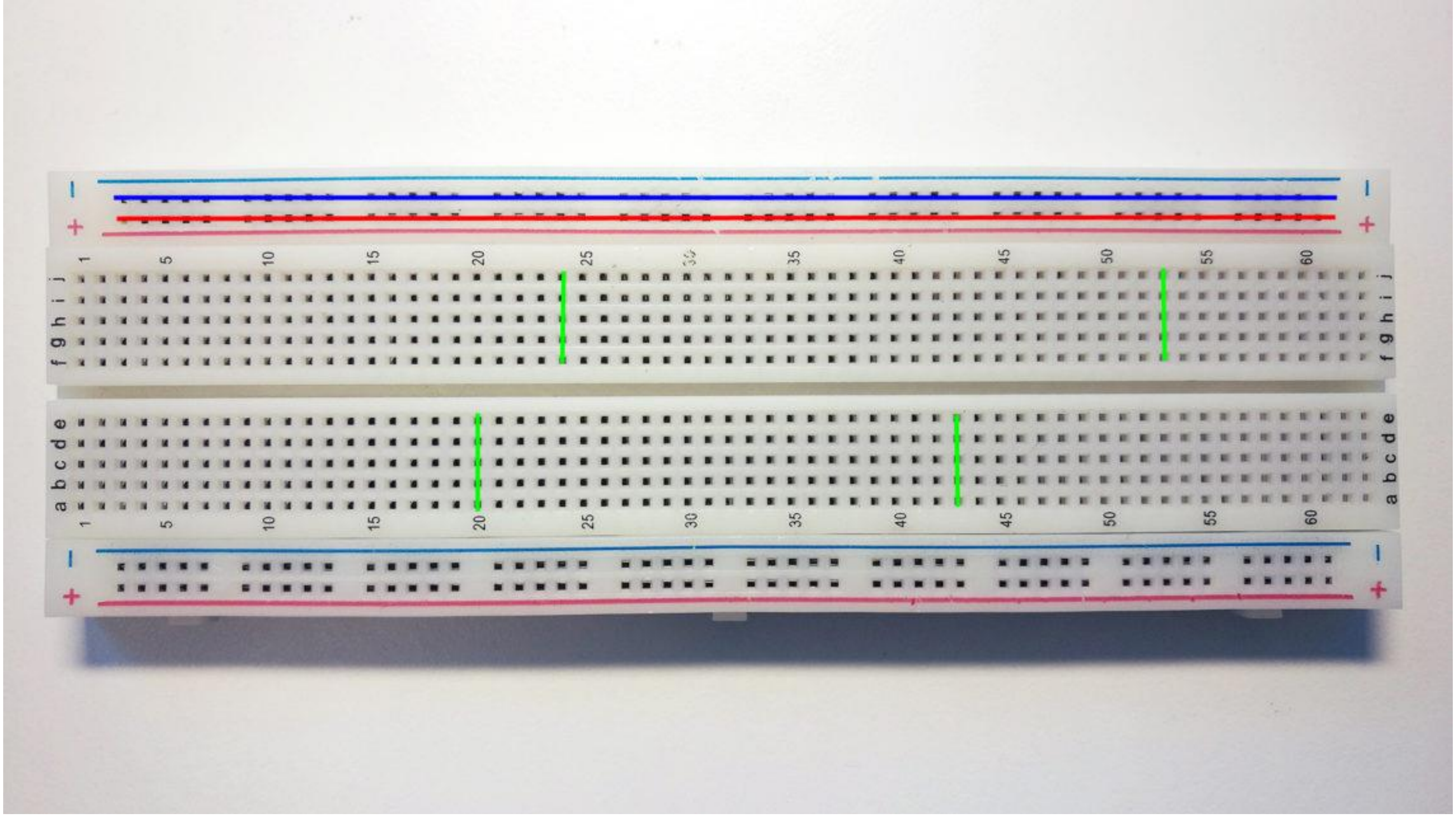
There are also things called **rails**, or **power rails**. They don't automatically come with power on them, though! Since you use power all of the time all over your board, they provide a single long row that you can provide electricity to. If you ever need power or a ground - just plug it into those rows.

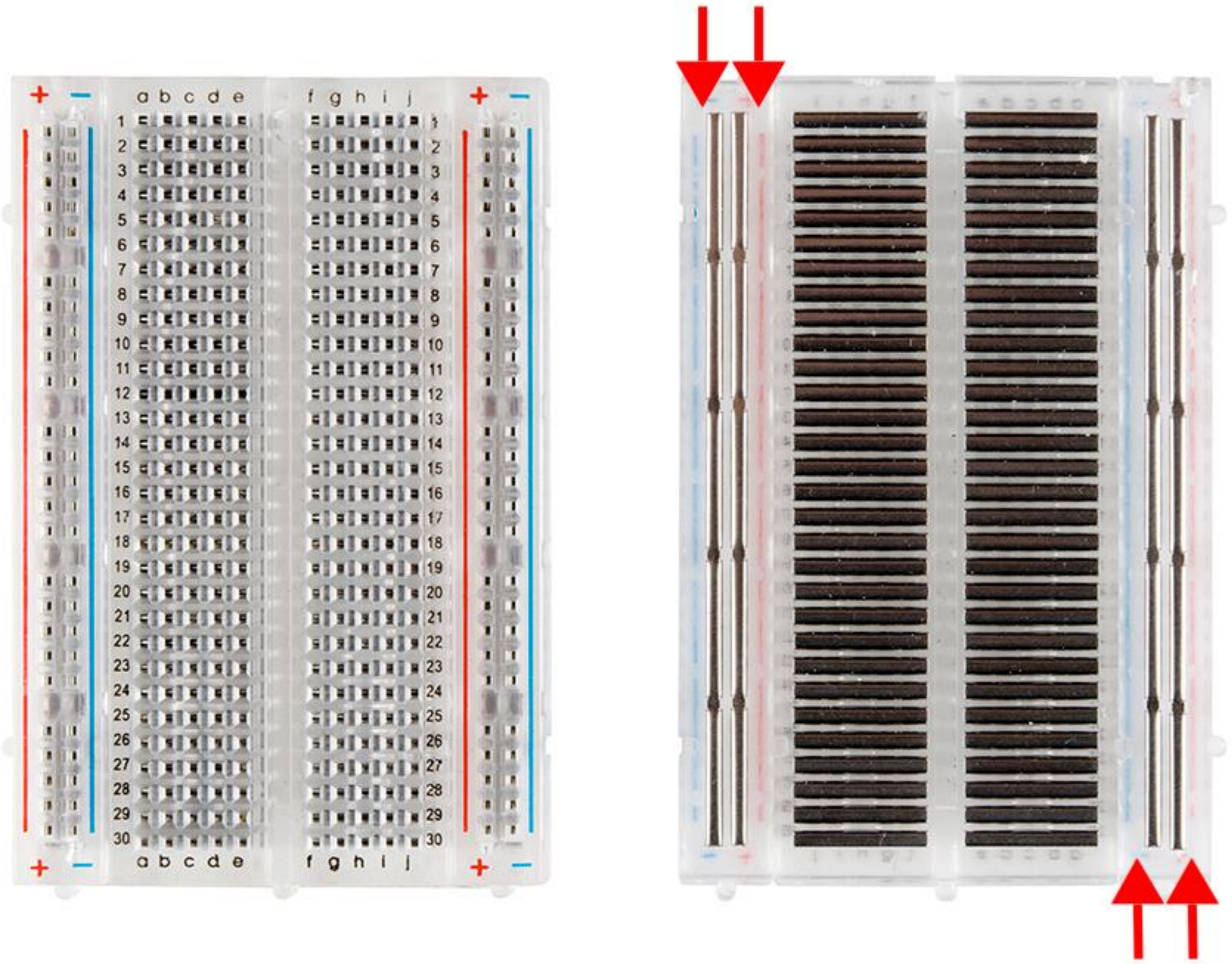



Power Rails
Terminal Strips (5 Hole Rows)
Center Divider
Terminal Strips (5 Hole Rows)
Power Rails




+
-
60 55 50 45 40 35 30 25 20 15 10 5 1
A B C D E
F G H I J
60 55 50 45 40 35 30 25 20 15 10 5 1
+
-


1 5 10 15 20 25 35 40 45 50 55 60
f g h i j
a b c d e
1 5 10 15 20 25 30 35 40 45 50 55 60


+ −
a b c d e
f g h i j
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

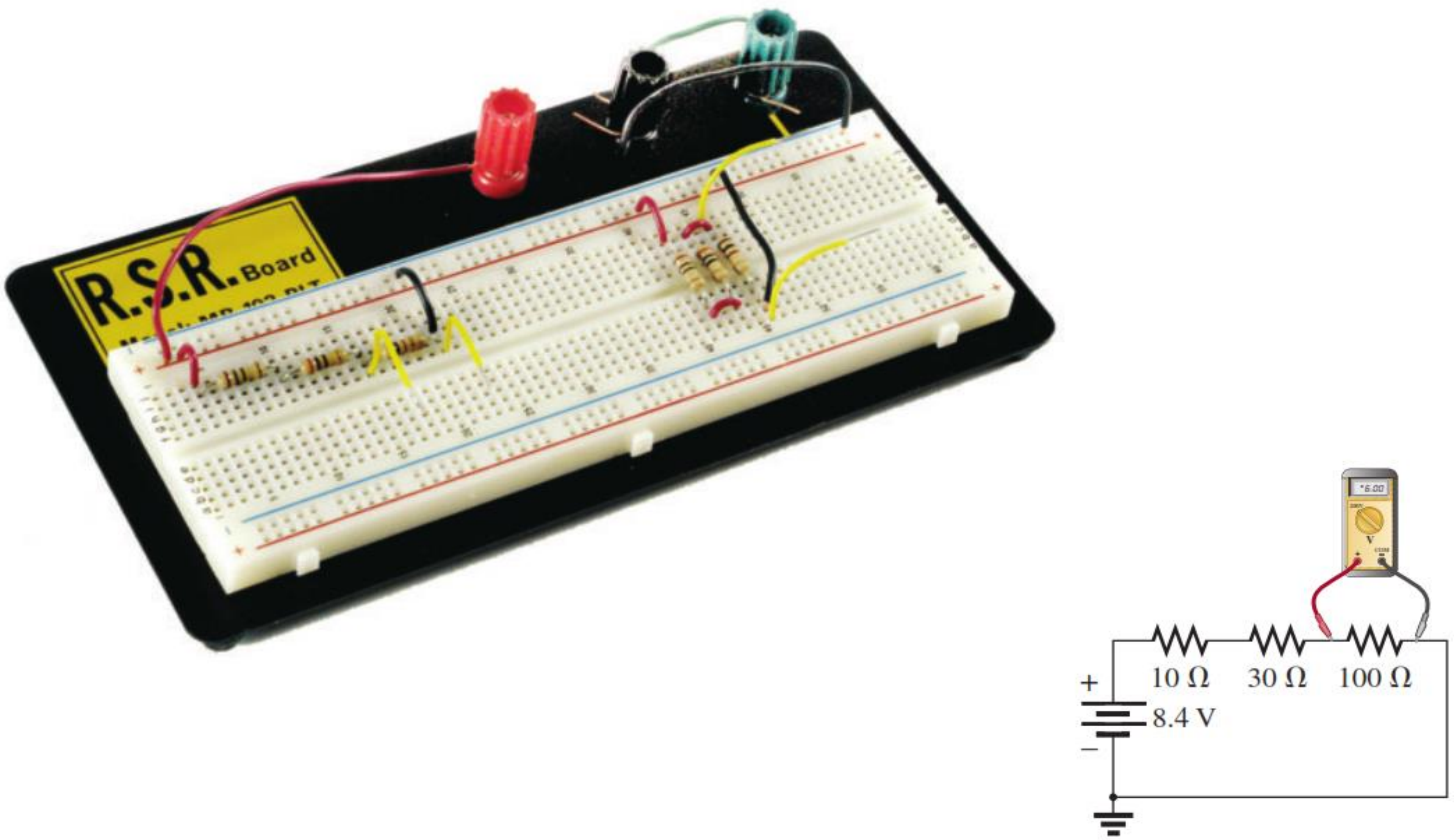
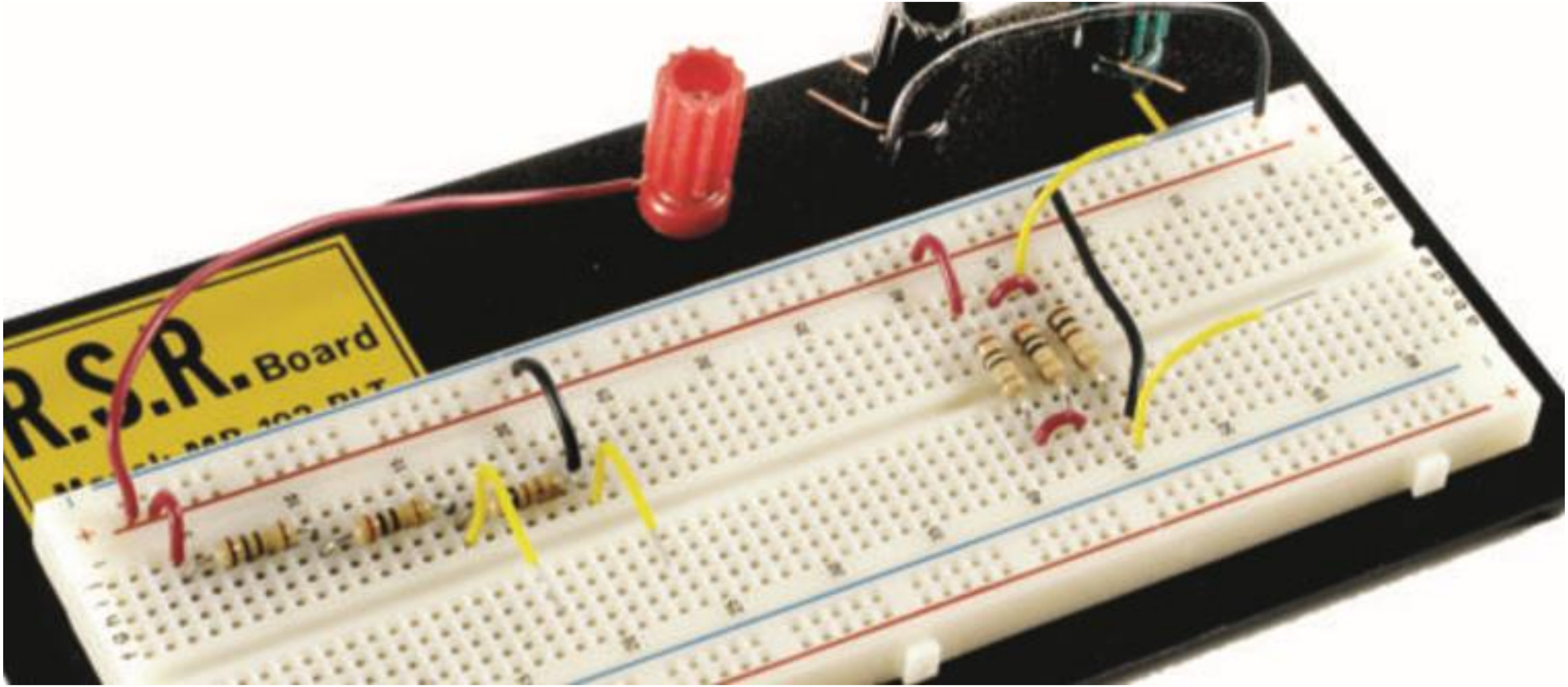
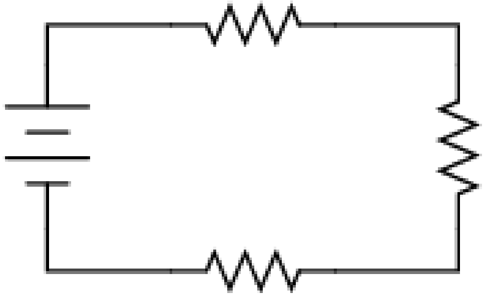


FIG. 5.76

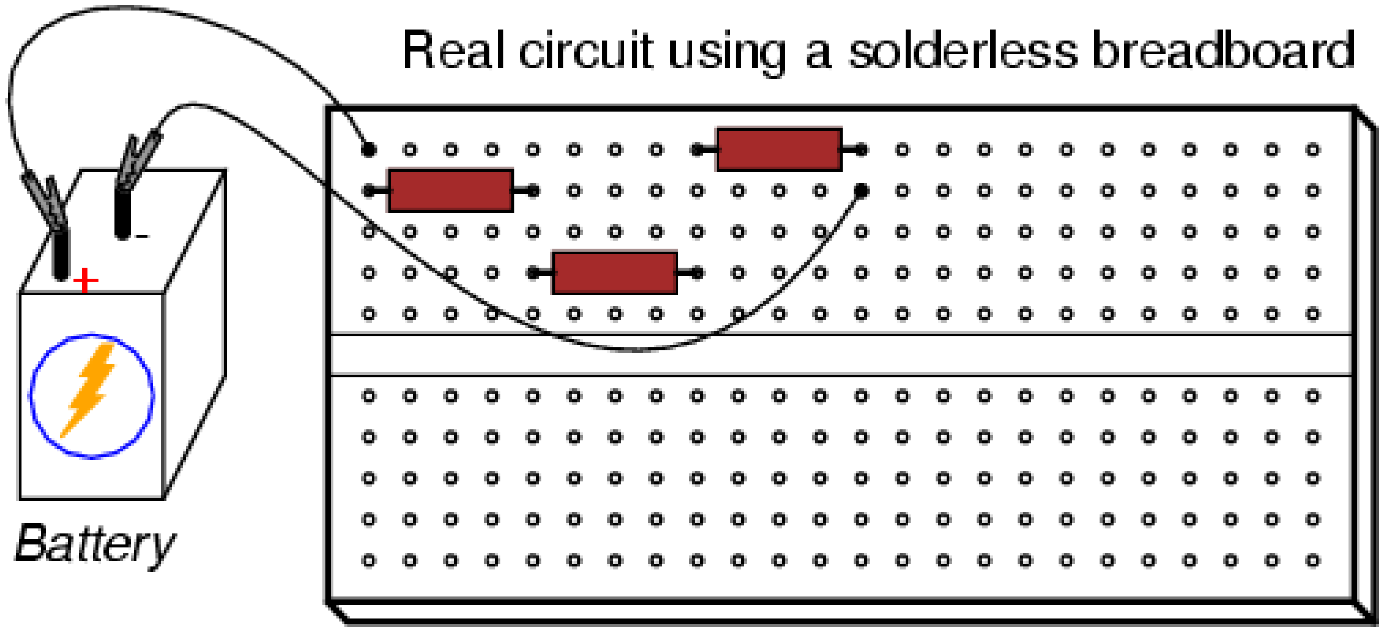
Two setups for the network in Fig. 5.12 on a protoboard with yellow leads added to each configuration to measure voltage V_3 with a voltmeter.


R.S.R. Board

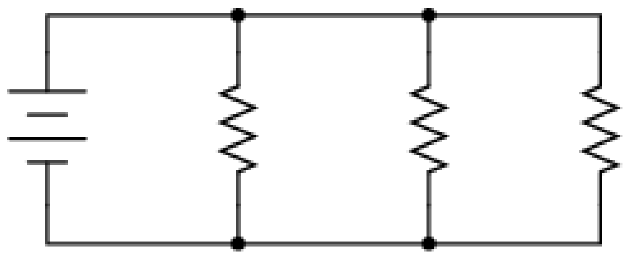
Schematic
diagram



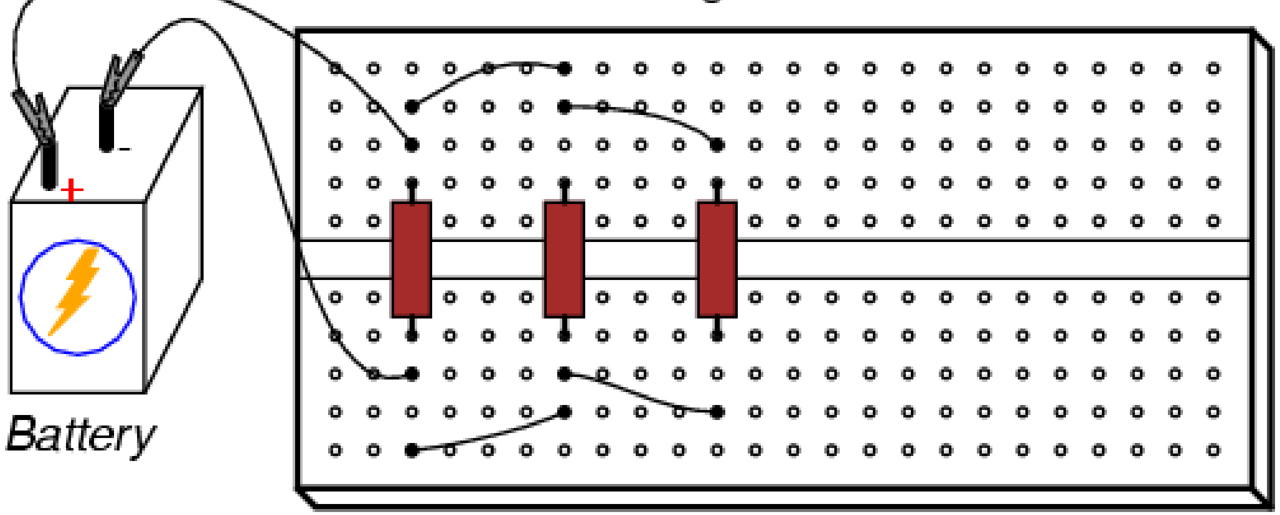
Real circuit using a solderless breadboard



Schematic
diagram



Real circuit using a solderless breadboard



5.6 KIRCHHOFF'S VOLTAGE LAW

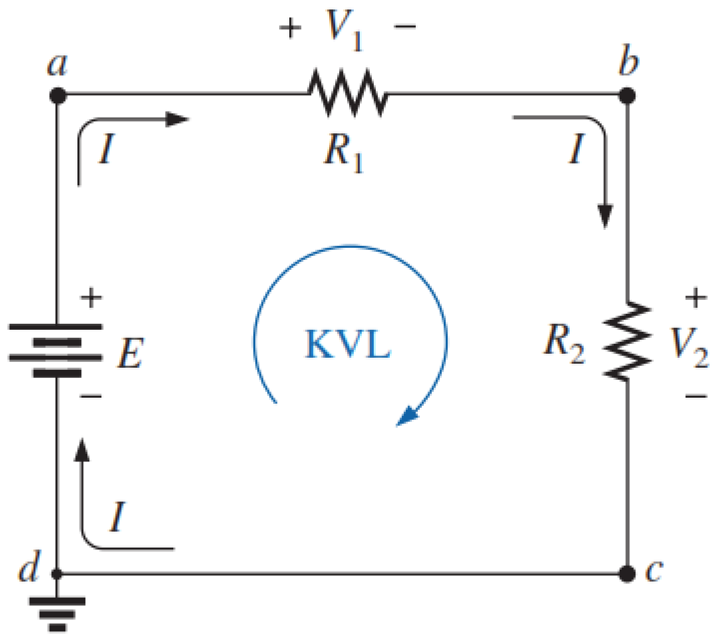


FIG. 5.26

Applying Kirchhoff's voltage law to a series dc circuit.

the algebraic sum of the potential rises and drops around a closed path (or closed loop) is zero.

In symbolic form it can be written as

$$\boxed{\Sigma_{\circlearrowright} V = 0} \qquad \text{(Kirchhoff's voltage law in symbolic form)} \quad \mathbf{(5.8)}$$

where Σ represents summation, $\circlearrowright$ the closed loop, and V the potential drops and rises. The term *algebraic* simply means paying attention to the signs that result in the equations as we add and subtract terms.

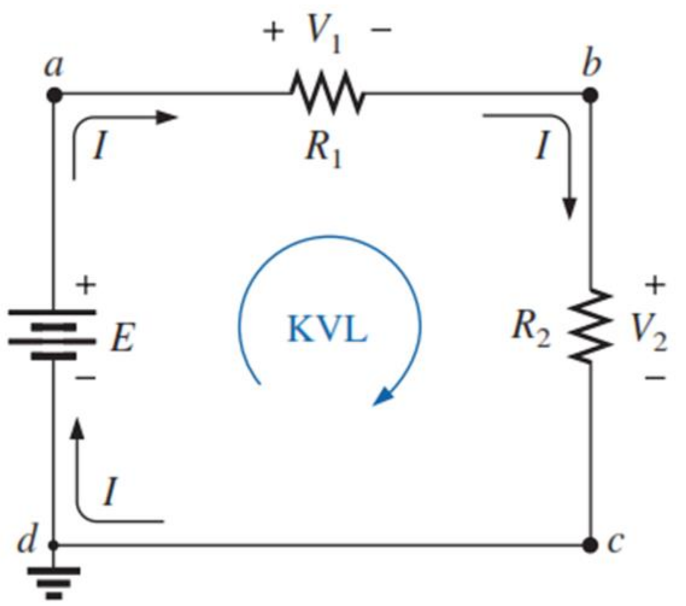


FIG. 5.26
Applying Kirchhoff's voltage law to a series dc circuit.

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

which can be rewritten as $\quad E = V_1 + V_2$

The result is particularly interesting because it tells us that

the applied voltage of a series dc circuit will equal the sum of the voltage drops of the circuit.

Kirchhoff's voltage law can also be written in the following form:

$$\boxed{\Sigma_{\circlearrowright} V_{\text{rises}} = \Sigma_{\circlearrowright} V_{\text{drops}}} \qquad \textbf{(5.9)}$$

revealing that

the sum of the voltage rises around a closed path will always equal the sum of the voltage drops.

EXAMPLE 5.8 Use Kirchhoff's voltage law to determine the unknown voltage for the circuit in Fig. 5.27.

$$+E_1 - V_1 - V_2 - E_2 = 0$$

$$V_1 = E_1 - V_2 - E_2$$

$$= 16\text{ V} - 4.2\text{ V} - 9\text{ V}$$

$$V_1 = \mathbf{2.8\text{ V}}$$

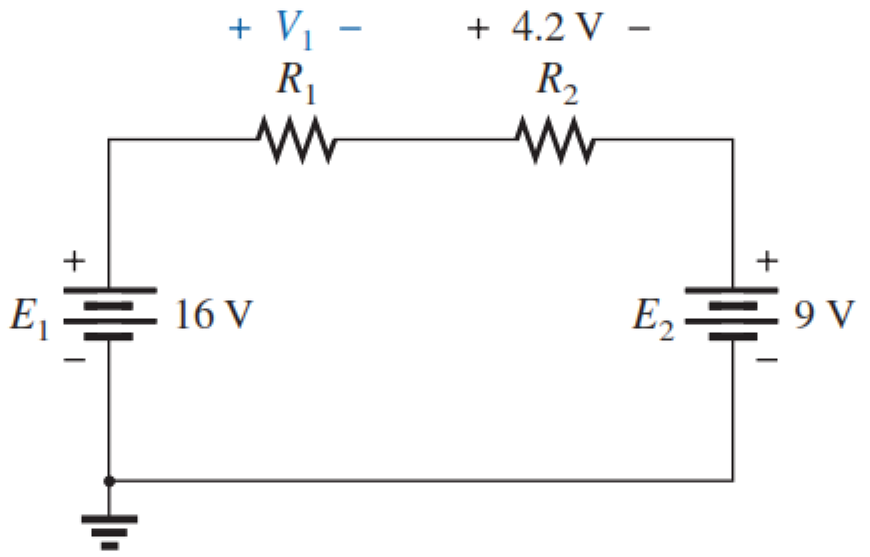


FIG. 5.27

Series circuit to be examined in Example 5.8.

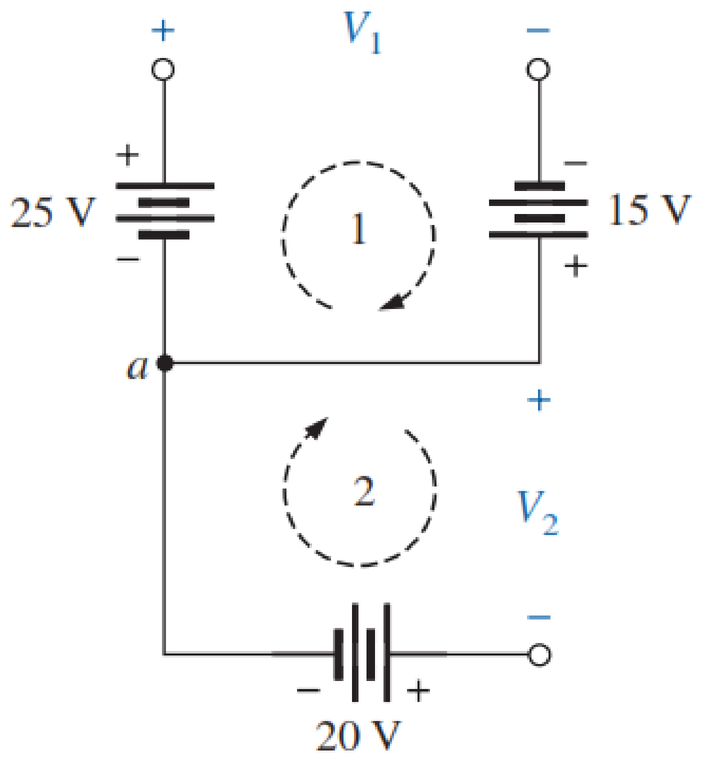
EXAMPLE 5.10 Using Kirchhoff's voltage law, determine voltages V_1 and V_2 for the network in Fig. 5.29.

Solution: For path 1, starting at point a in a clockwise direction,

$$+25\text{ V} - V_1 + 15\text{ V} = 0$$

and

$$V_1 = \mathbf{40\text{ V}}$$



For path 2, starting at point a in a clockwise direction,

$$-V_2 - 20\text{ V} = 0$$

and

$$V_2 = \mathbf{-20\text{ V}}$$

The minus sign in the solution simply indicates that the actual polarities are different from those assumed.

The next example demonstrates that you do not need to know what elements are inside a container when applying Kirchhoff's voltage law. They could all be voltage sources or a mix of sources and resistors. It doesn't matter—simply pay strict attention to the polarities encountered.

$$+60\text{ V} - 40\text{ V} - V_x + 30\text{ V} = 0$$
$$V_x = 60\text{ V} + 30\text{ V} - 40\text{ V} = 90\text{ V} - 40\text{ V}$$
$$V_x = \mathbf{50\text{ V}}$$

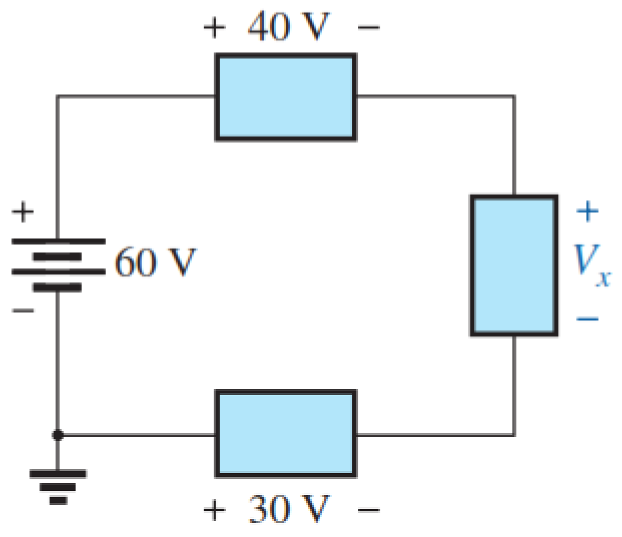
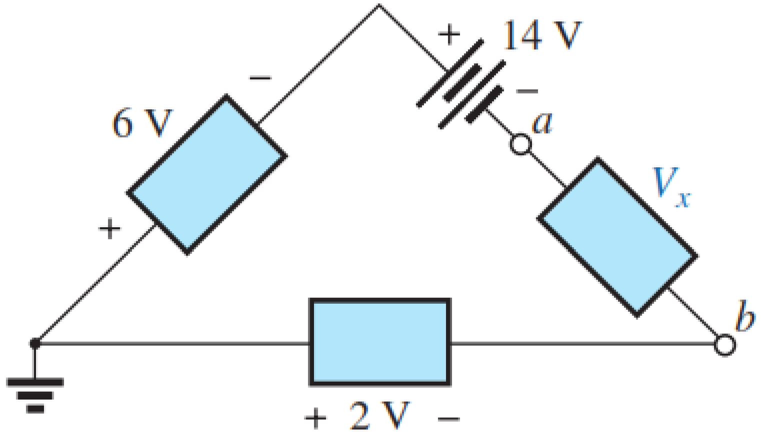


FIG. 5.30
Series configuration to be examined in Example 5.11.

EXAMPLE 5.12 Determine the voltage V_x for the circuit in Fig. 5.31. Note that the polarity of V_x was not provided.



$$-6\text{ V} - 14\text{ V} - V_x + 2\text{ V} = 0$$

and
$$V_x = -20\text{ V} + 2\text{ V}$$

so that
$$V_x = \mathbf{-18\ V}$$

Since the result is negative, we know that point *a* should be negative and point *b* should be positive, but the magnitude of 18 V is correct.

EXAMPLE 5.13 For the series circuit in Fig. 5.32.

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

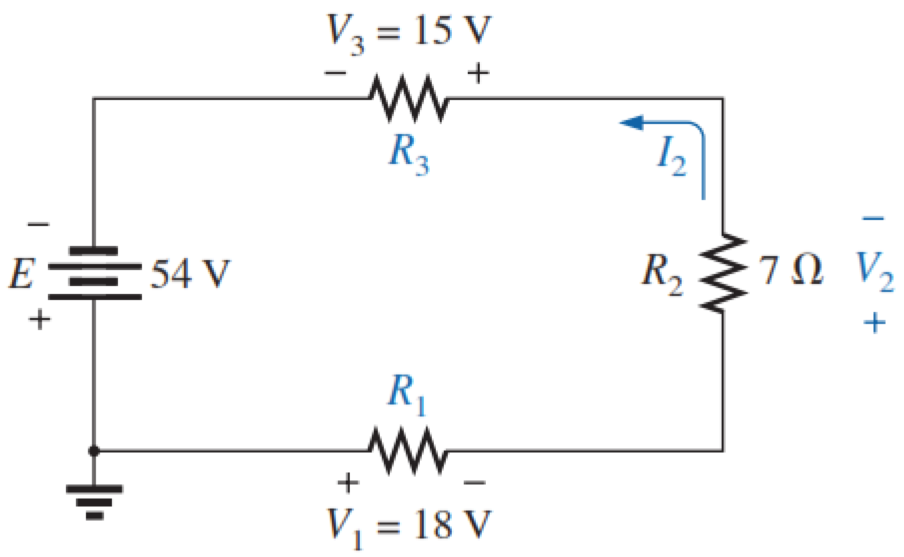


FIG. 5.32

Solution:

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

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

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

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

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

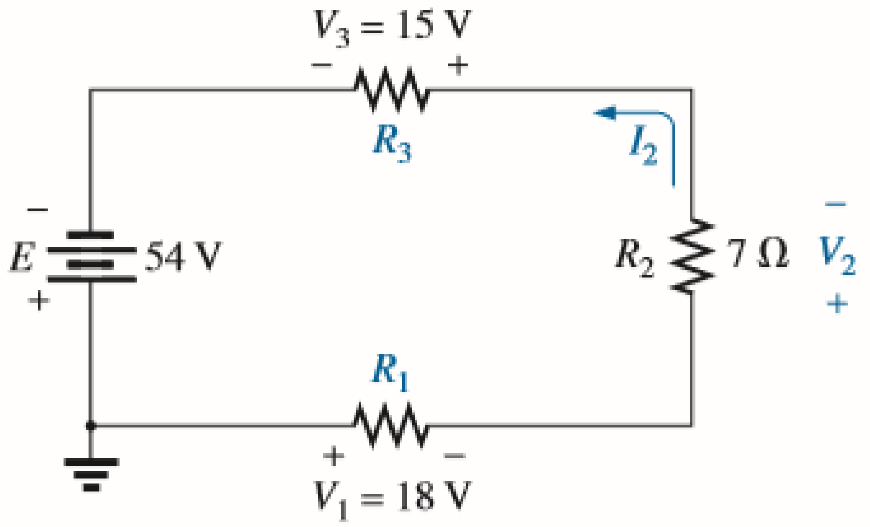


FIG. 5.32

Series configuration to be examined in Example 5.13.

5.7 VOLTAGE DIVISION IN A SERIES CIRCUIT

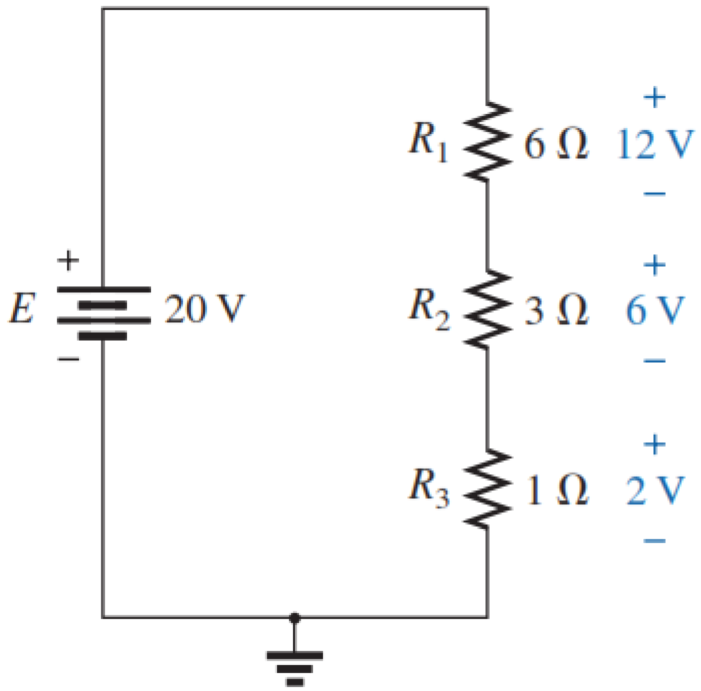
the voltage across series resistive elements will divide as the magnitude of the resistance levels.

In other words,

in a series resistive circuit, the larger the resistance, the more of the applied voltage it will capture.

In addition,

the ratio of the voltages across series resistors will be the same as the ratio of their resistance levels.



Voltage Divider Rule (VDR) ***the voltage across a resistor in a series circuit is equal to the value of that resistor times the total applied voltage divided by the total resistance of the series configuration.***

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

$$\boxed{V_x = R_x \frac{E}{R_T}} \qquad \text{(voltage divider rule)}$$

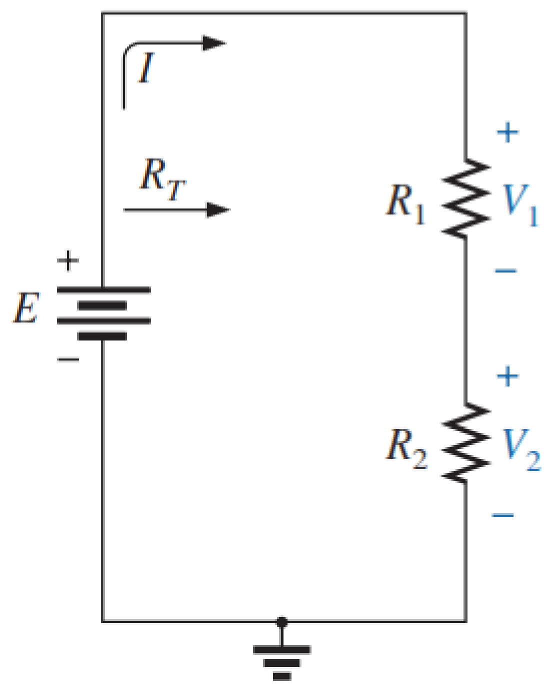
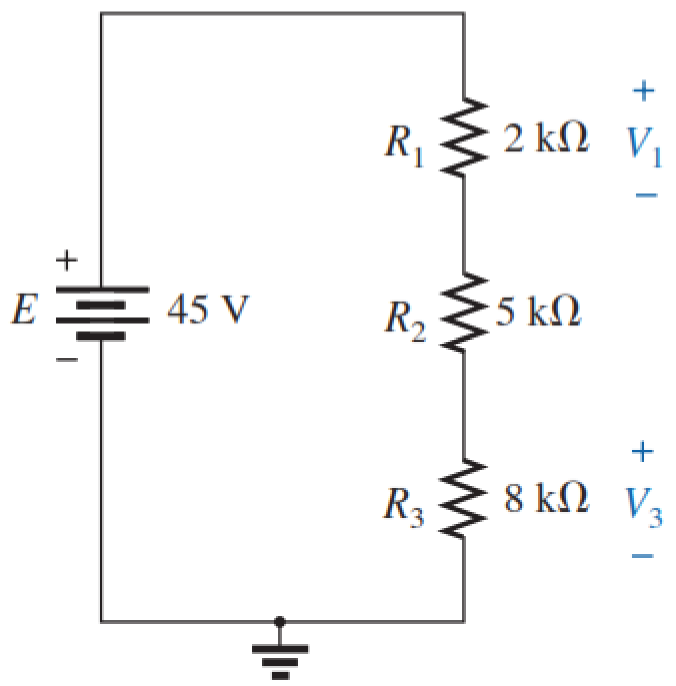


FIG. 5.36
Developing the voltage divider rule.

EXAMPLE 5.16 Using the voltage divider rule, determine voltages V_1 and V_3 for the series circuit in Fig. 5.38.



Solution:

$$R_T = R_1 + R_2 + R_3$$
$$= 2\ \text{k}\Omega + 5\ \text{k}\Omega + 8\ \text{k}\Omega$$
$$R_T = 15\text{k}\Omega$$

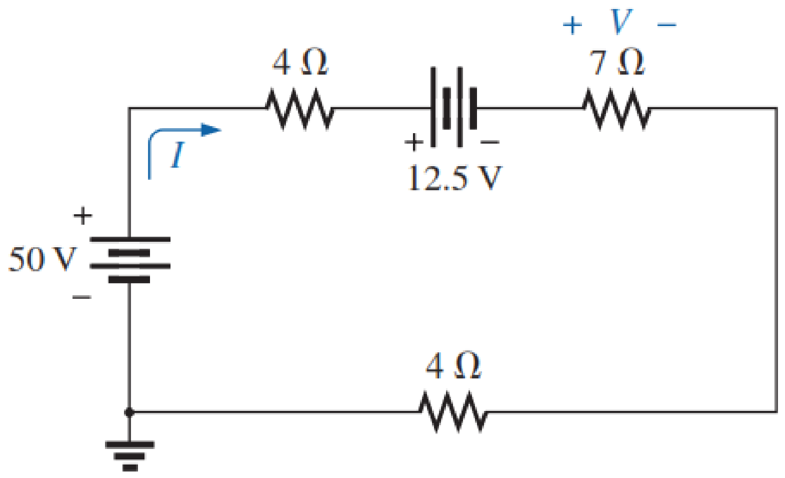
$$V_1 = R_1\frac{E}{R_T} = 2\ \text{k}\Omega\left(\frac{45\ \text{V}}{15\text{k}\Omega}\right) = \mathbf{6\ V}$$

and

$$V_3 = R_3\frac{E}{R_T} = 8\ \text{k}\Omega\left(\frac{45\ \text{V}}{15\ \Omega}\right) = \mathbf{24\ V}$$

5.8 INTERCHANGING SERIES ELEMENTS

EXAMPLE 5.20 Determine I and the voltage across the 7 Ω resistor for the network in Fig. 5.43.

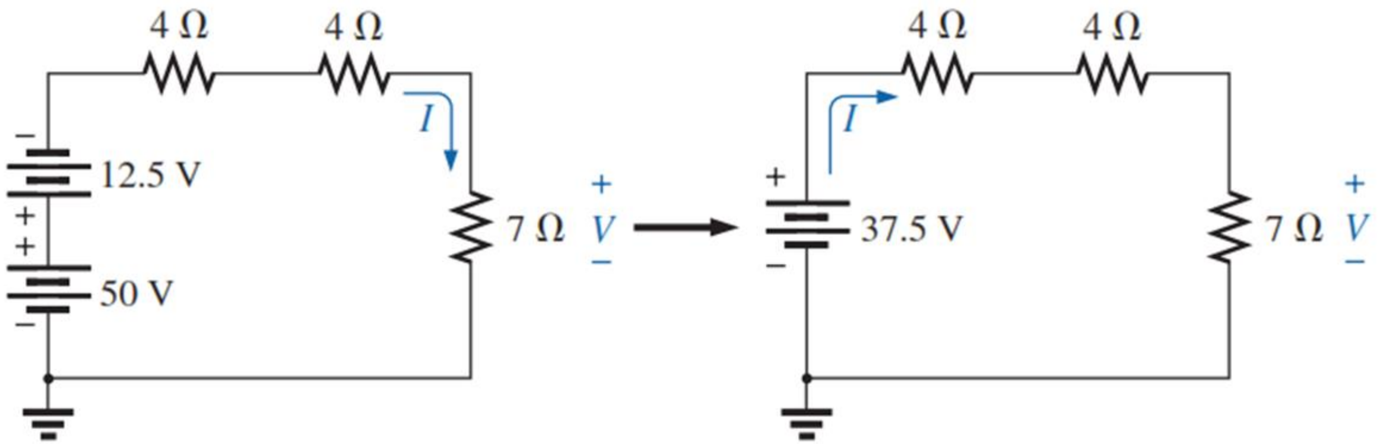


Solution: The network is redrawn in Fig. 5.44.

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

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

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



Voltage Sources and Ground

Except for a few special cases, electrical and electronic systems are grounded for reference and safety purposes. The symbol for the ground

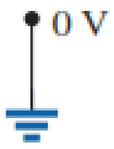


FIG. 5.45
Ground potential.

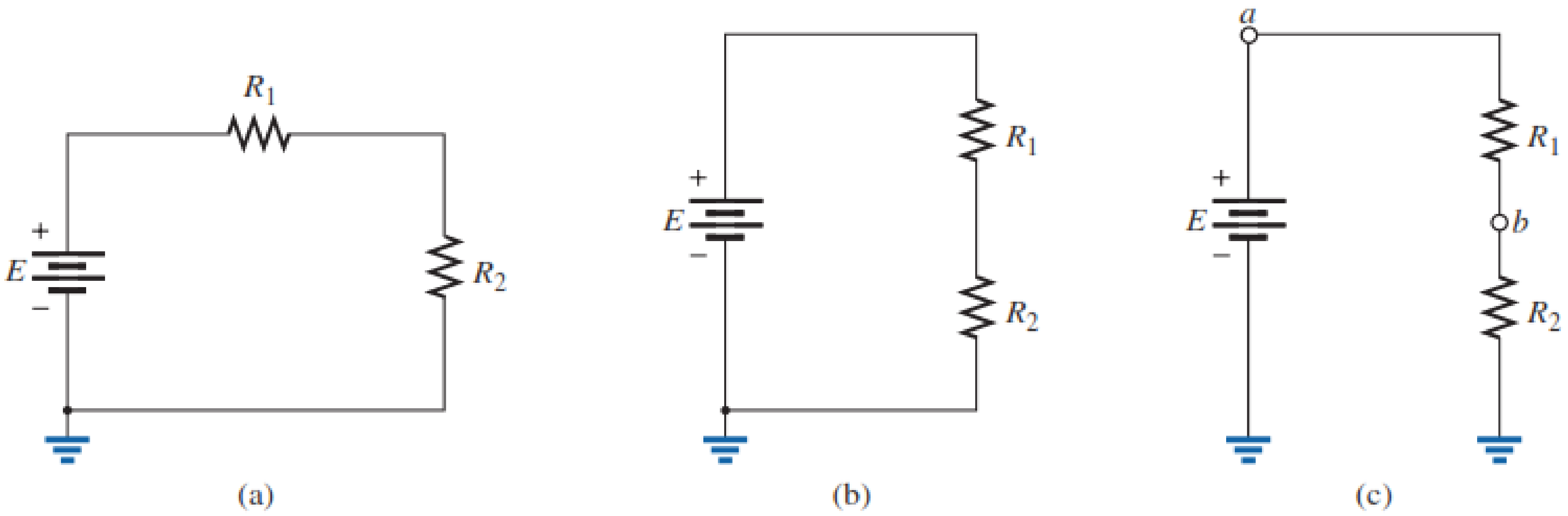


FIG. 5.46
Three ways to sketch the same series dc circuit.

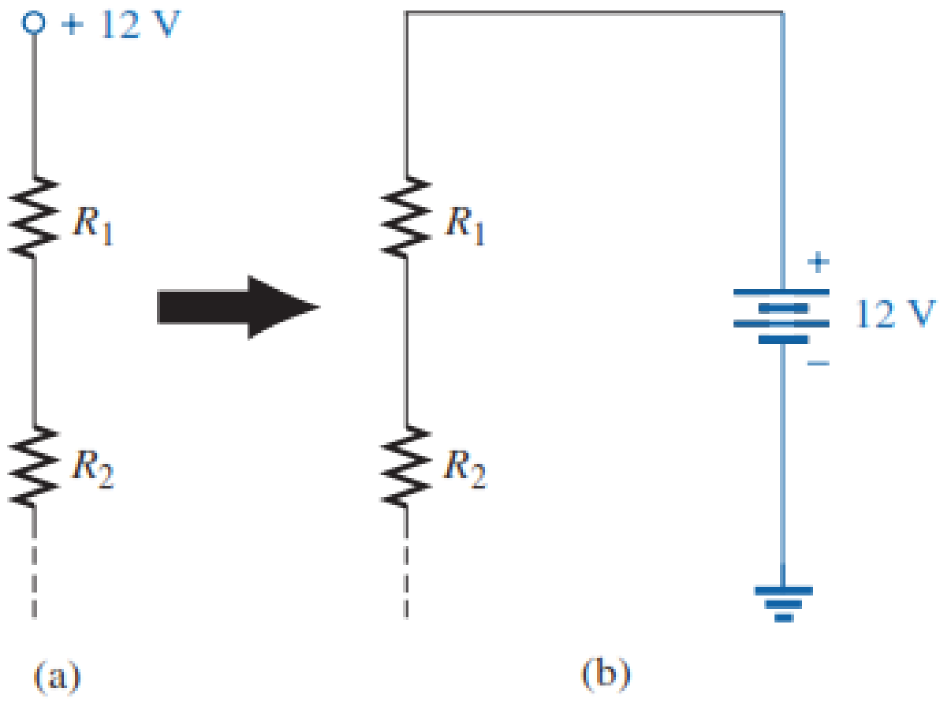


FIG. 5.47

Replacing the special notation for a dc voltage source with the standard symbol.

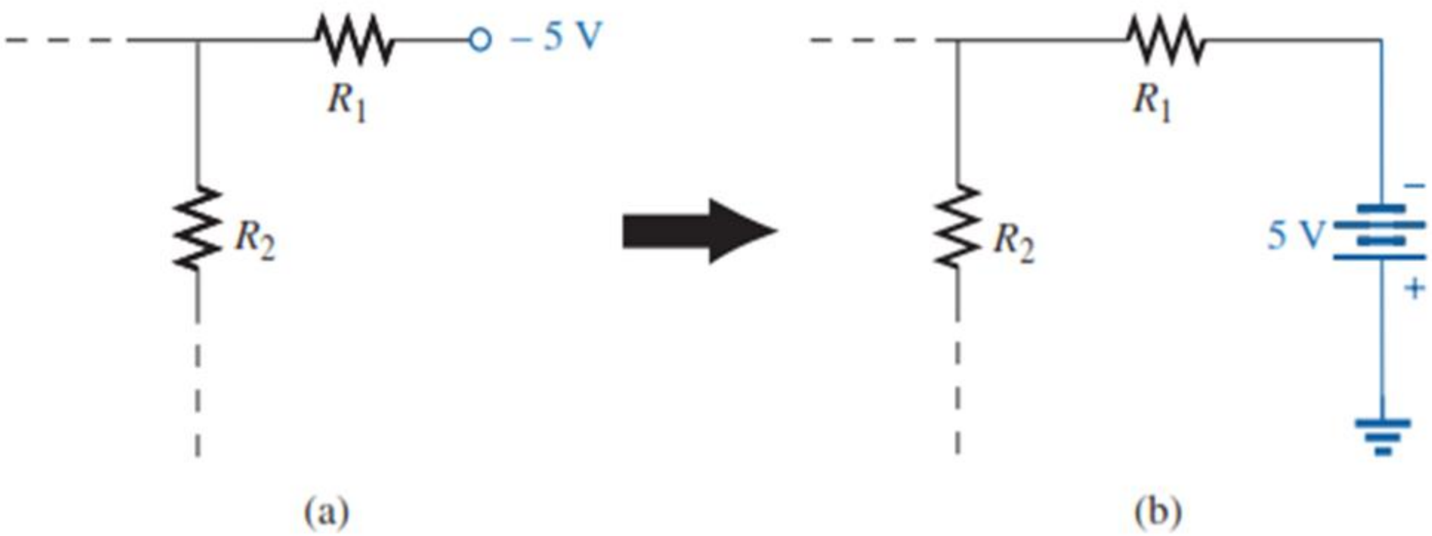
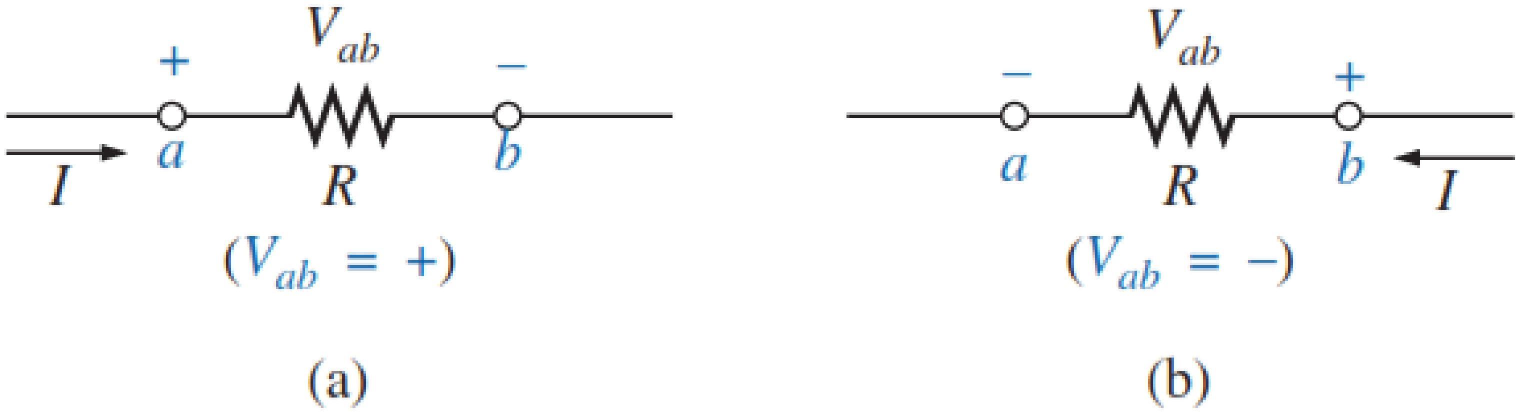
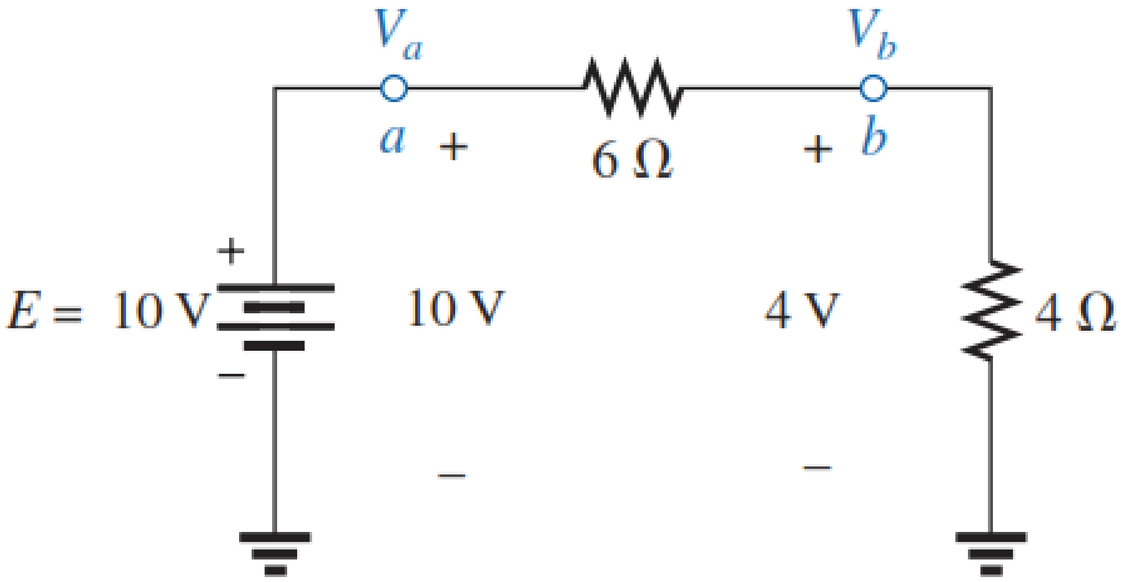


FIG. 5.48

Replacing the notation for a negative dc supply with the standard notation.



the voltage V_{ab} is the voltage at point a with respect to (w.r.t.) point b.



$$\boxed{V_{ab} = V_a - V_b}$$

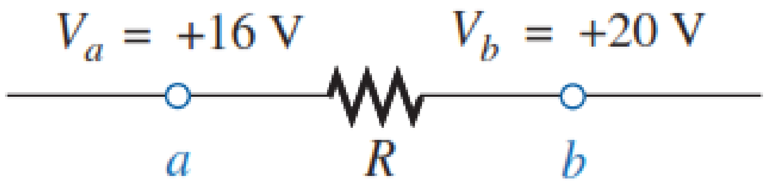
$$\begin{aligned} V_{ab} &= V_a - V_b = 10\text{ V} - 4\text{ V} \\ &= 6\text{ V} \end{aligned}$$

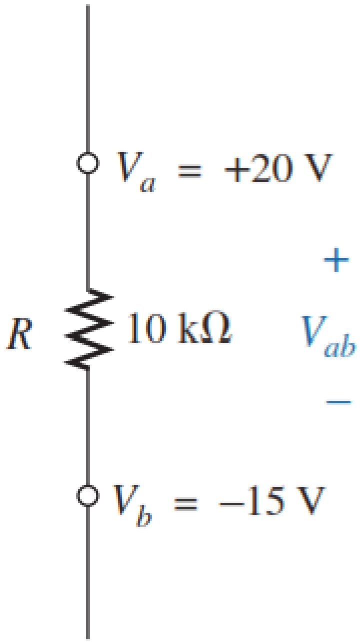
In Fig. 5.51, V_a is the voltage from point a to ground. In this case, it is obviously 10 V since it is right across the source voltage E. The voltage V_b is the voltage from point b to ground. Because it is directly across the 4 Ω resistor, $V_b = 4$ V.

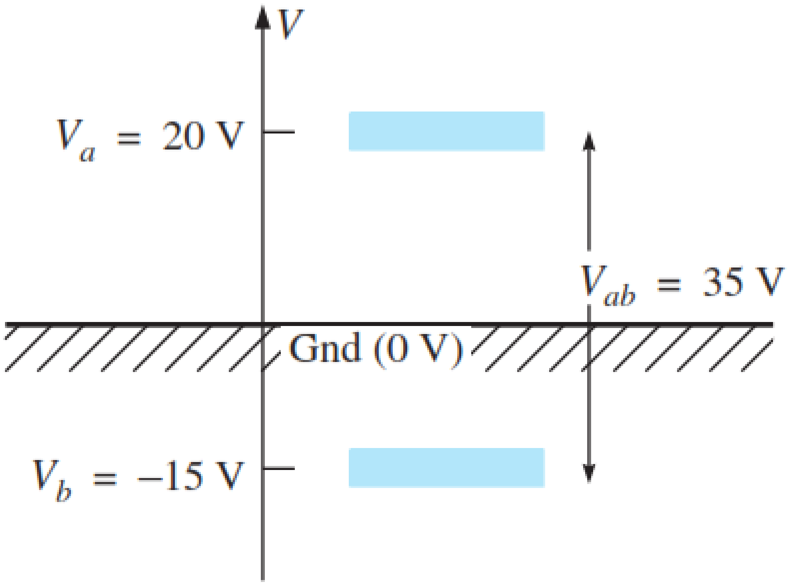
In summary:

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

Find the voltage V_{ab}







EXAMPLE 5.24 Find the voltages V_b, V_c, and V_{ac} for the network in Fig. 5.56.

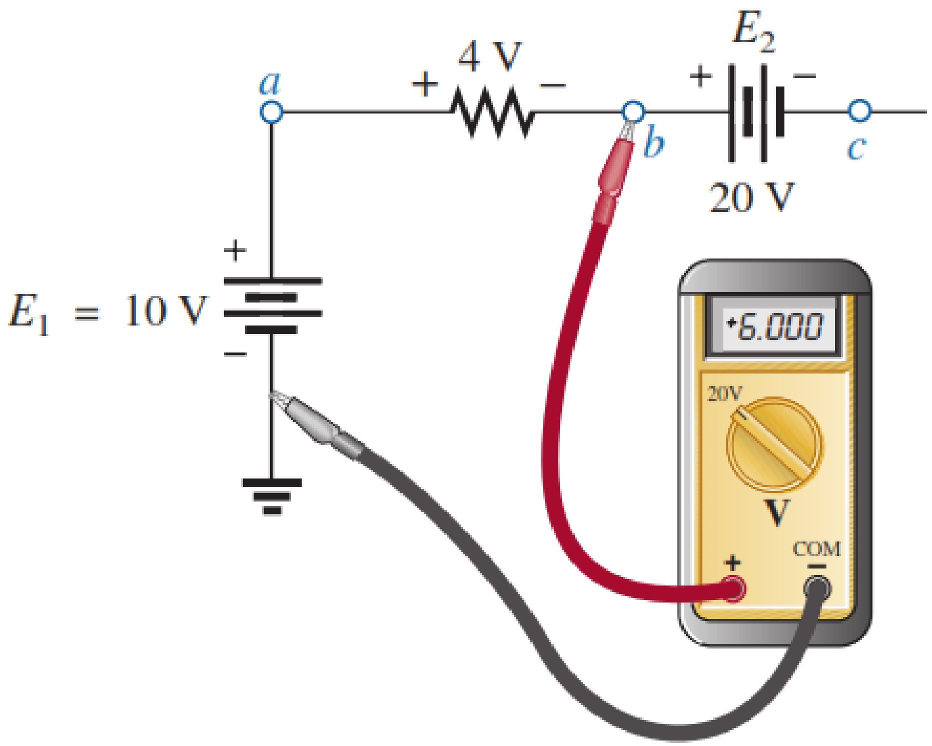
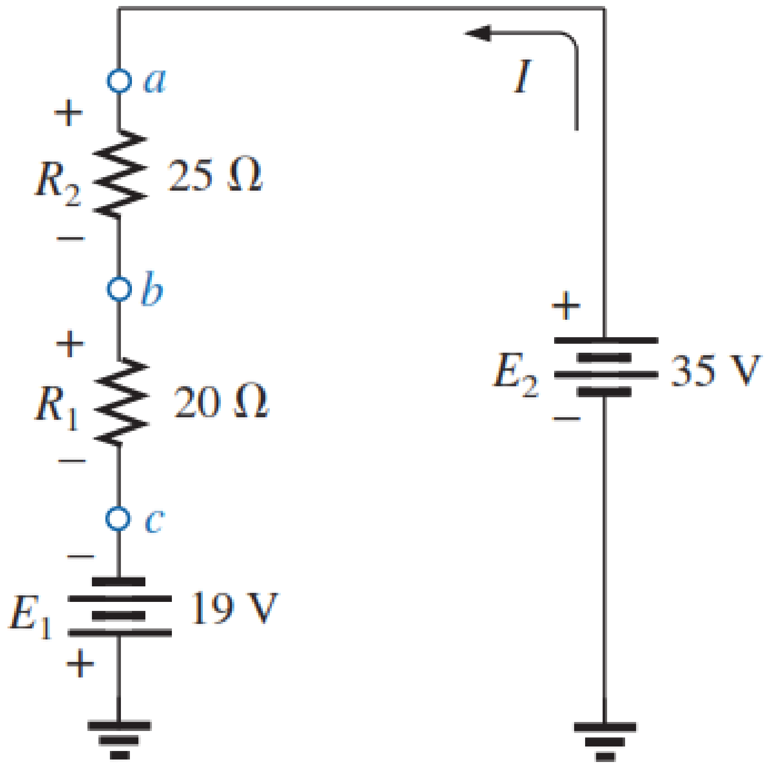


FIG. 5.56

Determine V_{ab}, V_{cb}, and V_c for the network



$$I = \frac{54\text{ V}}{45\ \Omega} = 1.2\text{ A}$$

$$V_{ab} = IR_2 = (1.2\text{ A})(25\ \Omega) = \mathbf{30\ V}$$

$$V_{cb} = -IR_1 = -(1.2\text{ A})(20\ \Omega) = \mathbf{-24\ V}$$

$$V_c = E_1 = \mathbf{-19\ V}$$

EXAMPLE 5.26 Using the voltage divider rule, determine the voltages V_1 and V_2 of Fig. 5.62.

Solution: Redrawing the network with the standard battery symbol results in the network in Fig. 5.63. Applying the voltage divider rule,

$$V_1 = \frac{R_1 E}{R_1 + R_2} = \frac{(4\ \Omega)(24\ \text{V})}{4\ \Omega + 2\ \Omega} = \mathbf{16\ V}$$

$$V_2 = \frac{R_2 E}{R_1 + R_2} = \frac{(2\ \Omega)(24\ \text{V})}{4\ \Omega + 2\ \Omega} = \mathbf{8\ V}$$

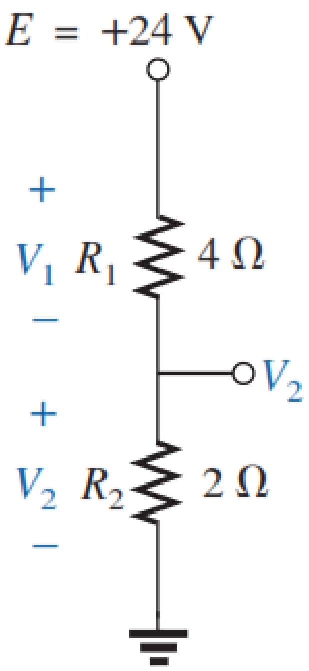


FIG. 5.62
Example 5.26.

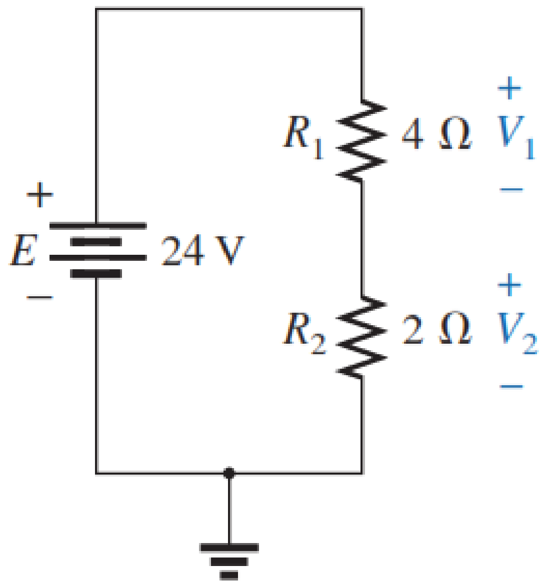


FIG. 5.63
Circuit of Fig. 5.62 redrawn.

Thank You