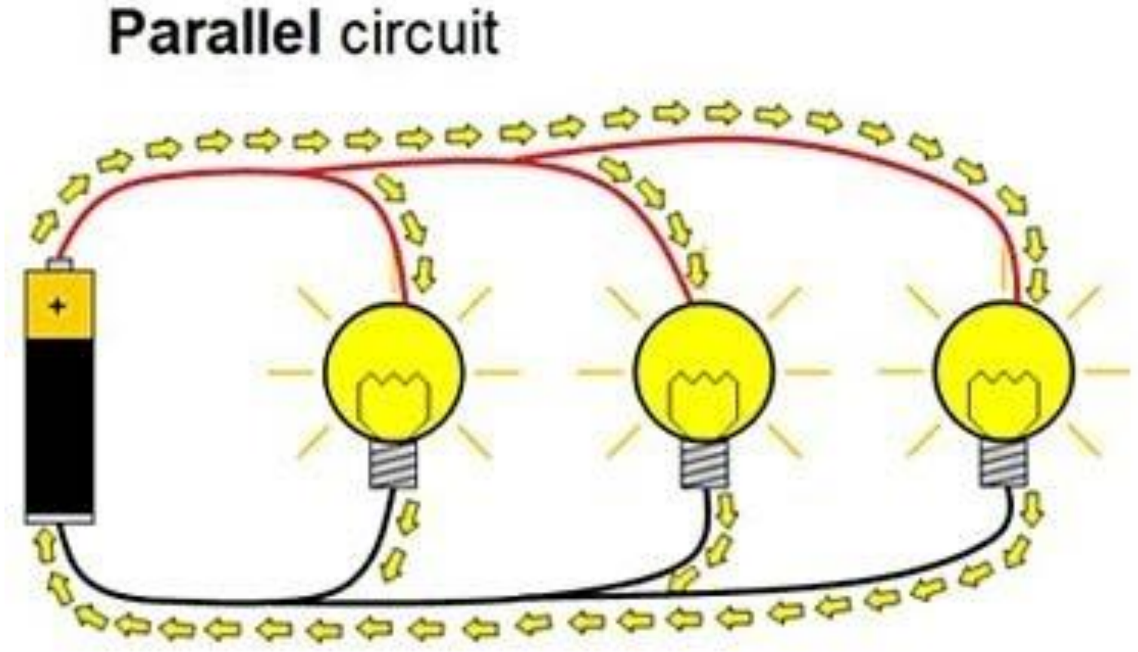
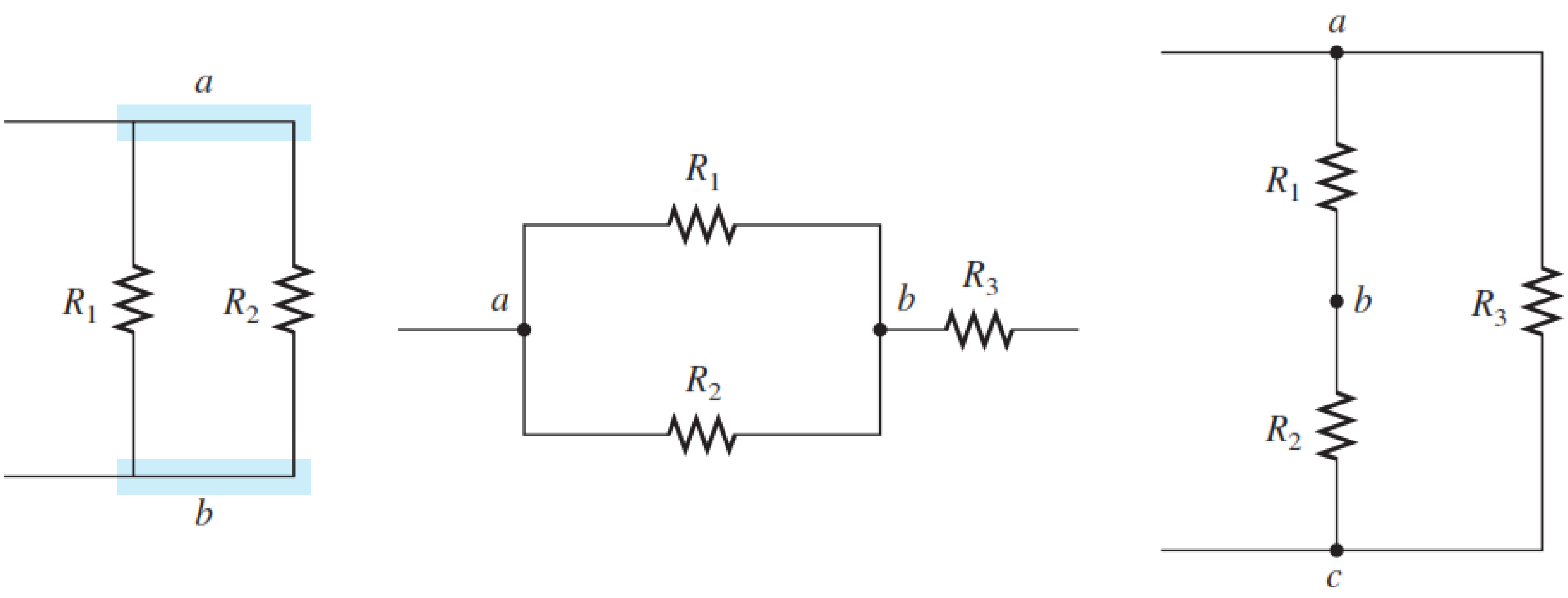
Parallel dc Circuits



two elements, branches, or circuits are in parallel if they have two points in common.



(a) (b) (c)

Fig. 6.1(b), resistors R_1 and R_2 are in parallel because they again have points *a* and *b* in common. R_1 is not in parallel with R_3 because they are connected at only one point (*b*). Further, R_1 and R_3 are not in series because a third connection appears at point *b*. The same can be said for

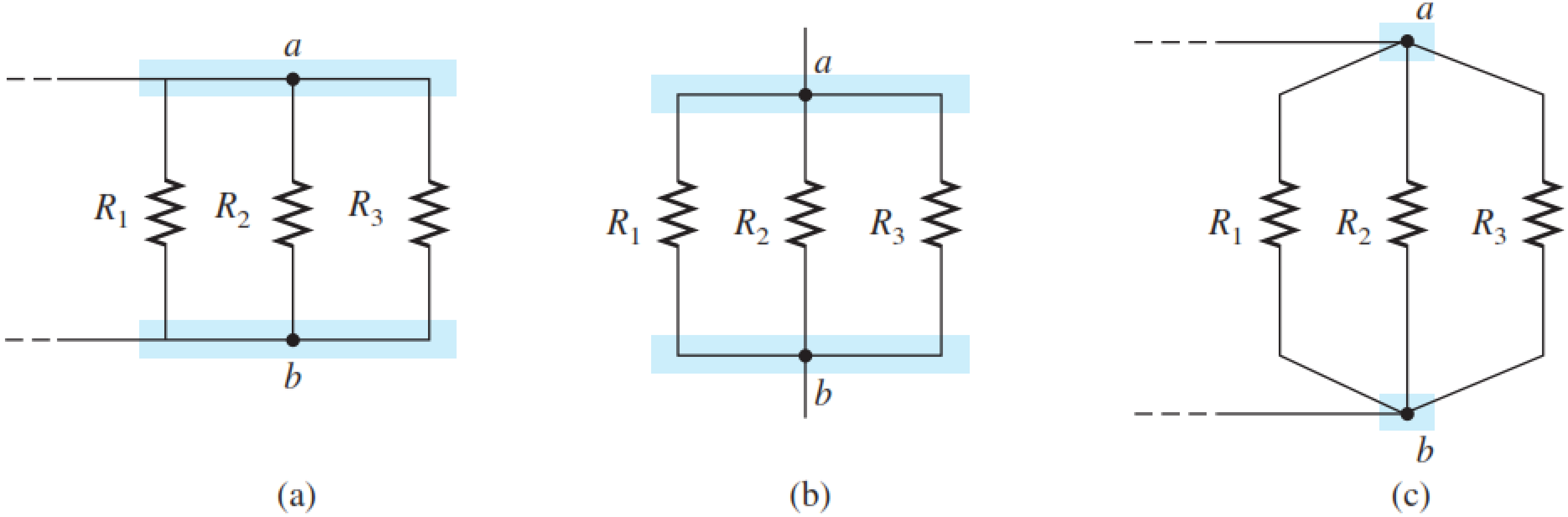


FIG. 6.2
Schematic representations of three parallel resistors.

$$\boxed{\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_N}} \tag{6.1}$$

Since $G = 1/R$, the equation can also be written in terms of conductance levels as follows:

$$\boxed{G_T = G_1 + G_2 + G_3 + \cdots + G_N} \quad \text{(siemens, S)} \tag{6.2}$$

$$R_T = \frac{1}{\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3} + \cdots + \dfrac{1}{R_N}}$$

EXAMPLE 6.3 Find the total resistance of the configuration in Fig. 6.6.

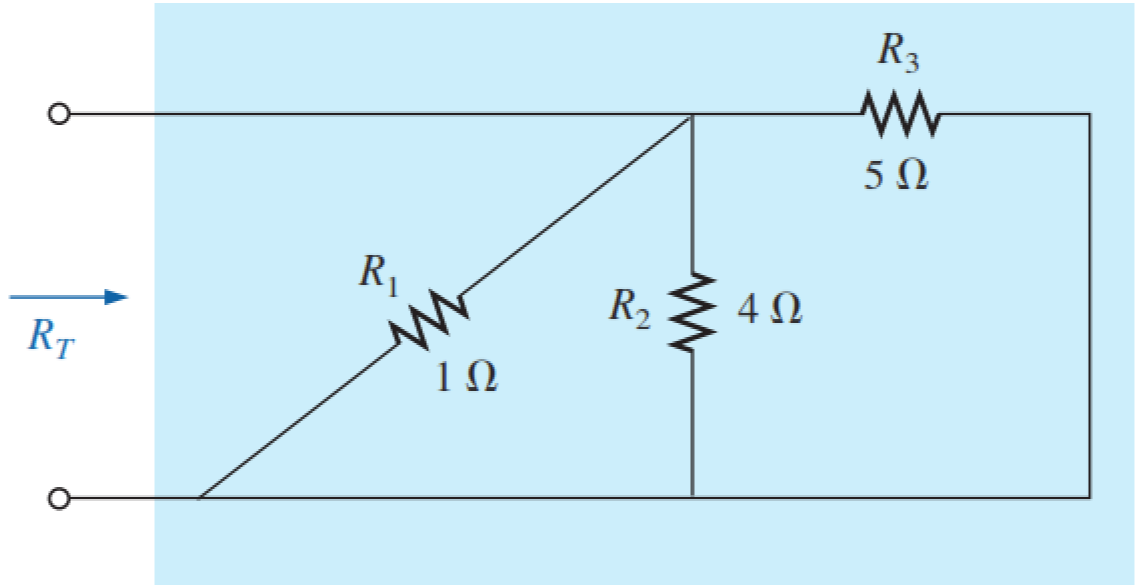
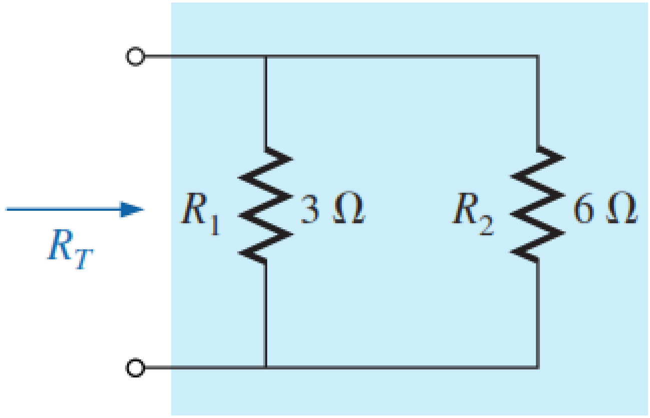


FIG. 6.6

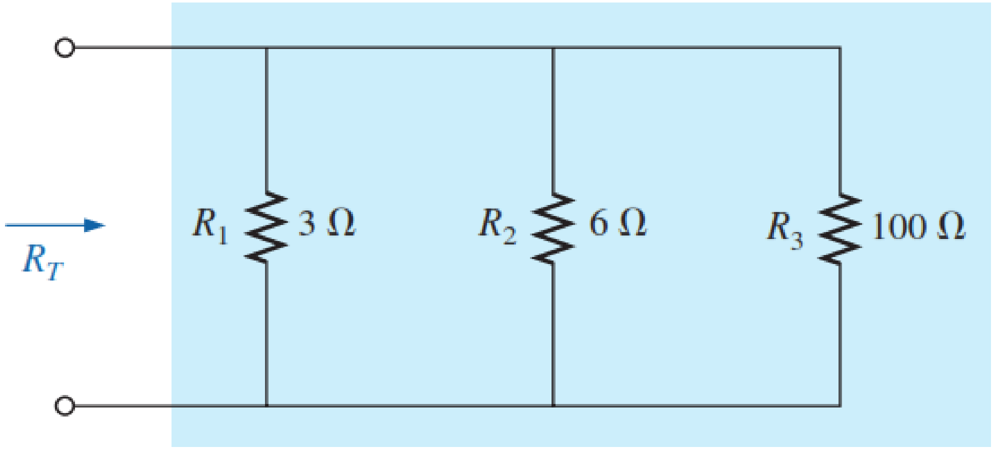
the total resistance of parallel resistors is always less than the value of the smallest resistor.

the total resistance of parallel resistors will always drop as new resistors are added in parallel, irrespective of their value.



a. What is the effect of adding another resistor of 100 Ω in parallel with the parallel resistors of Example 6.1 as shown in Fig. 6.8?

b. What is the effect of adding a parallel 1 Ω resistor to the configuration in Fig. 6.8?



a. Applying Eq. (6.3):

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{1}{\frac{1}{3\ \Omega} + \frac{1}{6\ \Omega} + \frac{1}{100\ \Omega}}$$

$$= \frac{1}{0.333\ \mathrm{S} + 0.167\ \mathrm{S} + 0.010\ \mathrm{S}} = \frac{1}{0.510\ \mathrm{S}} = \mathbf{1.96\ \Omega}$$

The parallel combination of the 3 Ω and 6 Ω resistors resulted in a total resistance of 2 Ω in Example 6.1. The effect of adding a resistor in parallel of 100 Ω had little effect on the total resistance because its resistance level is significantly higher (and conductance level significantly less) than the other two resistors. The total change in resistance was less than 2%. However, do note that the total resistance dropped with the addition of the 100 Ω resistor.

b. Applying Eq. (6.3):

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}} = \frac{1}{\frac{1}{3\ \Omega} + \frac{1}{6\ \Omega} + \frac{1}{100\ \Omega} + \frac{1}{1\ \Omega}}$$

$$= \frac{1}{0.333\ \mathrm{S} + 0.167\ \mathrm{S} + 0.010\ \mathrm{S} + 1\ \mathrm{S}} = \frac{1}{0.51\ \mathrm{S}} = \mathbf{0.66\ \Omega}$$

For equal resistors in parallel, the equation for the total resistance becomes significantly easier to apply. For N equal resistors in parallel, Eq. (6.3) becomes

$$R_T = \frac{1}{\dfrac{1}{R} + \dfrac{1}{R} + \dfrac{1}{R} + \cdots + \dfrac{1}{R_N}}$$

$$= \frac{1}{N\left(\dfrac{1}{R}\right)} = \frac{1}{\dfrac{N}{R}}$$

and

$$\boxed{R_T = \frac{R}{N}} \qquad \textbf{(6.4)}$$

In other words,

the total resistance of N parallel resistors of equal value is the resistance of one resistor divided by the number (N) of parallel resistors.

EXAMPLE 6.6 Find the total resistance for the configuration

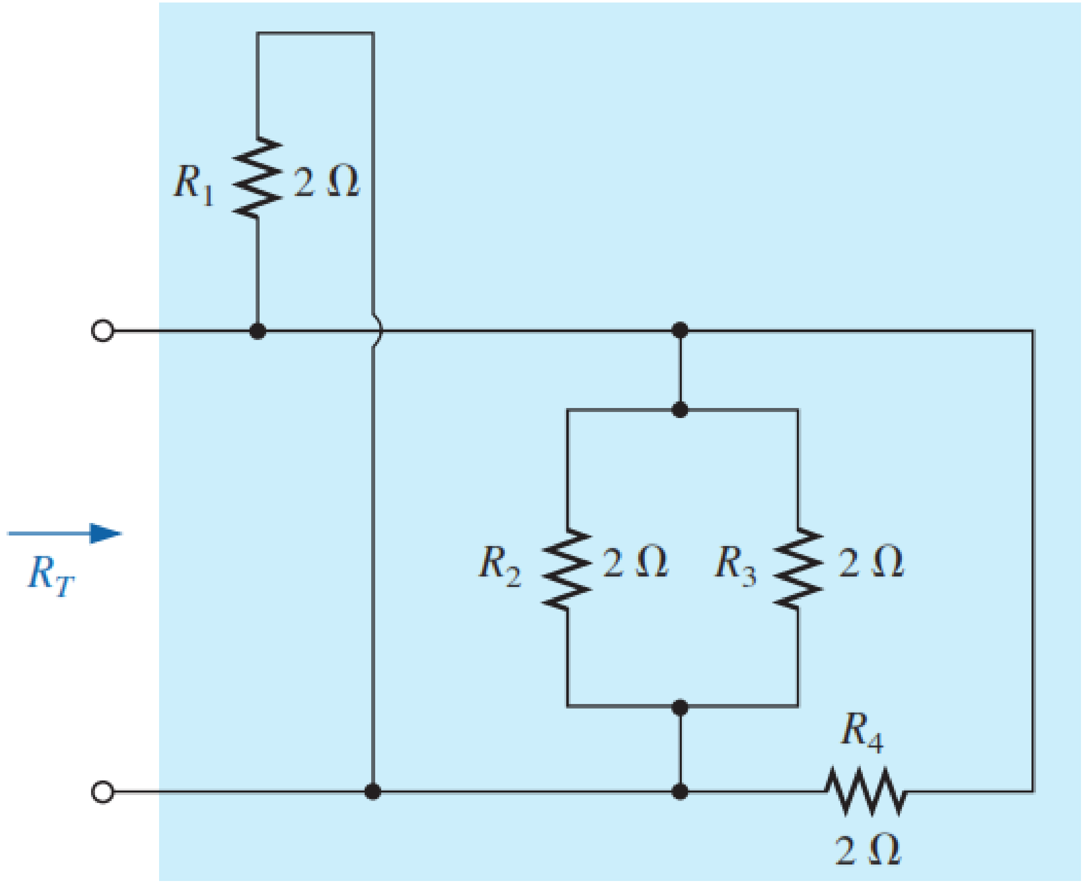


FIG. 6.10

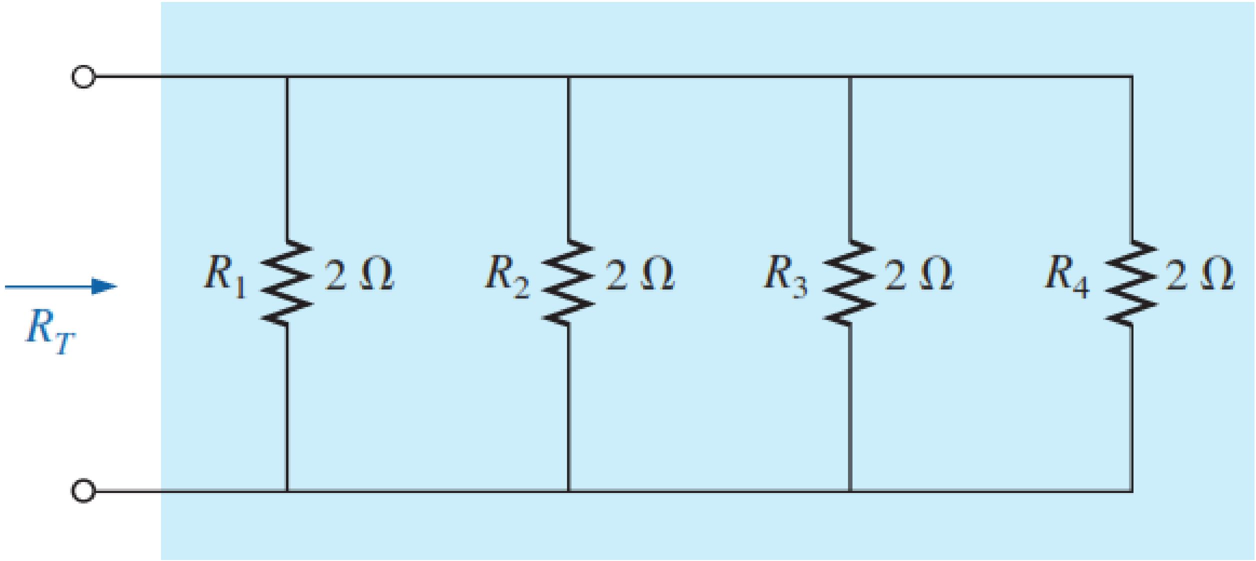


FIG. 6.11
Network in Fig. 6.10 redrawn.

$$R_T = \frac{R}{N} = \frac{2\ \Omega}{4} = \mathbf{0.5\ \Omega}$$

Special Case: Two Parallel Resistors

and

$$\boxed{R_T = \frac{R_1 R_2}{R_1 + R_2}} \qquad \textbf{(6.5)}$$

In words, the equation states that

the total resistance of two parallel resistors is simply the product of their values divided by their sum.

parallel resistors can be interchanged without affecting the total resistance.

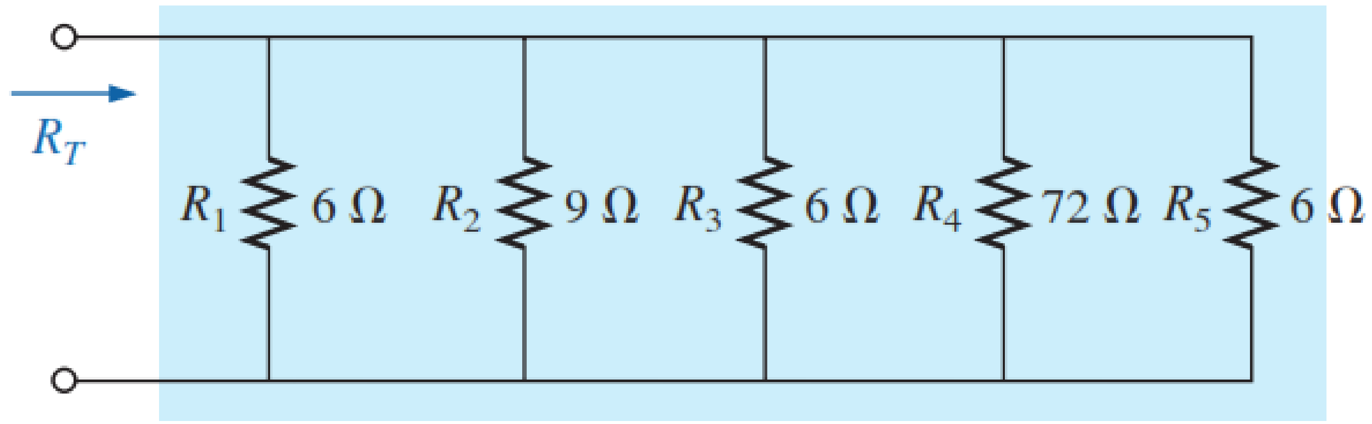


FIG. 6.13

Parallel network for Example 6.9.

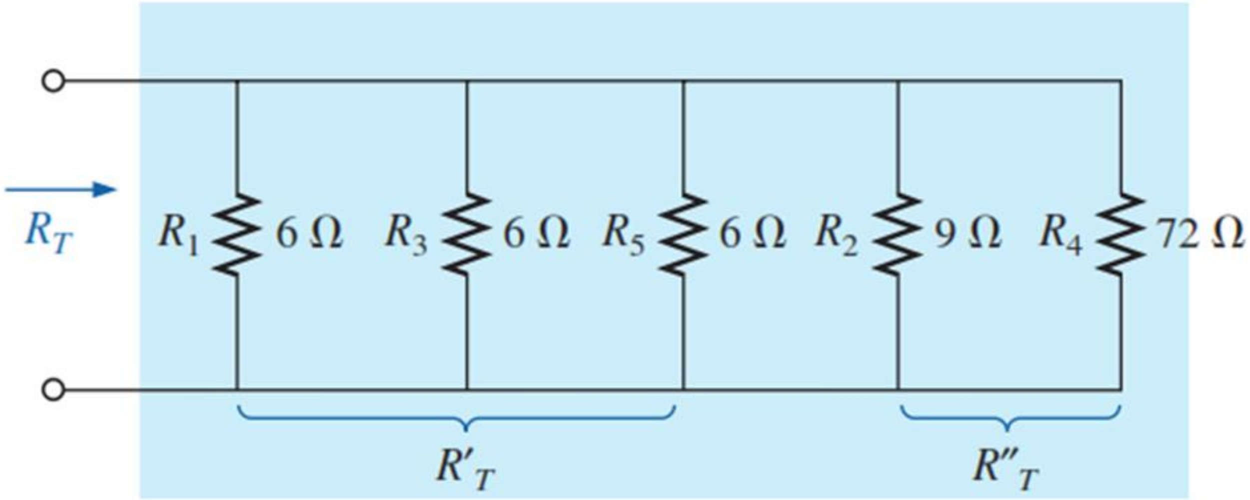


FIG. 6.14

Redrawn network in Fig. 6.13 (Example 6.9).

Solution: The network is redrawn in Fig. 6.14.

Eq. (6.4): $$R'_T = \frac{R}{N} = \frac{6\ \Omega}{3} = 2\ \Omega$$

Eq. (6.5): $$R''_T = \frac{R_2R_4}{R_2 + R_4} = \frac{(9\ \Omega)(72\ \Omega)}{9\ \Omega + 72\ \Omega} = \frac{648}{81}\ \Omega = 8\ \Omega$$

Eq. (6.5): $$R_T = \frac{R'_TR''_T}{R'_T + R''_T} = \frac{(2\ \Omega)(8\ \Omega)}{2\ \Omega + 8\ \Omega} = \frac{16}{10}\ \Omega = \mathbf{1.6\ \Omega}$$

EXAMPLE 6.10 Determine the value of R_2 in Fig. 6.15 to establish a total resistance of 9 kΩ.

Solution:

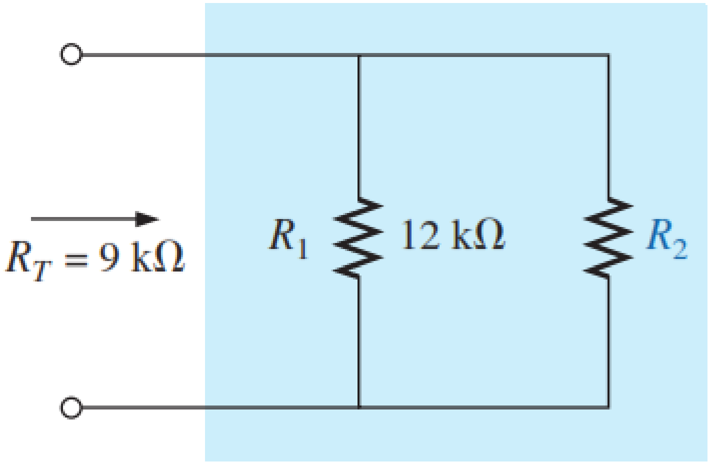


FIG. 6.15

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

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

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

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

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

and
$$R_2 = \frac{R_T R_1}{R_1 - R_T}$$

Substituting values:

$$R_2 = \frac{(9\text{ k}\Omega)(12\text{ k}\Omega)}{12\text{ k}\Omega - 9\text{ k}\Omega} = \frac{108}{3}\text{ k}\Omega = \mathbf{36\text{ k}\Omega}$$

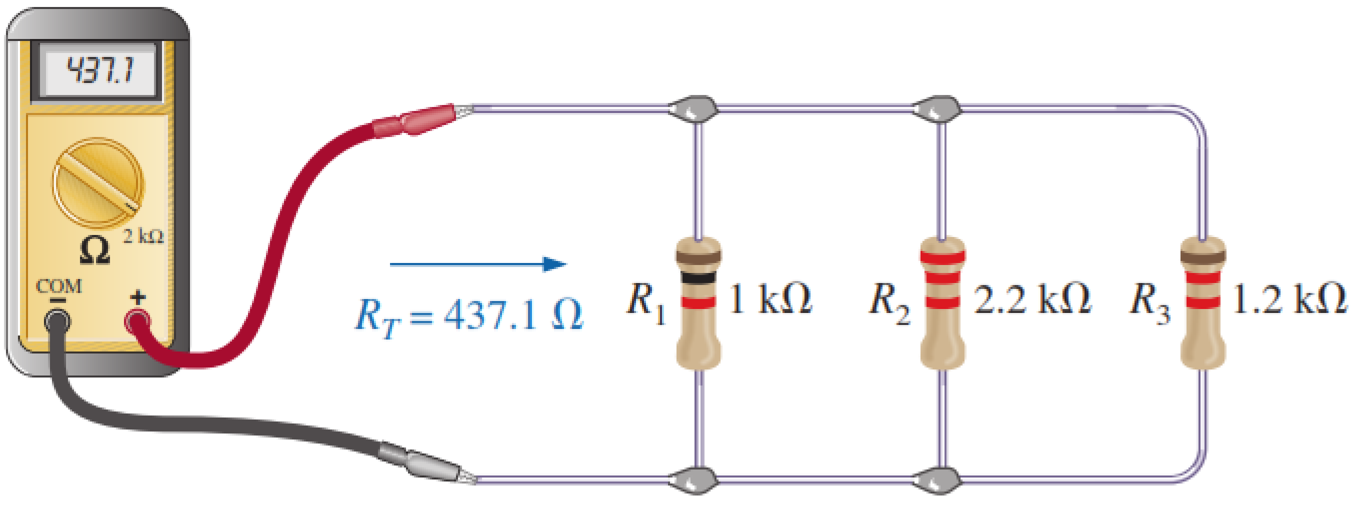


FIG. 6.17

Using an ohmmeter to measure the total resistance of a parallel network.

always keep in mind that ohmmeters can never be applied to a "live" circuit. It is not enough to set the supply to 0 V or to turn it off. It may still load down (change the network configuration of) the circuit and change the reading. It is best to remove the supply and apply the ohmmeter to the two resulting terminals. Since all the resistors are in the kilohm range, the 20 kΩ scale was chosen first. We then moved down to the 2 kΩ scale for increased precision. Moving down to the 200 Ω scale resulted in an "OL" indication since we were below the measured resistance value.

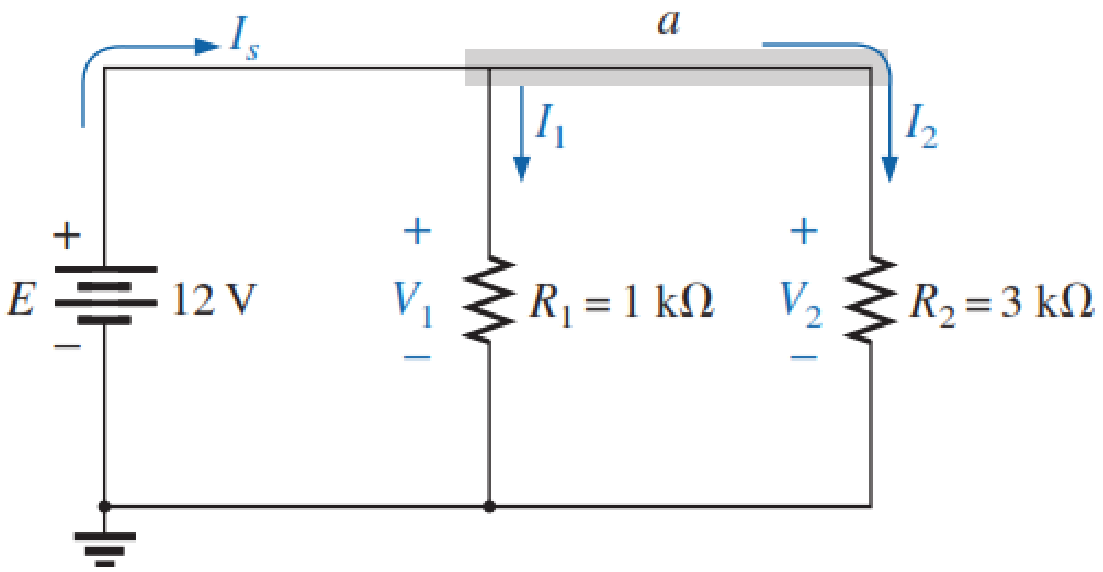


FIG. 6.18
Parallel network.

$$\boxed{V_1 = V_2 = E}$$

$$\boxed{I_s = \frac{E}{R_T}}$$

$$\boxed{I_1 = \frac{V_1}{R_1} = \frac{E}{R_1} \quad \text{and} \quad I_2 = \frac{V_2}{R_2} = \frac{E}{R_2}}$$

the voltage is always the same across parallel elements.

Therefore, remember that

if two elements are in parallel, the voltage across them must be the same. However, if the voltage across two neighboring elements is the same, the two elements may or may not be in parallel.

EXAMPLE 6.12 For the parallel network in Fig. 6.22:

a. Find the total resistance.
b. Calculate the source current.
c. Determine the current through each parallel branch.
d. Show that Eq. (6.9) is satisfied.

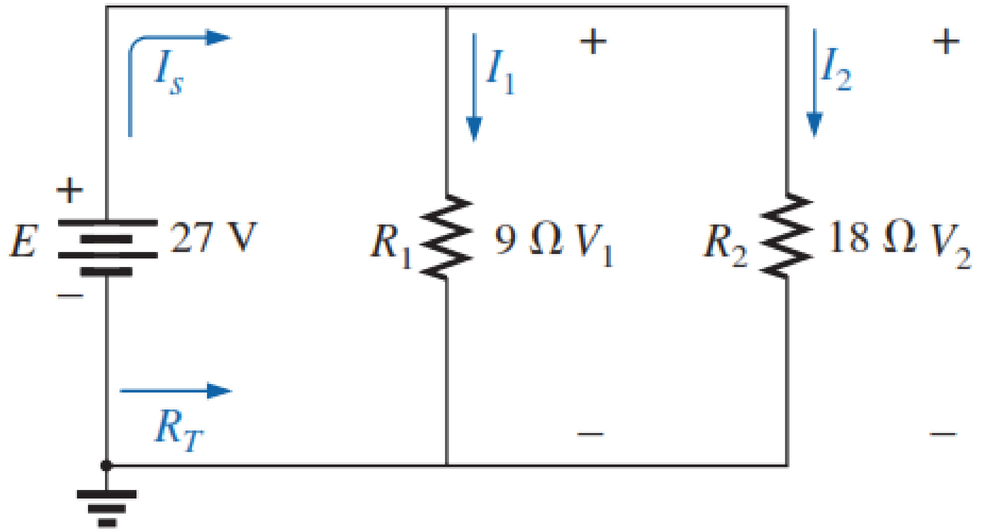


FIG. 6.22
Parallel network for Example 6.12.

Solutions:

a. Using Eq. (6.5):

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

b. Applying Ohm's law:

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

c. Applying Ohm's law:

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

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

d. Substituting values from parts (b) and (c):

$$I_s = \mathbf{4.5\ A} = I_1 + I_2 = 3\ \text{A} + 1.5\ \text{A} = \mathbf{4.5\ A} \quad \text{(checks)}$$

EXAMPLE 6.13 For the parallel network in Fig. 6.23.

a. Find the total resistance.
b. Calculate the source current.
c. Determine the current through each branch.

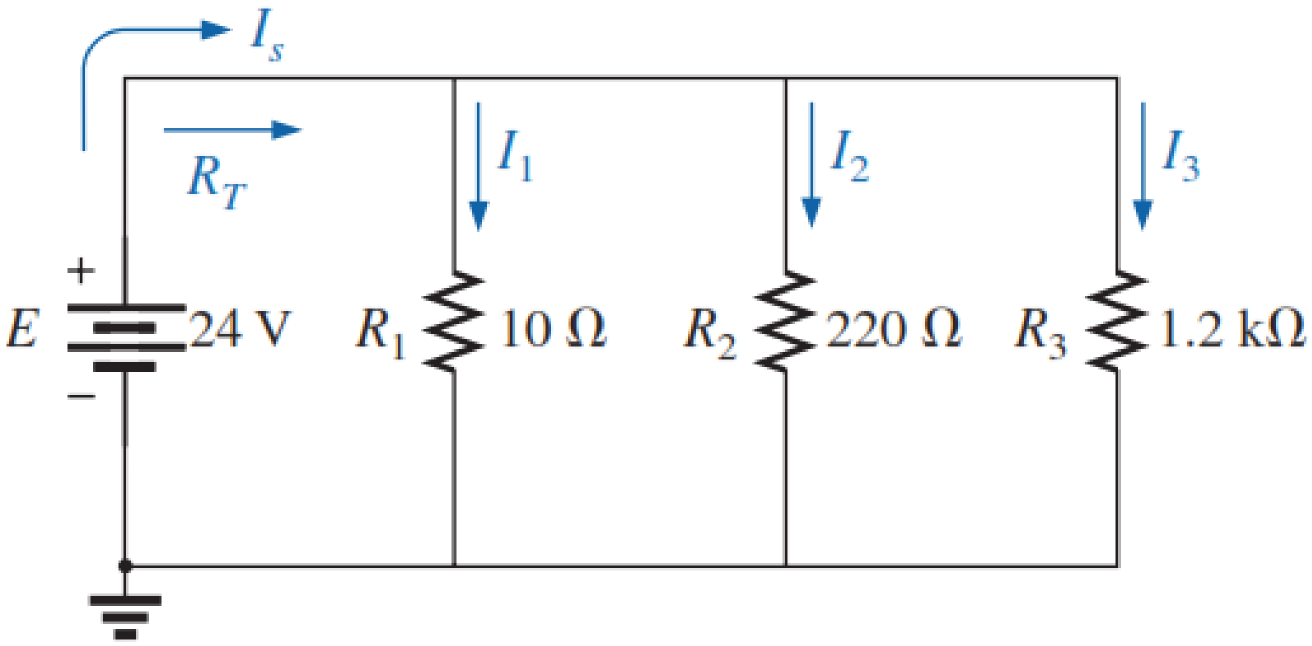


FIG. 6.23
Parallel network for Example 6.13.

c. Applying Ohm's law:

$$I_1 = \frac{V_1}{R_1} = \frac{E}{R_1} = \frac{24\text{ V}}{10\ \Omega} = \mathbf{2.4\ A}$$

$$I_2 = \frac{V_2}{R_2} = \frac{E}{R_2} = \frac{24\text{ V}}{220\ \Omega} = \mathbf{0.11\ A}$$

$$I_3 = \frac{V_3}{R_3} = \frac{E}{R_3} = \frac{24\text{ V}}{1.2\text{ k}\Omega} = \mathbf{0.02\ A}$$

for parallel resistors, the greatest current will exist in the branch with the least resistance.

A more powerful statement is that

current always seeks the path of least resistance.

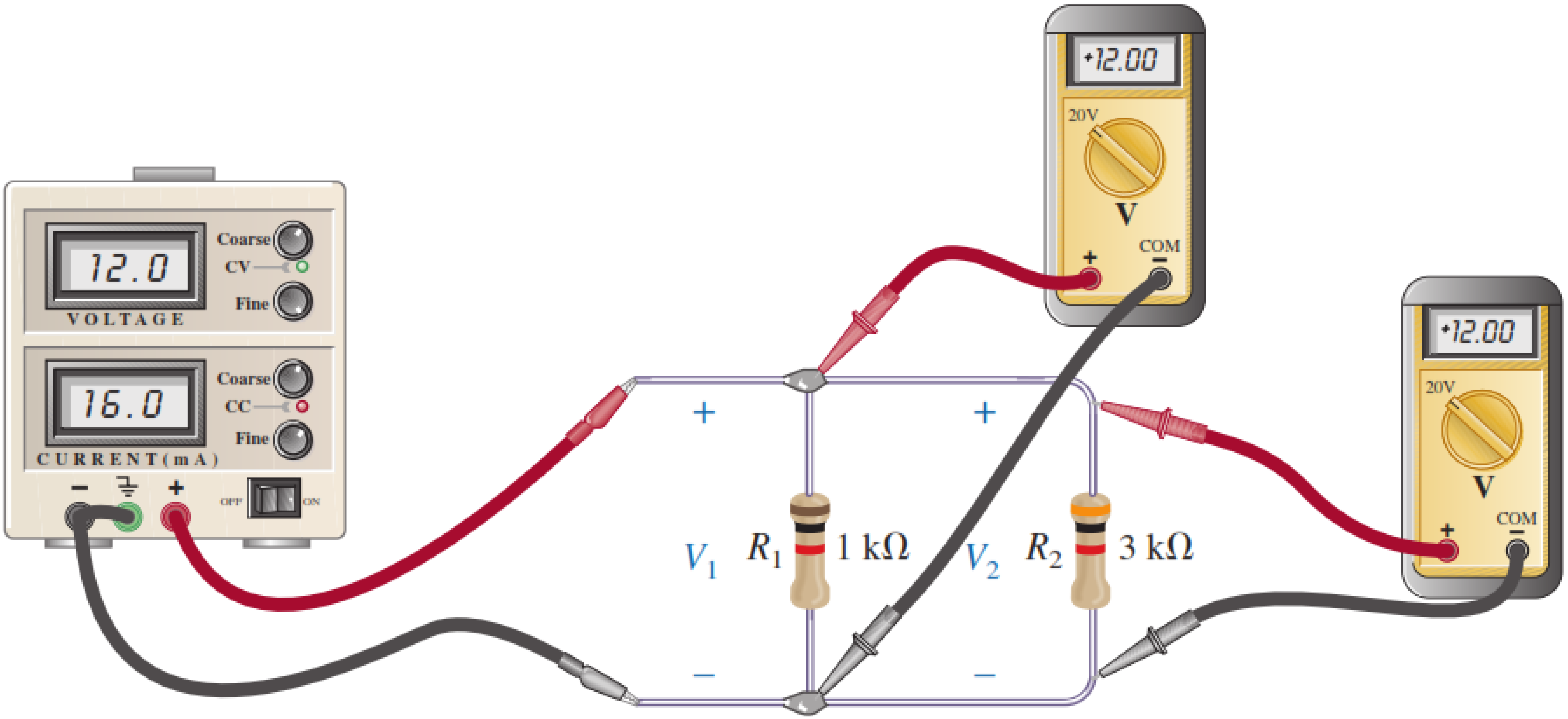


FIG. 6.26

Measuring the voltages of a parallel dc network.

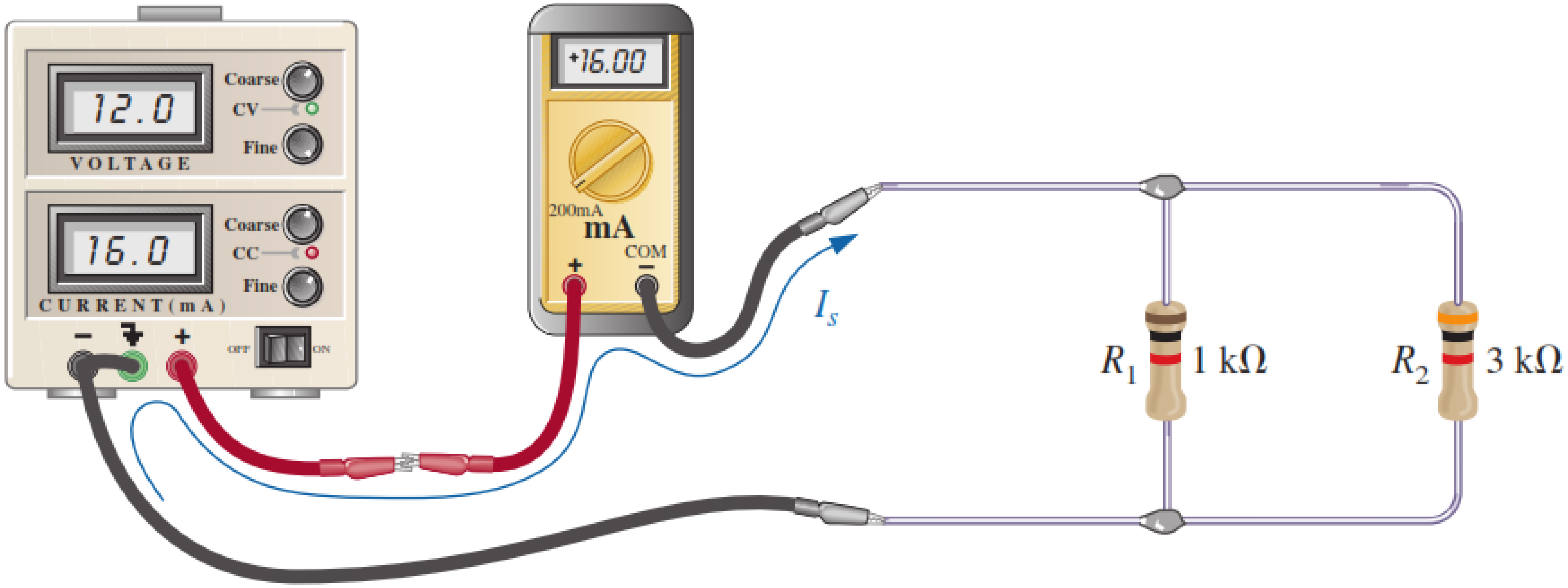
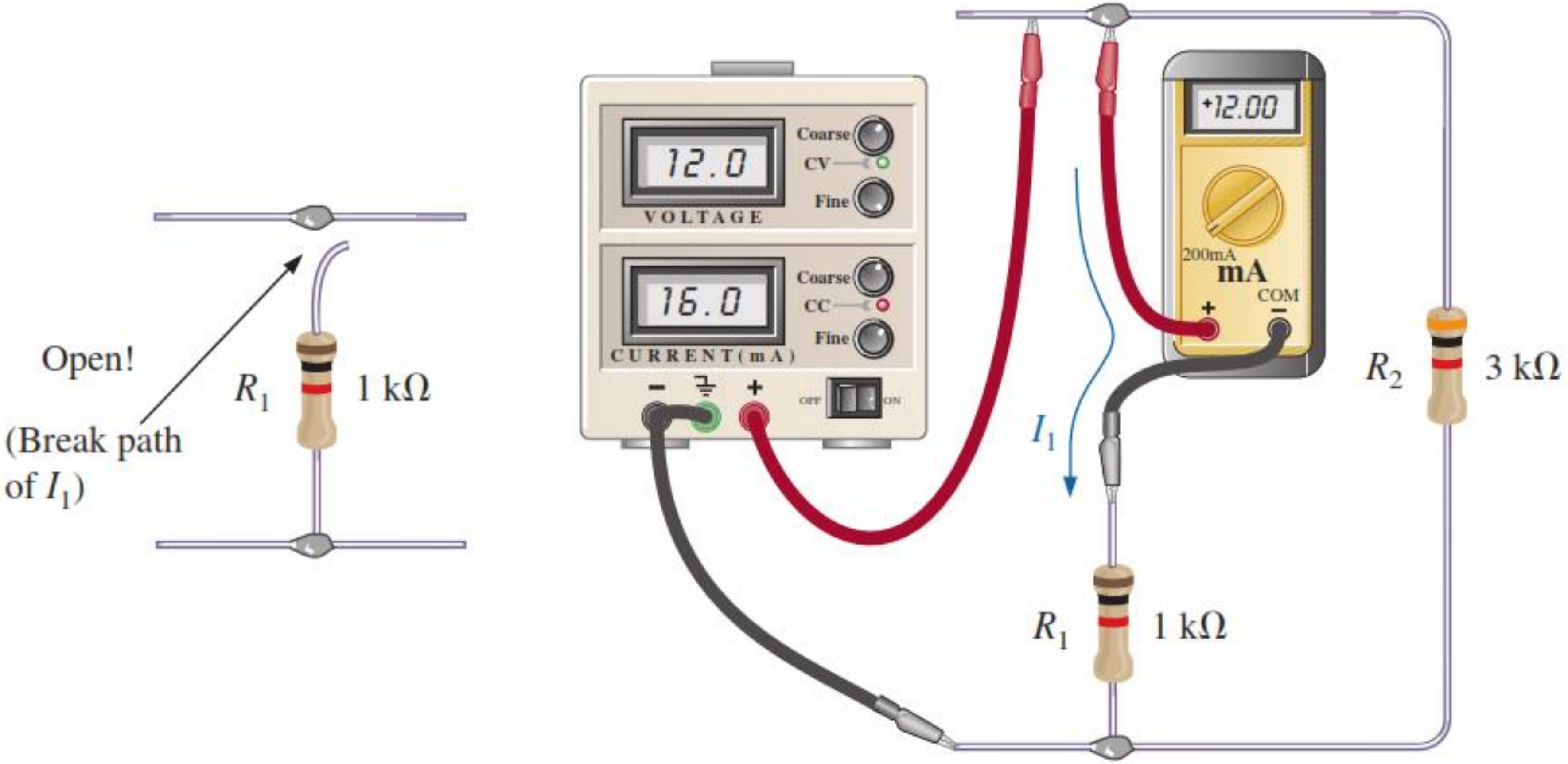


FIG. 6.27

Measuring the source current of a parallel network.



shown in Fig. 6.28(a), resistor R_1 must be disconnected from the upper connection point to establish an open circuit. The ammeter is then inserted between the resulting terminals so that the current enters the positive or red terminal, as shown in Fig. 6.28(b). Always remember: When using an ammeter, first establish an open circuit in the branch in which the current is to be measured, and then insert the meter.

6.4 POWER DISTRIBUTION IN A PARALLEL CIRCUIT

for any network composed of resistive elements, the power applied by the battery will equal that dissipated by the resistive elements.

For the parallel circuit in Fig. 6.29:

$$\boxed{P_E = P_{R_1} + P_{R_2} + P_{R_3}} \tag{6.10}$$

which is exactly the same as obtained for the series combination.

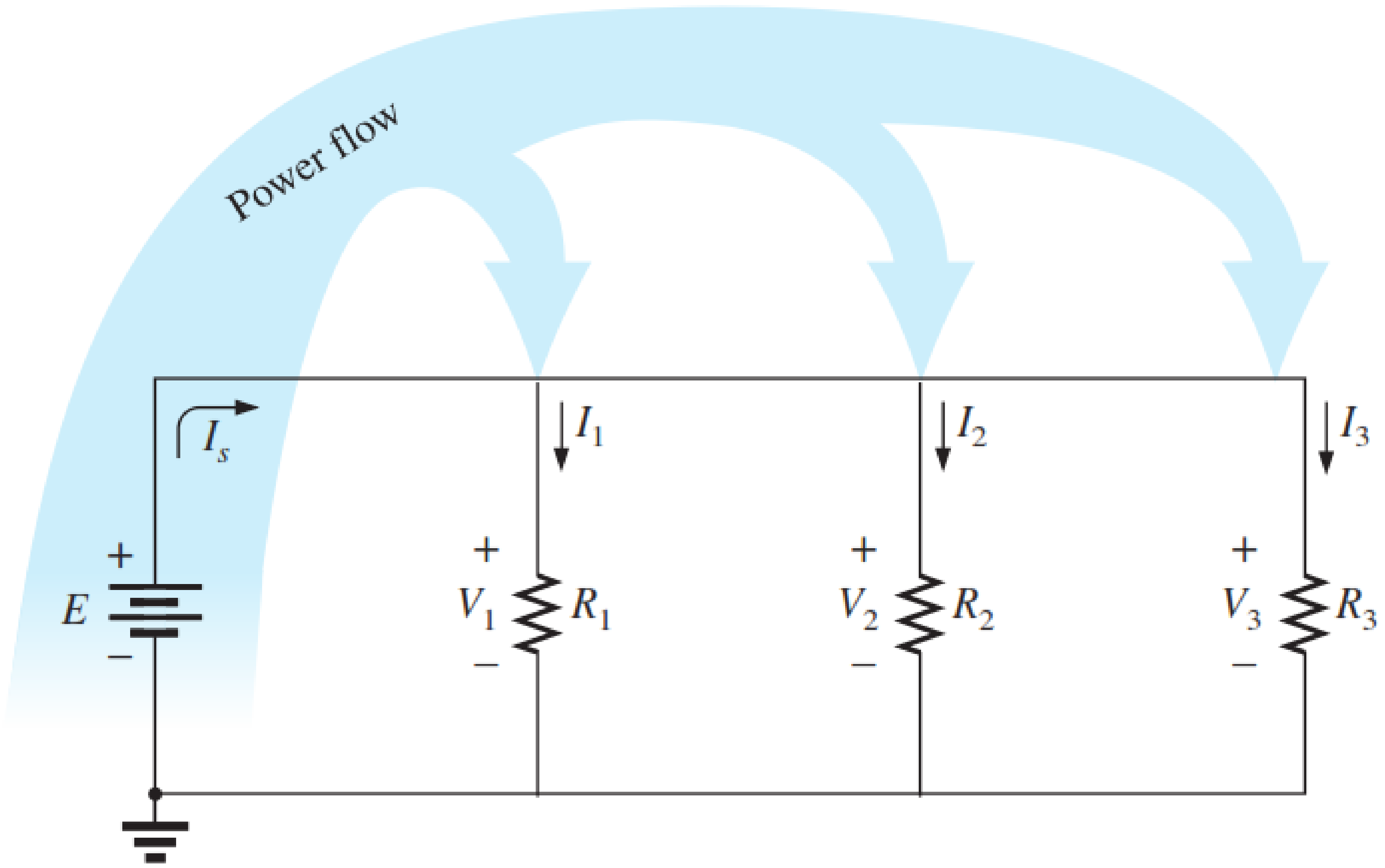


FIG. 6.29

Power flow in a dc parallel network.

The power delivered by the source in the same:

$$\boxed{P_E = EI_s} \qquad \text{(watts, W)} \tag{6.11}$$

as is the equation for the power to each resistor (shown for R_1 only):

$$\boxed{P_1 = V_1 I_1 = I_1^2 R_1 = \frac{V_1^2}{R_1}} \qquad \text{(watts, W)} \tag{6.12}$$

EXAMPLE 6.15 For the parallel network in Fig. 6.30 (all standard values):

a. Determine the total resistance R_T.
b. Find the source current and the current through each resistor.
c. Calculate the power delivered by the source.

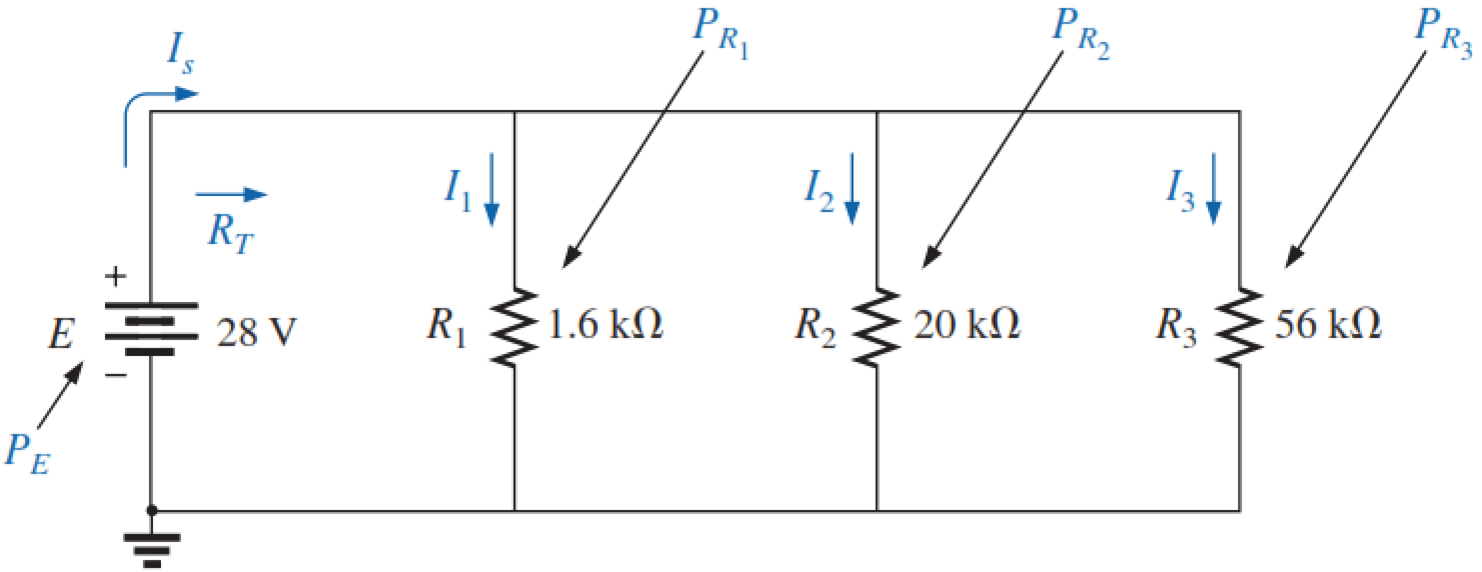


FIG. 6.30
Parallel network for Example 6.15.

KIRCHHOFF'S CURRENT LAW

The algebraic sum of the currents entering and leaving a junction (or region) of a network is zero.

The law can also be stated in the following way:

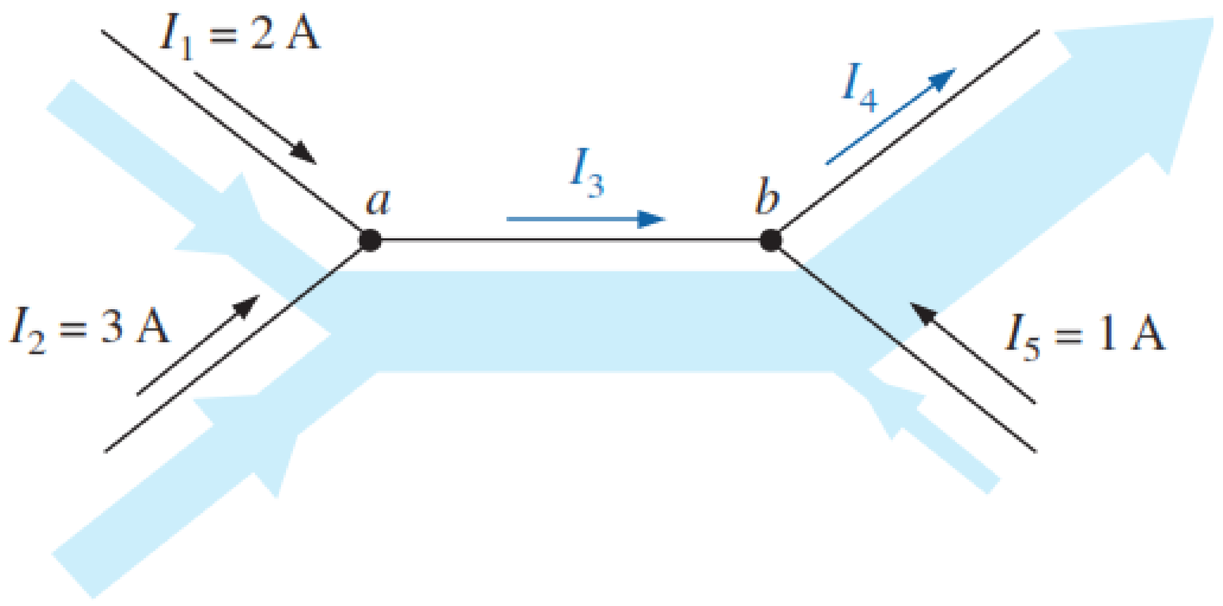
The sum of the currents entering a junction (or region) of a network must equal the sum of the currents leaving the same junction (or region).

In equation form, the above statement can be written as follows:

$$\boxed{\Sigma I_i = \Sigma I_o} \tag{6.13}$$

with I_i representing the current entering, or "in," and I_o representing the current leaving, or "out."

EXAMPLE 6.16 Determine currents I_3 and I_4 in Fig. 6.33 using Kirchhoff's current law.



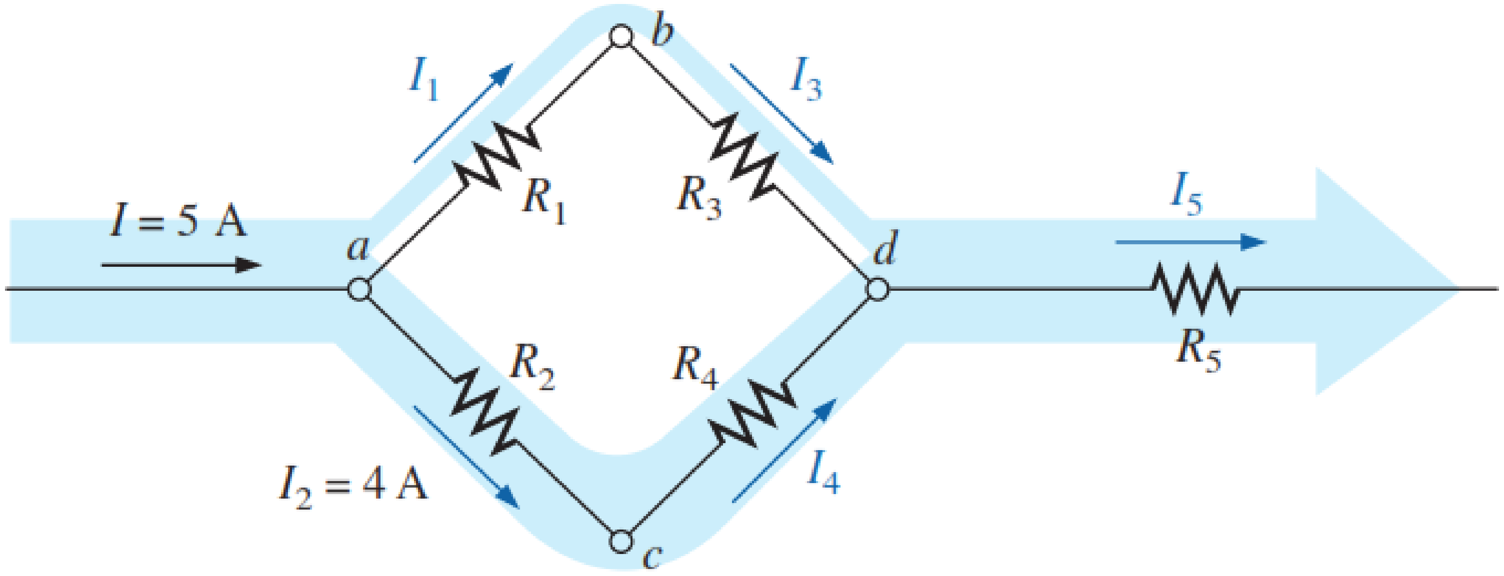
At node *a:*

$$\Sigma I_i = \Sigma I_o$$
$$I_1 + I_2 = I_3$$
$$2\text{ A} + 3\text{ A} = I_3 = \mathbf{5\text{ A}}$$

At node *b*, using the result just obtained:

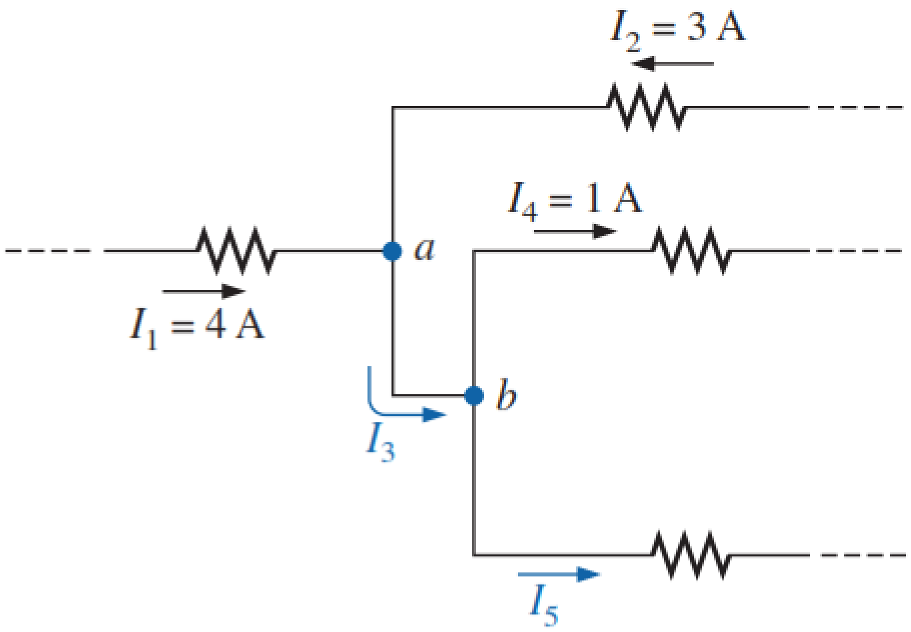
$$\Sigma I_i = \Sigma I_o$$
$$I_3 + I_5 = I_4$$
$$5\text{ A} + 1\text{ A} = I_4 = \mathbf{6\text{ A}}$$

EXAMPLE 6.17 Determine currents I_1, I_3, I_4, and I_5 for the network in Fig. 6.34.



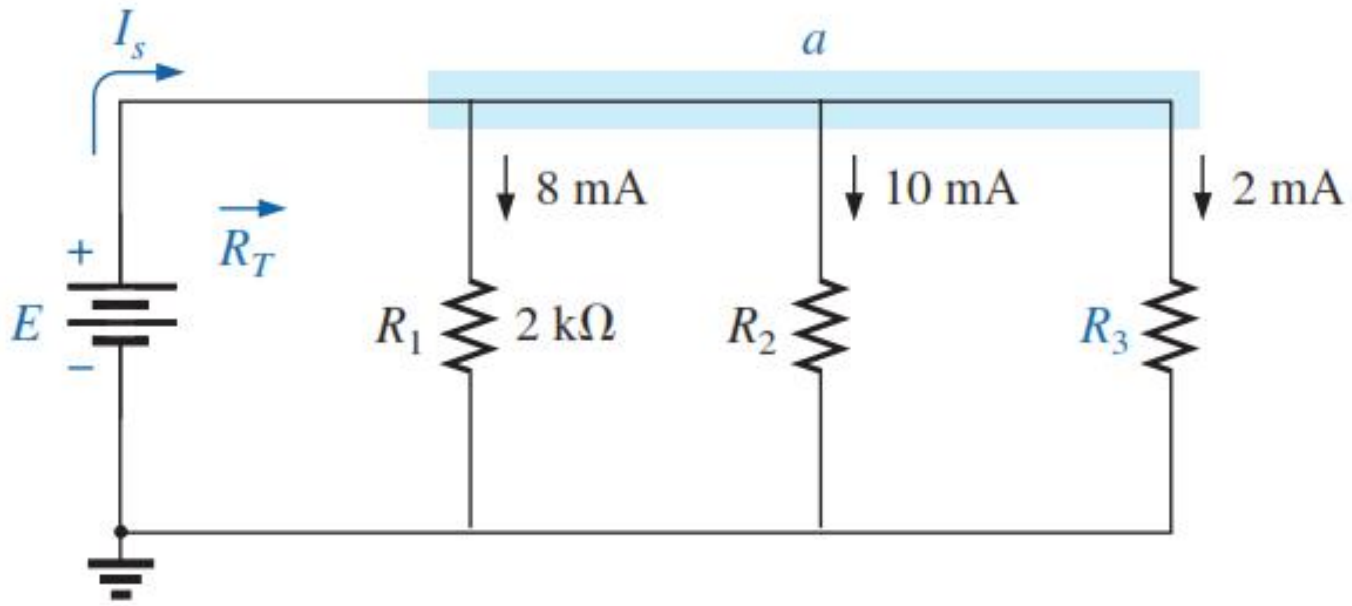
If we enclose the entire network, we find that the current entering from the far left is $I = 5$ A, while the current leaving from the far right is $I_5 = 5$ A. The two must be equal since the net current entering any system must equal the net current leaving.

EXAMPLE 6.18 Determine currents I_3 and I_5 in Fig. 6.35 through applications of Kirchhoff's current law.



EXAMPLE 6.19 For the parallel dc network in Fig. 6.36.

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



The application of Kirchhoff's current law is not limited to networks where all the internal connections are known or visible. For instance, all the currents of the integrated circuit in Fig. 6.38 are known except I_1. By treating the entire system (which could contain over a million elements) as a single node, we can apply Kirchhoff's current law as shown in Example 6.20.

With so many currents entering or leaving the system, it is difficult to know by inspection which direction should be assigned to I_1. *In such cases, simply make an assumption about the direction and then check out the result. If the result is negative, the wrong direction was assumed. If the result is positive, the correct direction was assumed. In either case, the magnitude of the current will be correct.*

EXAMPLE 6.20 Determine I_1 for the integrated circuit in Fig. 6.38.

Solution: Assuming that the current I_1 entering the chip results in the following when Kirchhoff's current law is applied:

$$\Sigma I_i = \Sigma I_o$$
$$I_1 + 10\text{ mA} + 4\text{ mA} + 8\text{ mA} = 5\text{ mA} + 4\text{ mA} + 2\text{ mA} + 6\text{ mA}$$
$$I_1 + 22\text{ mA} = 17\text{ mA}$$
$$I_1 = 17\text{ mA} - 22\text{ mA} = \mathbf{-5\text{ mA}}$$

We find that the direction for I_1 is *leaving* the IC, although the magnitude of 5 mA is correct.

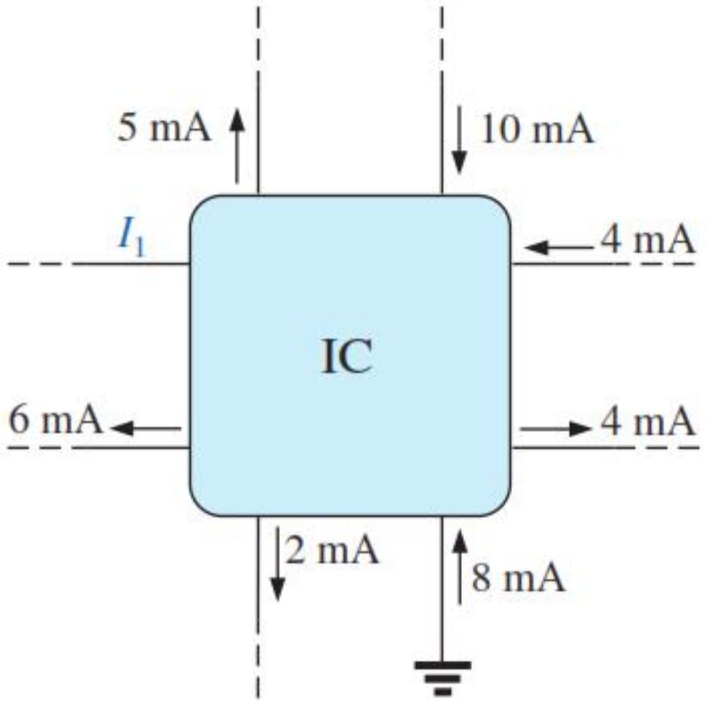


FIG. 6.38
Integrated circuit for Example 6.20.

As we leave this important section, be aware that Kirchhoff's current law will be applied in one form or another throughout the text. *Kirchhoff's laws are unquestionably two of the most important in this field because they are applicable to the most complex configurations in existence today*. They will not be replaced by a more important law or dropped for a more sophisticated approach.

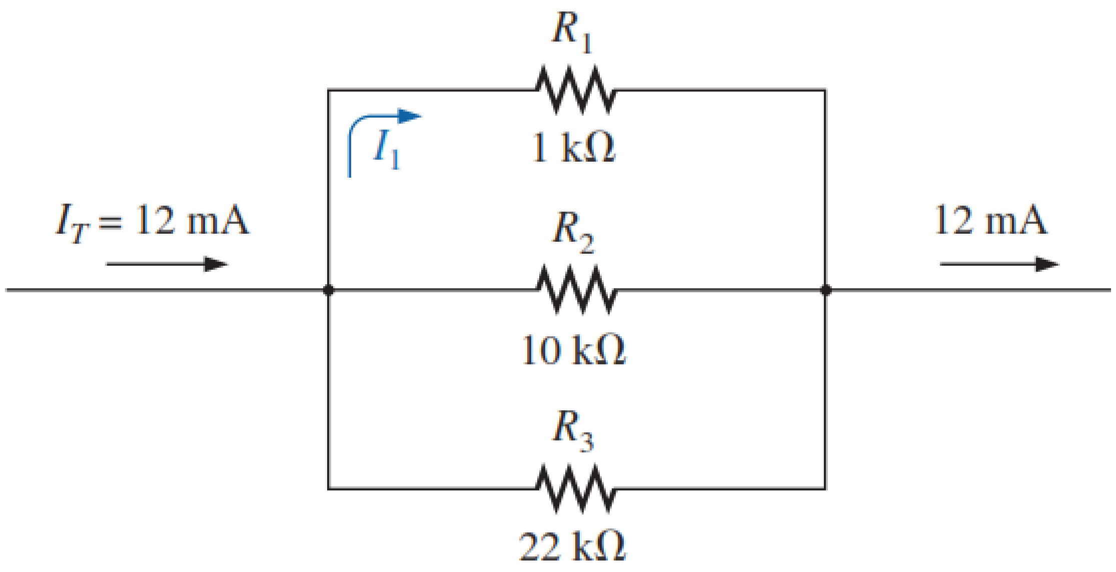
6.6 CURRENT DIVIDER RULE

For series circuits we have the powerful voltage divider rule for finding the voltage across a resistor in a series circuit. We now introduce the equally powerful **current divider rule (CDR)** for finding the current through a resistor in a parallel circuit.

the current through any branch of a parallel resistive network is equal to the total resistance of the parallel network divided by the resistor of interest and multiplied by the total current entering the parallel configuration.

$$\boxed{I_x = \frac{R_T}{R_x} I_T}$$

EXAMPLE 6.22 For the parallel network in Fig. 6.42, determine current I_1 using Eq. (6.14).



Solution: Eq. (6.3):

$$R_T = \cfrac{1}{\cfrac{1}{R_1} + \cfrac{1}{R_2} + \cfrac{1}{R_3}}$$

$$= \cfrac{1}{\cfrac{1}{1\ \text{k}\Omega} + \cfrac{1}{10\ \text{k}\Omega} + \cfrac{1}{22\ \text{k}\Omega}}$$

$$= \frac{1}{1 \times 10^{-3} + 100 \times 10^{-6} + 45.46 \times 10^{-6}}$$

$$= \frac{1}{1.145 \times 10^{-3}} = \mathbf{873.01\ \Omega}$$

Eq. (6.14): $I_1 = \dfrac{R_T}{R_1} I_T$

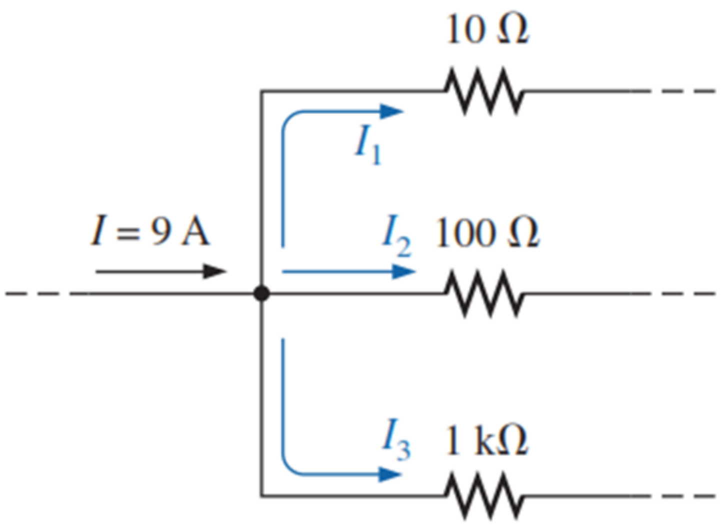
$$= \frac{(873.01\ \Omega)}{1\ \text{k}\Omega}(12\ \text{mA}) = (0.873)(12\ \text{mA}) = \mathbf{10.48\ mA}$$

and the smallest parallel resistor receives the majority of the current.

For two parallel elements of equal value, the current will divide equally.

For parallel elements with different values, the smaller the resistance, the greater the share of input current.

For parallel elements of different values, the current will split with a ratio equal to the inverse of their resistor values.



In Section 6.4, it was pointed out that current will always seek the path of least resistance. In Fig. 6.39, for example, the current of 9 A is faced with splitting between the three parallel resistors. Based on the previous sections, it should now be clear without a single calculation that the majority of the current will pass through the smallest resistor of 10 Ω, and the least current will pass through the 1 kΩ resistor.

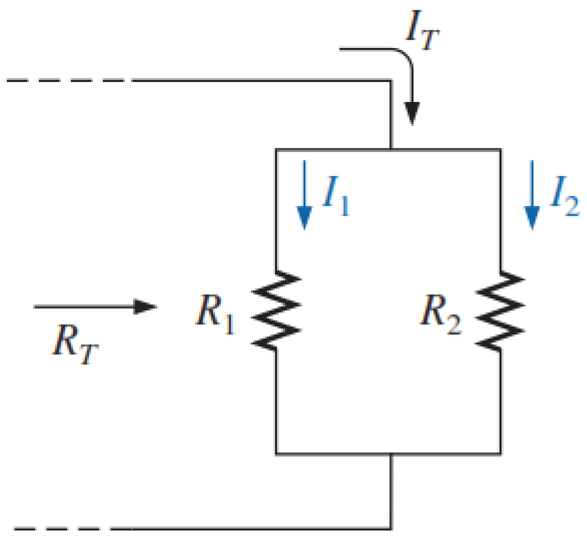
Special Case: Two Parallel Resistors

For the case of two parallel resistors as shown in Fig 6.43, the total resistance is determined by

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

Substituting R_T into Eq. (6.14) for current I_1 results in

$$I_1 = \frac{R_T}{R_1} I_T = \frac{\left(\dfrac{R_1 R_2}{R_1 + R_2}\right)}{R_1} I_T$$



and

$$\boxed{I_1 = \left(\frac{R_2}{R_1 + R_2}\right) I_T} \tag{6.15a}$$

Similarly, for I_2,

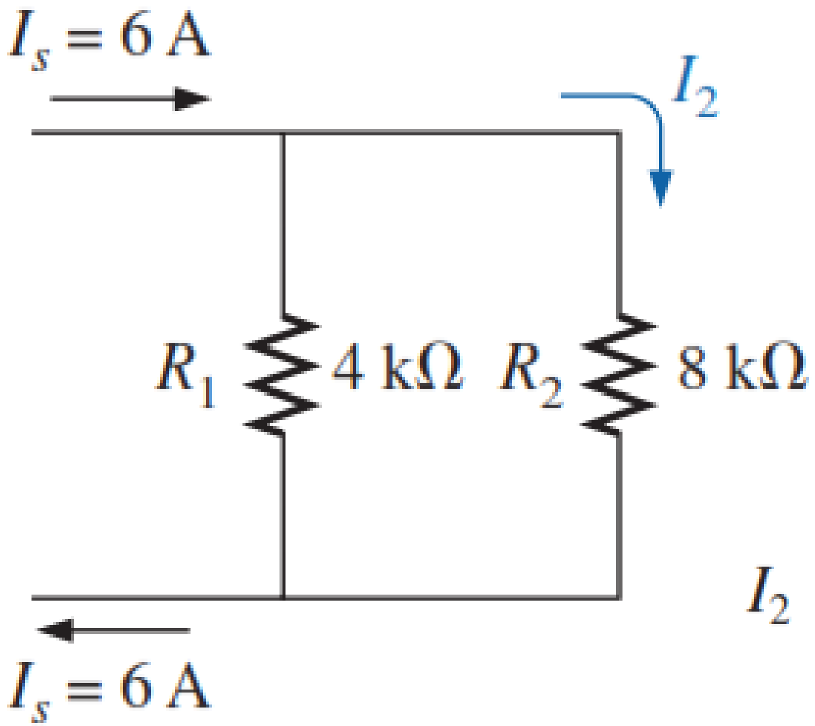
$$\boxed{I_2 = \left(\frac{R_1}{R_1 + R_2}\right) I_T} \tag{6.15b}$$

Eq. (6.15) states that

for two parallel resistors, the current through one is equal to the other resistor times the total entering current divided by the sum of the two resistors.

Since the combination of two parallel resistors is probably the most common parallel configuration, the simplicity of the format for Eq. (6.15) suggests that it is worth memorizing. Take particular note, however, that the denominator of the equation is simply the *sum,* not the total resistance, of the combination.

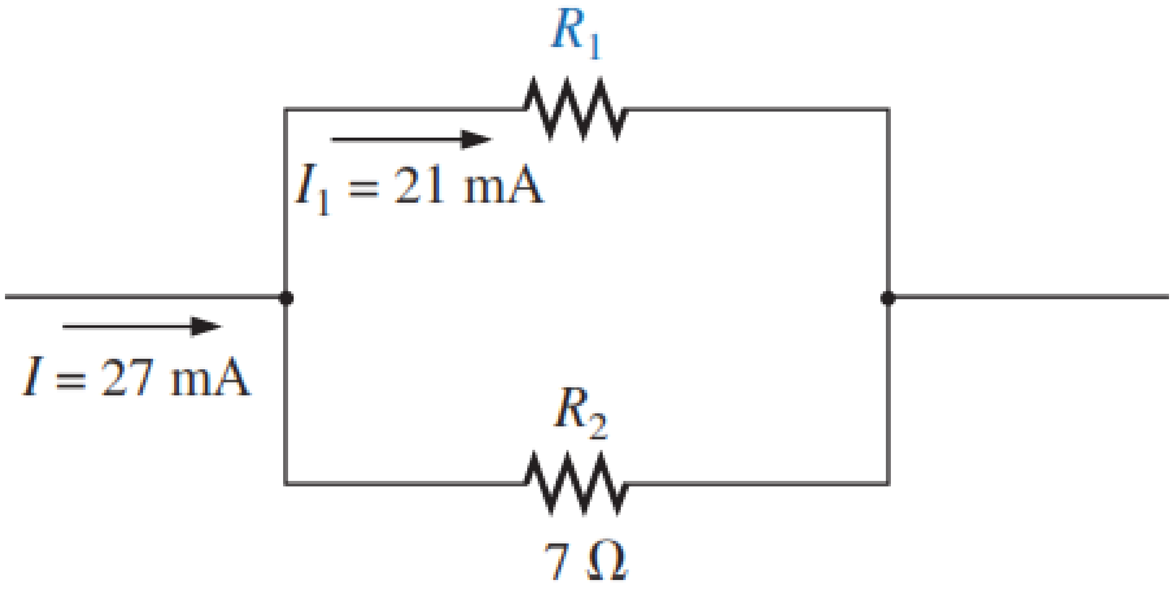
EXAMPLE 6.23 Determine current I_2 for the network in Fig. 6.44 using the current divider rule.

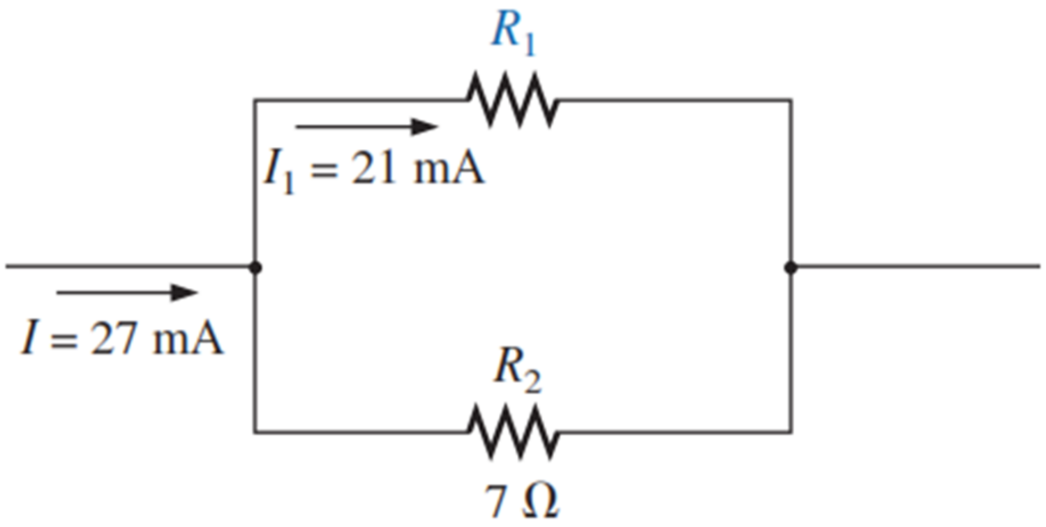


$$I_2 = \left(\frac{R_1}{R_1 + R_2}\right) I_T$$

$$= \left(\frac{4\text{ k}\Omega}{4\text{ k}\Omega + 8\text{ k}\Omega}\right) 6\text{ A} = (0.333)(6\text{ A}) = \mathbf{2\ A}$$

EXAMPLE 6.24 Determine resistor R_1 in Fig. 6.45 to implement the division of current shown.





Applying Kirchhoff's current law:

$$\Sigma I_i = \Sigma I_o$$

$$I = I_1 + I_2$$

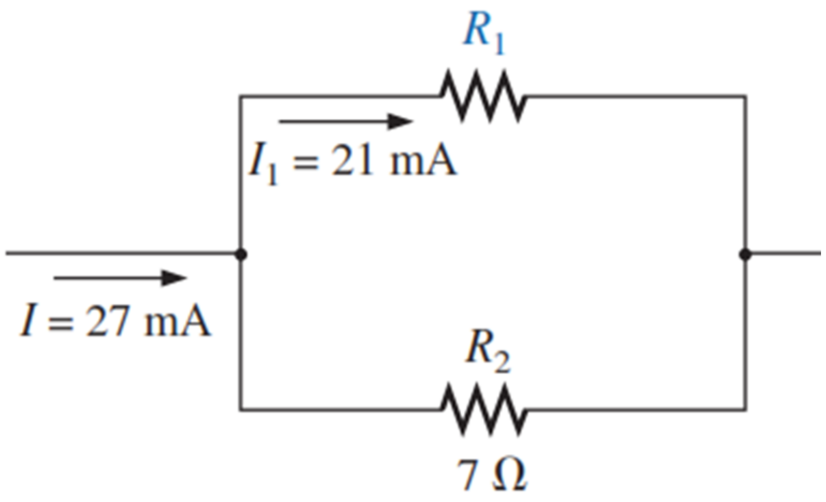
$$27\text{ mA} = 21\text{ mA} + I_2$$

and $$I_2 = 27\text{ mA} - 21\text{ mA} = 6\text{ mA}$$

The voltage V_2: $$V_2 = I_2R_2 = (6\text{ mA})(7\ \Omega) = 42\text{ mV}$$

so that $$V_1 = V_2 = 42\text{ mV}$$

Finally, $$R_1 = \frac{V_1}{I_1} = \frac{42\text{ mV}}{21\text{ mA}} = \mathbf{2\ \Omega}$$



Now for the other approach using the current divider rule:

$$I_1 = \frac{R_2}{R_1 + R_2} I_T$$

$$21 \text{ mA} = \left(\frac{7\ \Omega}{R_1 + 7\ \Omega}\right) 27 \text{ mA}$$

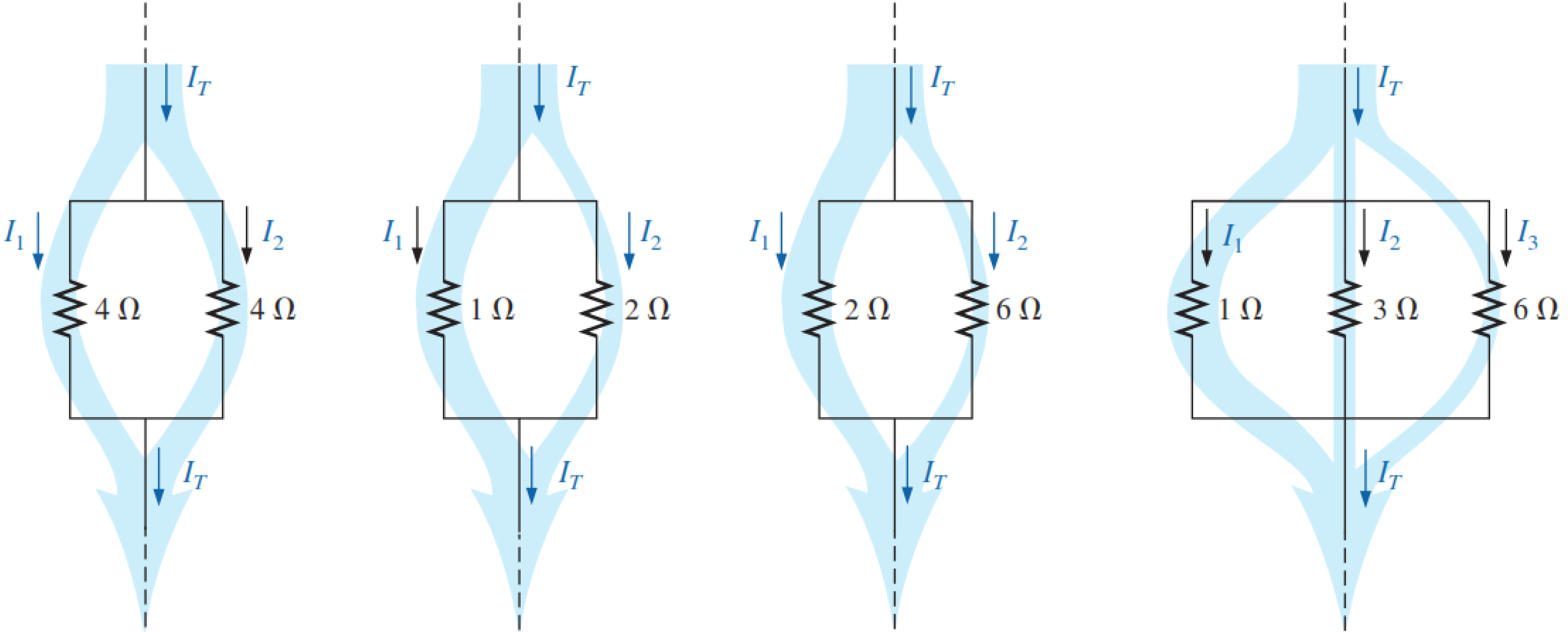
$$(R_1 + 7\ \Omega)(21 \text{ mA}) = (7\ \Omega)(27 \text{ mA})$$

$$(21 \text{ mA})R_1 + 147 \text{ mV} = 189 \text{ mV}$$

$$(21 \text{ mA})R_1 = 189 \text{ mV} - 147 \text{ mV} = 42 \text{ mV}$$

$$R_1 = \frac{42 \text{ mV}}{21 \text{ mA}} = \mathbf{2\ \Omega}$$

In summary, therefore, remember that current always seeks the path of least resistance, and the ratio of the resistor values is the inverse of the resulting current levels, as shown in Fig 6.46. The thickness of the blue bands in Fig. 6.46 reflects the relative magnitude of the current in each branch.



CIRCUIT BREAKERS AND FUSES

- Fuses and Circuit Breakers (CB) are used for the protection of power system. The basic function is to break the circuit in case of faulty conditions so as to protect the power system equipment and auxiliaries.

- FUSE is a low resistance device which is placed in the circuit for protection. Under faulty conditions when the current becomes more than the desired value, then due to the increase in temperature the fuse wire melts and breaks, thus breaking the circuit.

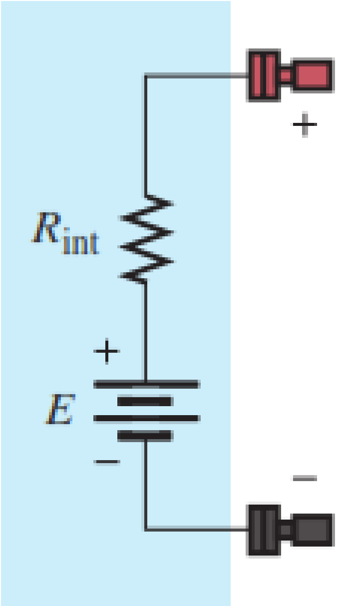
- These are used for lower power ratings and can be used only once, after that it has to be replaced with a new one.

- ✓ Circuit breaker is a switching device which can be operated manually as well as automatically for controlling and protection of electrical power system respectively.

- ✓ Comparing with the fuse which is a one-time device, the circuit breaker is a resettable device it can be used over and over again as well as a manual switch.

5.11 LOADING EFFECTS OF INSTRUMENTS

every practical (real-world) supply has an internal resistance in series with the idealized voltage source



Whenever you apply a meter to a circuit, you change the circuit and the response of the system. Fortunately, however, for most applications, considering the meters to be ideal is a valid approximation as long as certain factors are considered.

For instance,

any ammeter connected in a series circuit will introduce resistance to the series combination that will affect the current and voltages of the configuration.

The resistance between the terminals of an ammeter is determined by the chosen scale of the ammeter. In general,

for ammeters, the higher the maximum value of the current for a particular scale, the smaller the internal resistance will be.

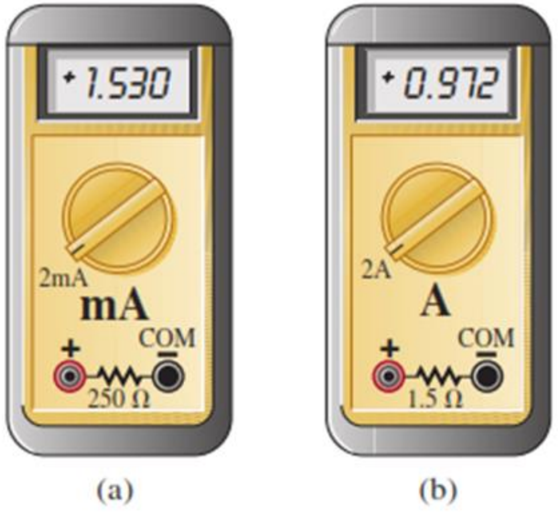
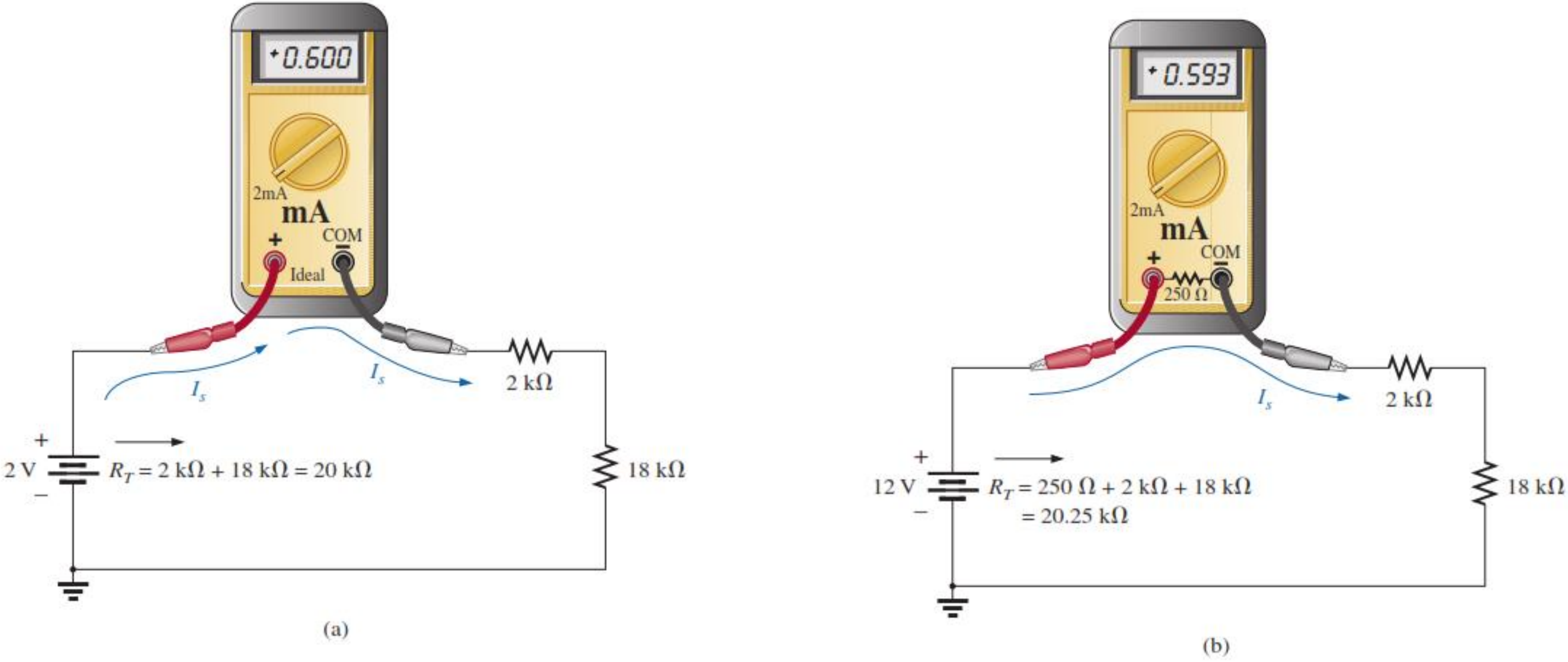


FIG. 5.73

Including the effects of the internal resistance of an ammeter: (a) 2 mA scale; (b) 2 A scale.



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

In summary, therefore, keep in mind that the insertion of an ammeter will add resistance to the branch and will affect the current and voltage levels. However, in most cases the effect is minimal, and the reading will provide a good first approximation to the actual level.

In previous chapters, we learned that ammeters are not ideal instruments. When you insert an ammeter, you actually introduce an additional resistance in series with the branch in which you are measuring the current. Generally, this is not a serious problem, but it can have a troubling effect on your readings, so it is important to be aware of it.

Voltmeters also have an internal resistance that appears between the two terminals of interest when a measurement is being made. While an ammeter places an additional resistance in series with the branch of interest, a voltmeter places an additional resistance *across* the element, as shown in Fig. 6.61. Since it appears in parallel with the element of interest, *the ideal level for the internal resistance of a voltmeter would be infinite ohms, just as zero ohms would be ideal for an ammeter.* Unfortunately, the internal resistance of any voltmeter is not infinite and changes from one type of meter to another.

Most digital meters have a fixed internal resistance level in the megohm range that remains the same *for all its scales.* For example, the meter in Fig. 6.61 has the typical level of 11 MΩ for its internal resistance, no matter which voltage scale is used. When the meter is placed across the 10 kΩ resistor, the total resistance of the combination is

$$R_T = 10\ \text{k}\Omega \,\|\, 11\ \text{M}\Omega = \frac{(10^4\,\Omega)(11 \times 10^6\,\Omega)}{10^4\,\Omega + (11 \times 10^6)} = 9.99\ \text{k}\Omega$$

and the behavior of the network is not seriously affected. The result, therefore, is that

most digital voltmeters can be used in circuits with resistances up to the high-kilohm range without concern for the effect of the internal resistance on the reading.

However, if the resistances are in the megohm range, you should investigate the effect of the internal resistance.

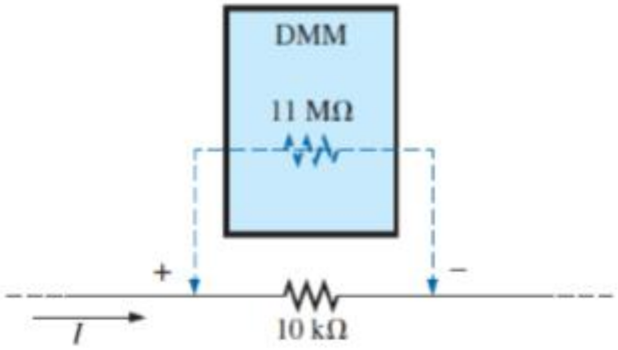
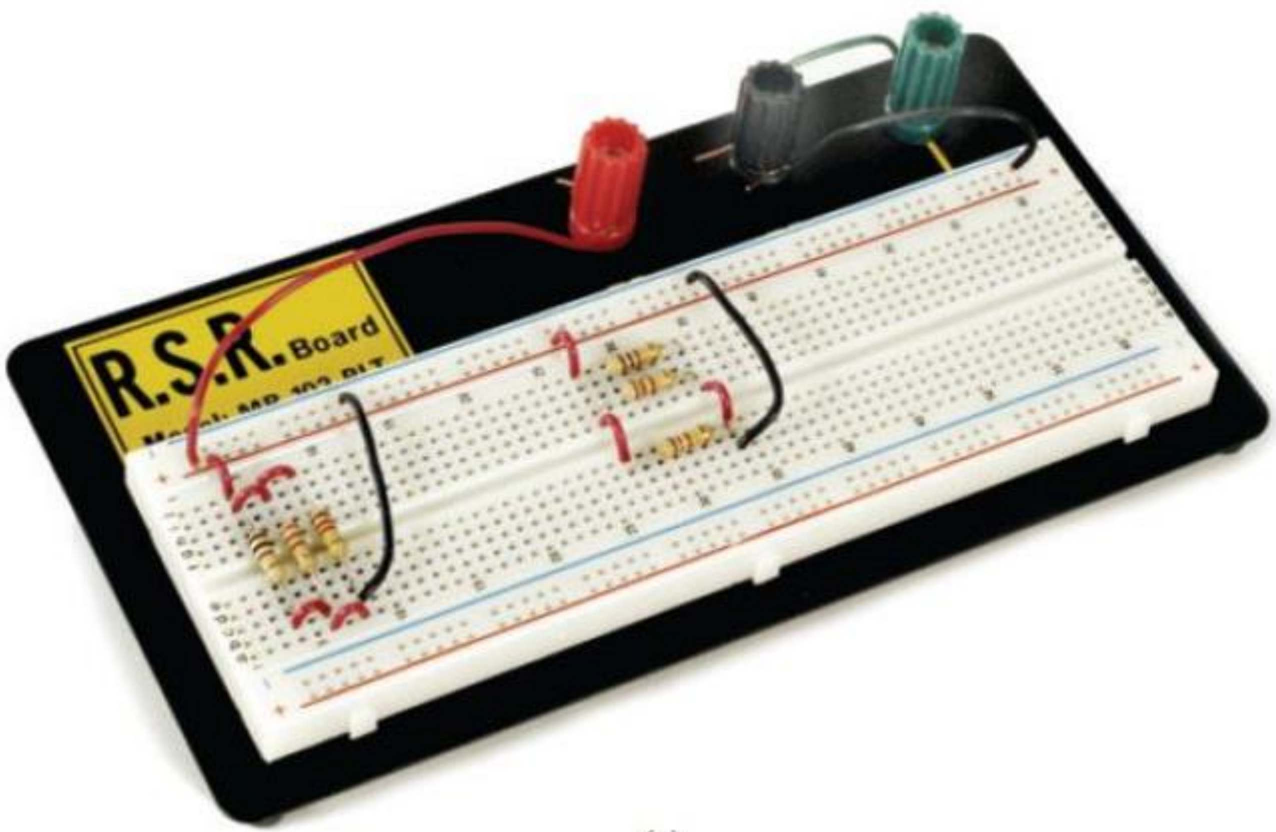
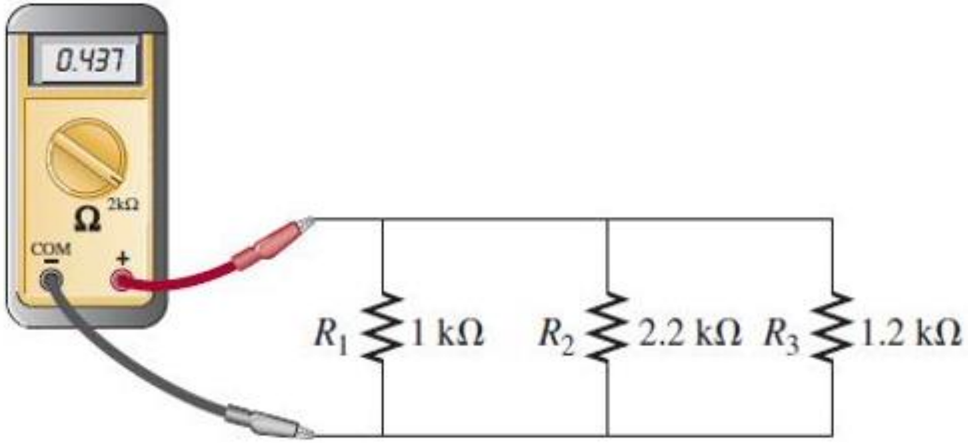


FIG. 6.61
Voltmeter loading.



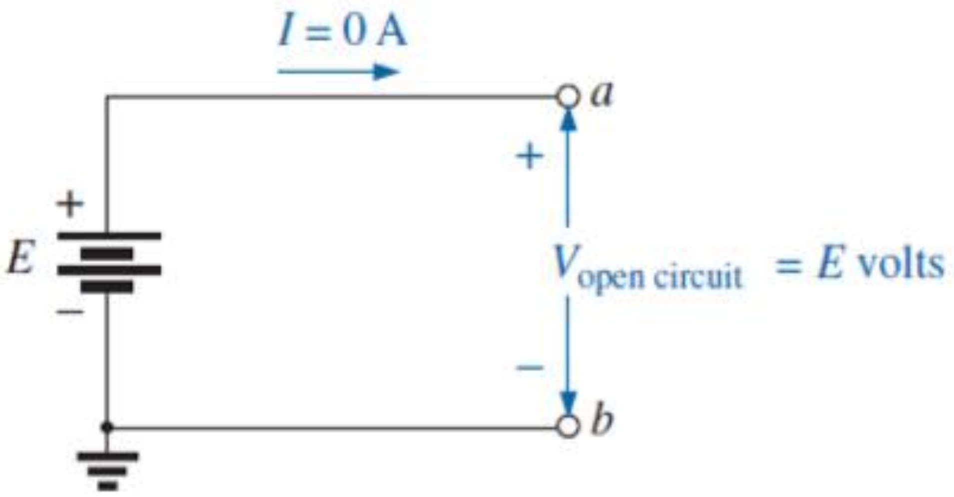
(a)



(b)

6.8 OPEN AND SHORT CIRCUITS

an open circuit can have a potential difference (voltage) across its terminals, but the current is always zero amperes.



In Fig. 6.49(b), an open circuit exists between terminals *a* and *b*. The voltage across the open-circuit terminals is the supply voltage, but the current is zero due to the absence of a complete circuit.

A **short circuit** is a very low resistance, direct connection between two terminals of a network, as shown in Fig. 6.51. The current through the short circuit can be any value, as determined by the system it is connected to, but the voltage across the short circuit is always zero volts because the resistance of the short circuit is assumed to be essentially zero ohms and $V = IR = I(0\ \Omega) = 0\ \text{V}$.

In summary, therefore,

a short circuit can carry a current of a level determined by the external circuit, but the potential difference (voltage) across its terminals is always zero volts.

In Fig. 51(a), the current through the 2 Ω resistor is 5 A. If a short circuit should develop across the 2 Ω resistor, the total resistance of the parallel combination of the 2 Ω resistor and the short (of essentially zero ohms) will be

$$2\,\Omega \parallel 0\,\Omega = \frac{(2\,\Omega)(0\,\Omega)}{2\,\Omega + 0\,\Omega} = 0\,\Omega$$

as indicated in Fig. 51(b), and the current will rise to very high levels, as determined by Ohm's law:

$$I = \frac{E}{R} = \frac{10\text{ V}}{0\,\Omega} \rightarrow \infty\text{ A}$$

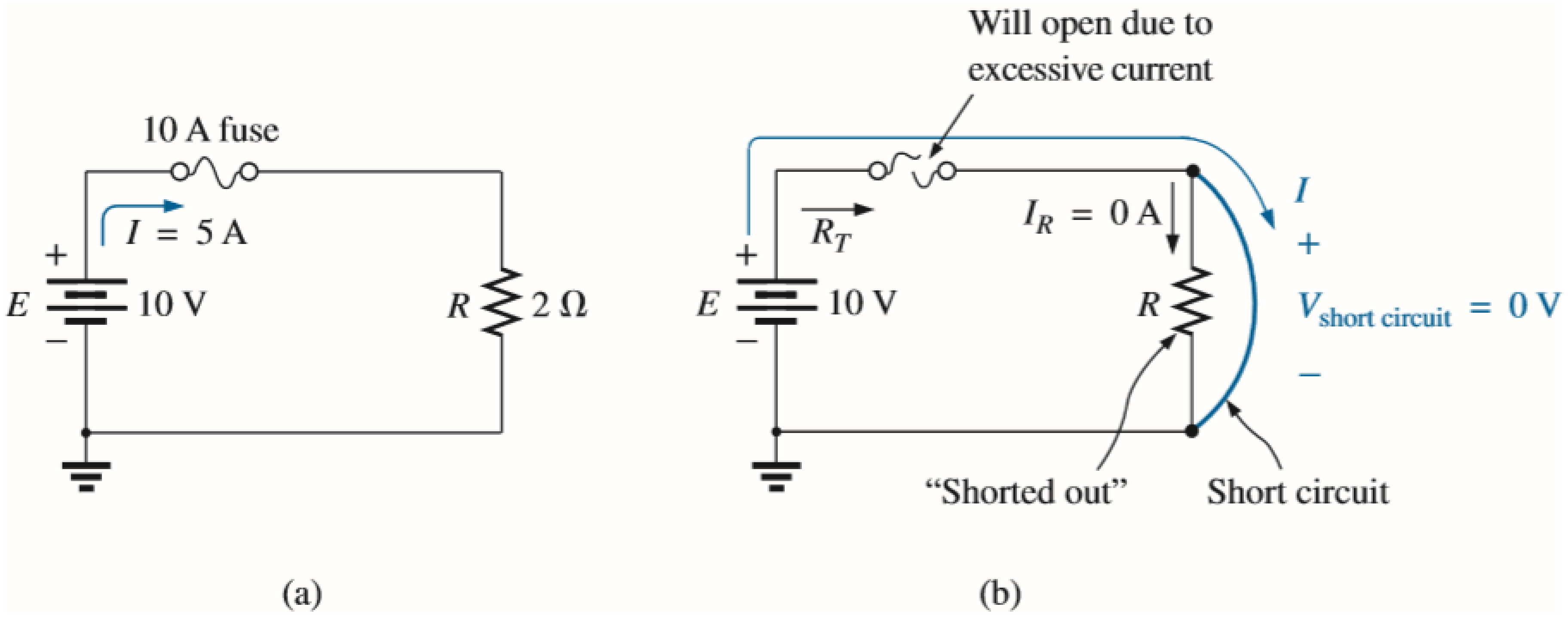


FIG. 51

Demonstrating the effect of a short circuit on current levels.

$$I = \frac{E}{R} = \frac{10\ \text{V}}{0\ \Omega} \rightarrow \infty\ \text{A}$$

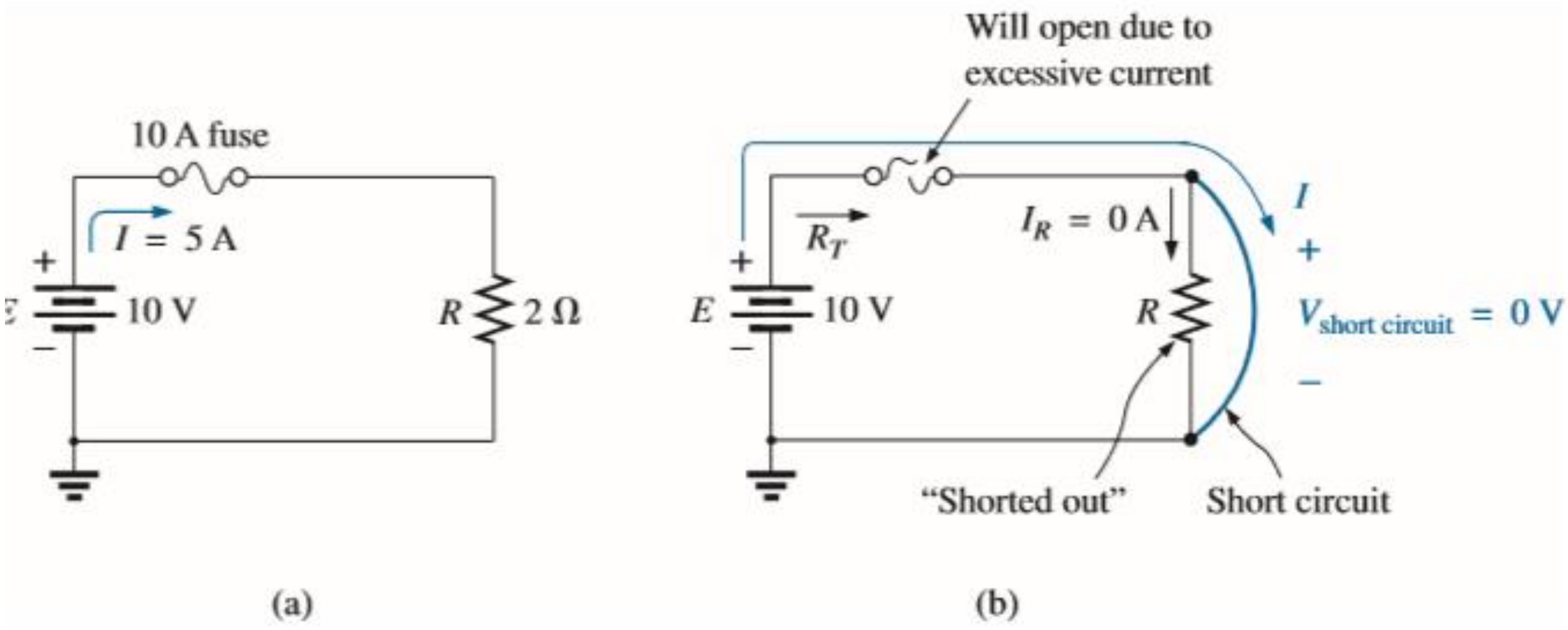


FIG. 51

Demonstrating the effect of a short circuit on current levels.

The effect of the 2 Ω resistor has effectively been "shorted out" by the low-resistance connection. The maximum current is now limited only by the circuit breaker or fuse in series with the source.

EXAMPLE 6.25 Determine voltage V_{ab} for the network in Fig. 6.54.

Solution: The open circuit requires that I be zero amperes. The voltage drop across both resistors is therefore zero volts since $V = IR = (0)R = 0$ V. Applying Kirchhoff's voltage law around the closed loop,

$$V_{ab} = E = \mathbf{20\ V}$$

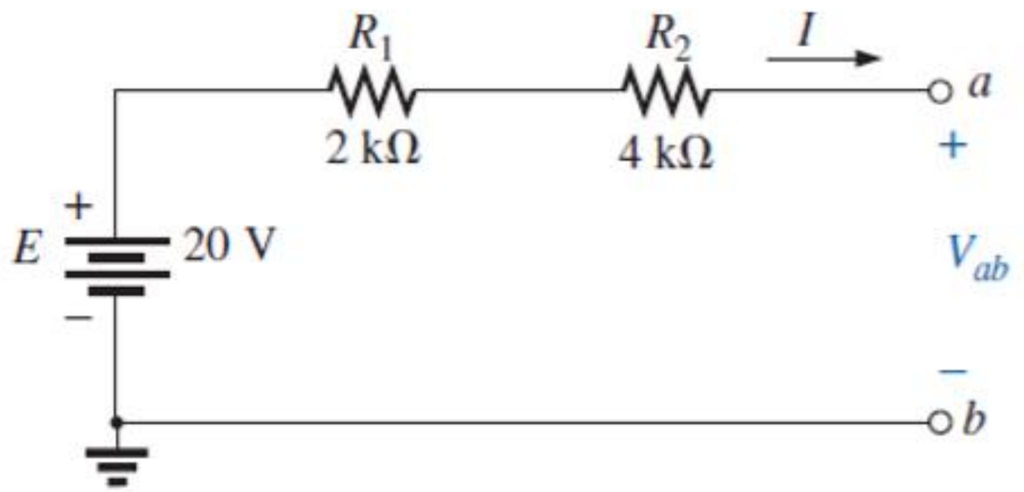


FIG. 6.54

EXAMPLE 26 Determine voltages V_{ab} and V_{cd} for the network in Fig. 54.

Solution: The current through the system is zero amperes due to the open circuit, resulting in a 0 V drop across each resistor. Both resistors can therefore be replaced by short circuits, as shown in Fig. 55. Voltage V_{ab} is then directly across the 10 V battery, and

$$V_{ab} = E_1 = \mathbf{10\ V}$$

Voltage V_{cd} requires an application of Kirchhoff's voltage law:

$$+E_1 - E_2 - V_{cd} = 0$$

or
$$V_{cd} = E_1 - E_2 = 10\text{ V} - 30\text{ V} = \mathbf{-20\ V}$$

The negative sign in the solution indicates that the actual voltage V_{cd} has the opposite polarity of that appearing in Fig. 54.

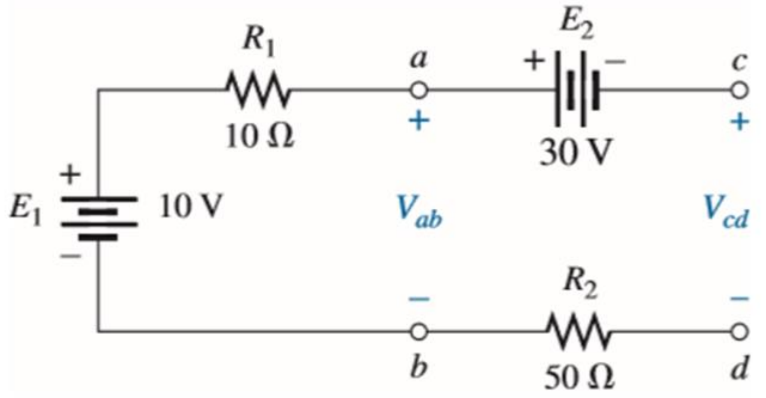


FIG. 54
Network for Example 26.

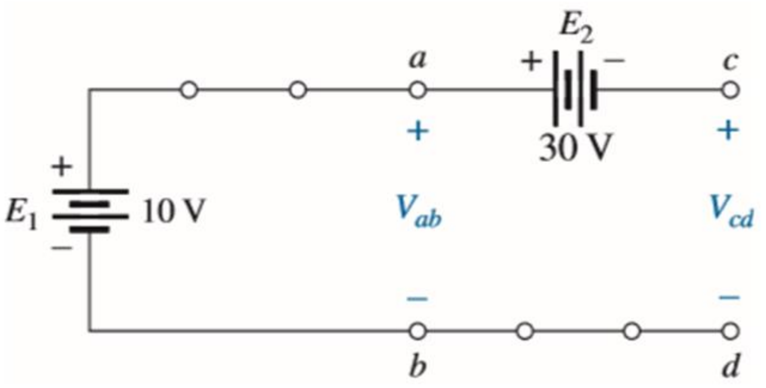
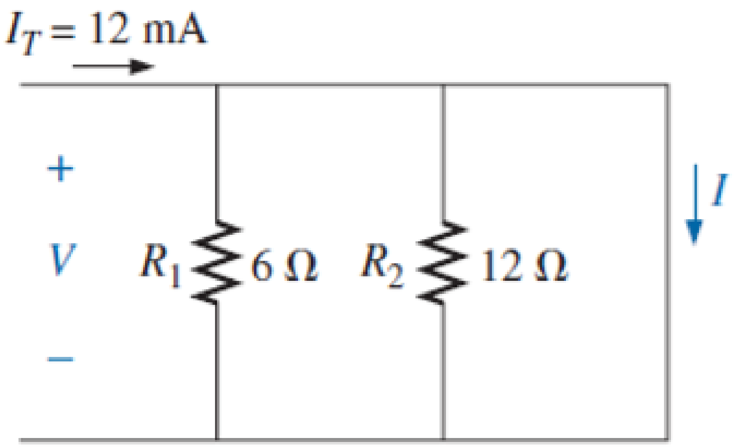


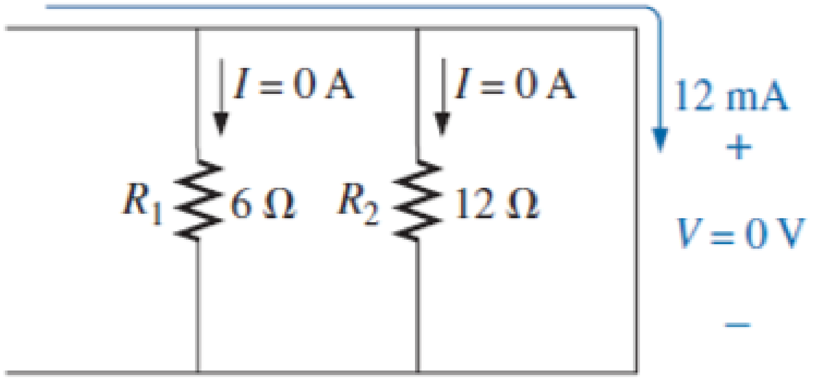
FIG. 55

EXAMPLE 6.27 Determine the unknown voltage and current for each network in Fig. 6.57.

Solution: For the network in Fig. 6.57(a), the current I_T will take the path of least resistance, and since the short-circuit condition at the end of the network is the least-resistance path, all the current will pass through the short circuit. This conclusion can be verified using the current divider rule. The voltage across the network is the same as that across the short circuit and will be zero volts, as shown in Fig. 6.58(a).

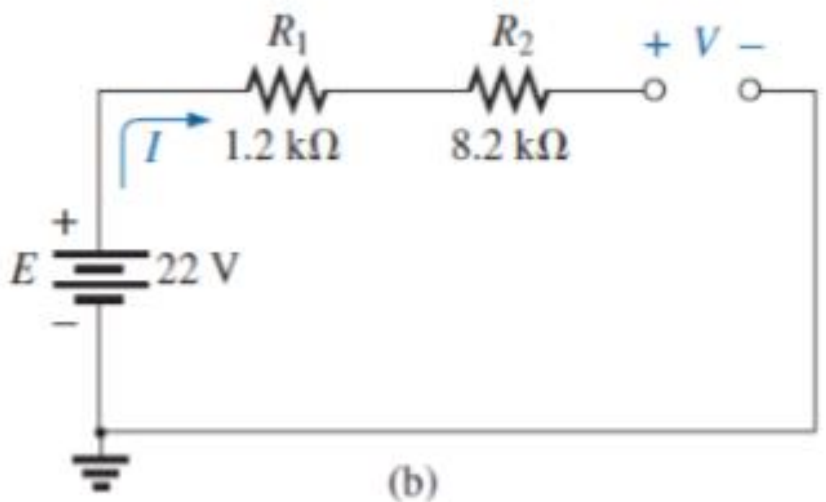


(a)

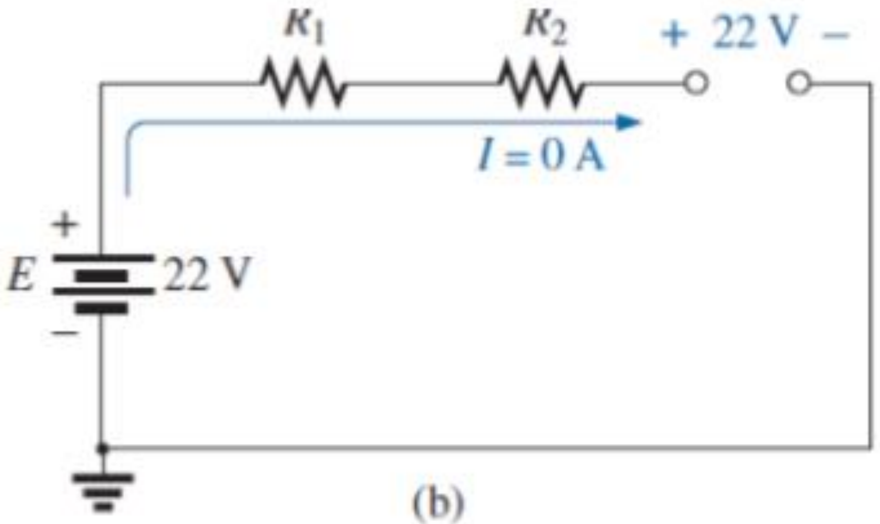


(a)

For the network in Fig. 6.57(b), the open-circuit condition requires that the current be zero amperes. The voltage drops across the resistors must therefore be zero volts, as determined by Ohm's law [$V_R = IR = (0)R = 0$ V], with the resistors acting as a connection from the supply to the open circuit. The result is that the open-circuit voltage is $E = 22$ V, as shown in Fig. 6.58(b).



(b)



(b)

EXAMPLE 6.28 Determine V and I for the network in Fig. 6.59 if resistor R_2 is shorted out.

Solution: The redrawn network appears in Fig. 6.60. The current through the 3 Ω resistor is zero due to the open circuit, causing all the current I to pass through the jumper. Since $V_{3\Omega} = IR = (0)R = 0$ V, the voltage V is directly across the short, and

$$V = \mathbf{0\ V}$$

with

$$I = \frac{E}{R_1} = \frac{6\text{ V}}{2\ \Omega} = \mathbf{3\ A}$$

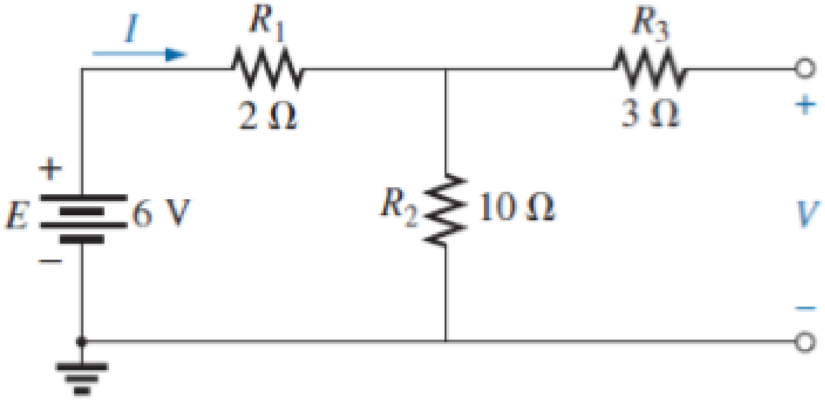


FIG. 6.59

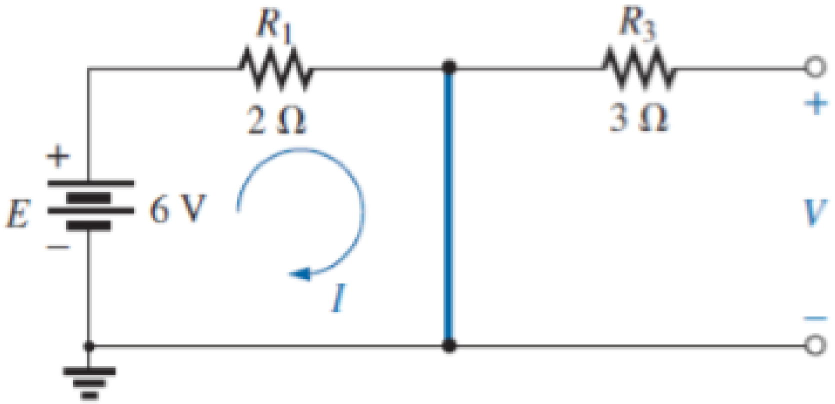


FIG. 6.60

Thank You!