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Open Circuits

As the name implies, an *open* is a gap, break, or interruption in a circuit path. No current can flow through an open, so no current can flow in a series circuit containing an open. Since no current can flow through it, an open has infinite resistance ($R = \infty$), which is consistent with Ohm's law:

$$I = \frac{E}{\infty} = 0$$

A circuit containing an open is said to be an *open circuit*, or to be *open-circuited*. Now, our definition implies that an open is a fault condition, or the result of a circuit failure of some type, and it is certainly true that an open circuit is a common result of component failure, or of disintegration of a conducting path, such as the breaking of a wire. However, in many situations, an open circuit is a normal and useful concept, particularly in circuit analysis. All practical circuits are designed to produce a certain amount of current, voltage, or power in some type of *load*, such as a lamp, electric motor, measuring instrument, loudspeaker, or electronic device. For analysis purposes, the load is often represented by its resistance, designated R_L, and in many cases it is useful to study circuit conditions when the load is removed, that is, when the load is open: $R_L = \infty$. We hear, for example, phrases such as "the open-circuit load voltage," or "the output voltage when the load is open."

It is a common error to believe that since the current in an open is zero, the voltage across the open must also be zero. That is certainly not the case, and the reader should take time to reflect on why it is not. Many examples come to mind, one of the most convincing being the voltage across the terminals of a battery having no circuitry connected to it. Another example is the voltage across terminals *a–b* in Example 4.5, which we found to be 16 V. Certainly there is no current flowing from *a* to *b* in that example.

Example 4.6 (Analysis)

What is the voltage V across the switch terminals in Figure 4.13 when the switch is opened?

SOLUTION When the switch is open, there is no current in the circuit. Consequently, *there is zero voltage drop across the resistors*. Therefore, by Kirchhoff's voltage law, the voltage across the switch terminals must be the same as the source voltage:

$$V = 60\ \text{V}$$

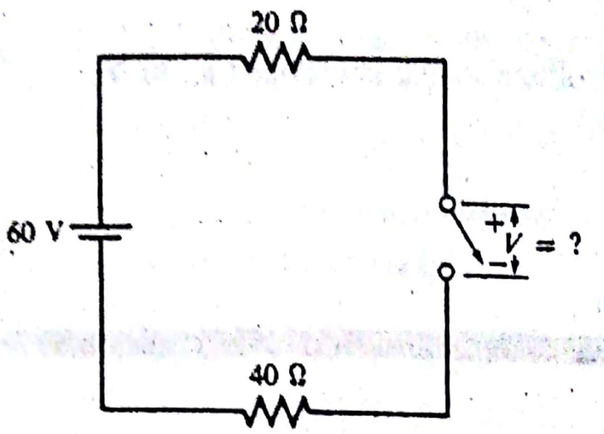

FIGURE 4.13 (Example 4.6)

Since I = 0 so no voltage drop so all source voltage will go to V terminal i.e 60 V

Example 4.7 (Troubleshooting)

None of the bulbs in a string of series-connected Christmas tree lights illuminate when the string is plugged in. The voltage measured at the wall outlet is 120 V. What is the problem? What measurement(s) would further confirm the diagnosis? Are there any dangerous voltages in the circuit?

SOLUTION Since none of the bulbs illuminate, there is no current in the circuit. Therefore, one of the bulbs, or the wire connecting them, is open. (The fact that there is voltage at the wall outlet tells us that a circuit breaker or fuse has not opened the circuit.) The voltage measured across each bulb is 0 V because there is no voltage drop across any bulb.

Although there is zero voltage across each bulb, there is still 120 V between the low side of the outlet and any point in the string lying on the outlet side of the break (see Figure 4.14).

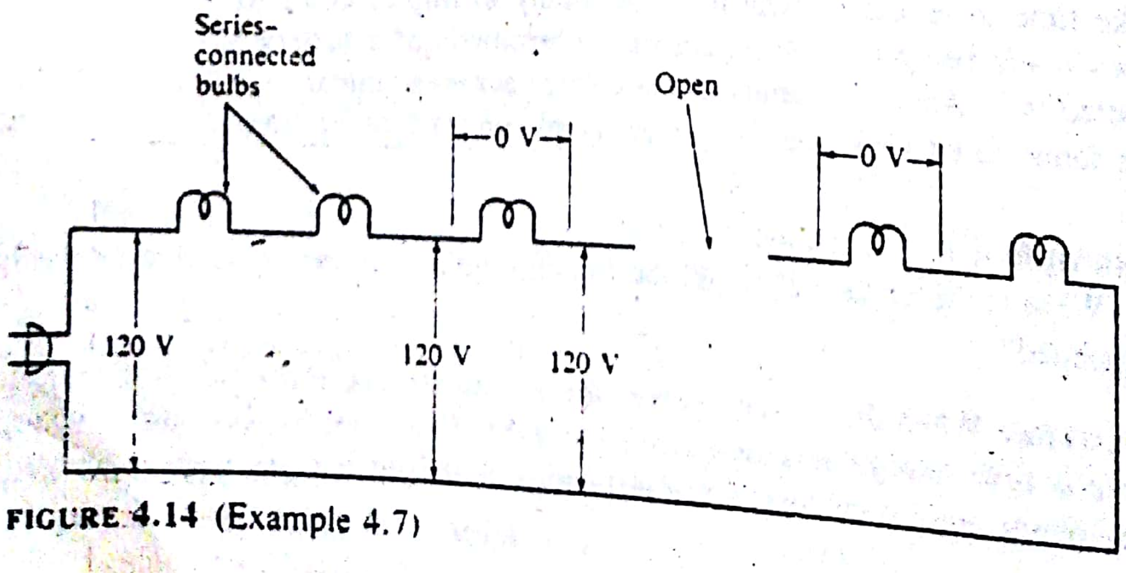

FIGURE 4.14 (Example 4.7)

Series-Connected Sources

Two or more voltage sources can be connected in series, or as components in a series path, or in a series circuit. If two series-connected sources tend to produce current in the same direction, they are said to be *series-aiding*, and their net effect on the circuit is the same as that of a single source whose voltage equals the *sum* of the two source voltages. As shown in Figure 4.15(a), the series-aiding connection is formed by connecting the positive terminal of one source to the negative terminal of the other.

When the two series sources are connected so that they tend to produce current in opposite directions, they are said to be *series-opposing*. The net effect on the circuit is the same as that of a single source equal in magnitude to the *difference* between the source voltages and having the same polarity as the larger of the two. This connection is formed by connecting terminals of like polarity (+ to + or − to −), as shown in Figure 4.15(b).

The results we have described can be extended in an obvious way to three or more sources. Note that Kirchhoff's voltage law can be used to determine the net voltage (called the *resultant*) of series-connected sources between any pair of terminals in a circuit. If voltage sources are in the same series path, but not necessarily connected directly to each other, the net effect on the circuit can still be determined by replacing them with a single equivalent source having the resultant voltage.

Example 4.8 (Analysis)

(a) Find the current in the circuit shown in Figure 4.16.

(b) Find V_{ab}.

SOLUTION

(a) Voltage sources E_1 and E_2 both tend to produce current in a clockwise direction in the circuit, while E_3 tends to produce current in a counterclockwise direction. The total resultant voltage, E_T, is therefore

$$E_T = 12\text{ V} + 25\text{ V} - 15\text{ V} = 22\text{ V}$$

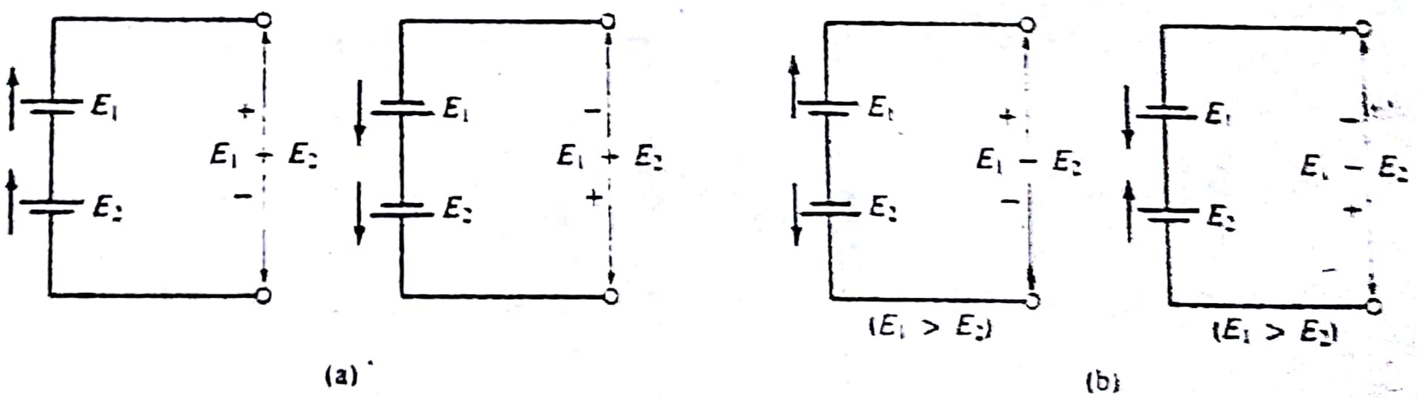

FIGURE 4.15 Series-connected voltage sources. (a) Series-aiding connections. Both sources tend to produce current in the same direction and the net voltage equals the sum of the two. (b) Series-opposing connections. The sources tend to produce current in opposite directions and the net voltage equals the difference between the two.

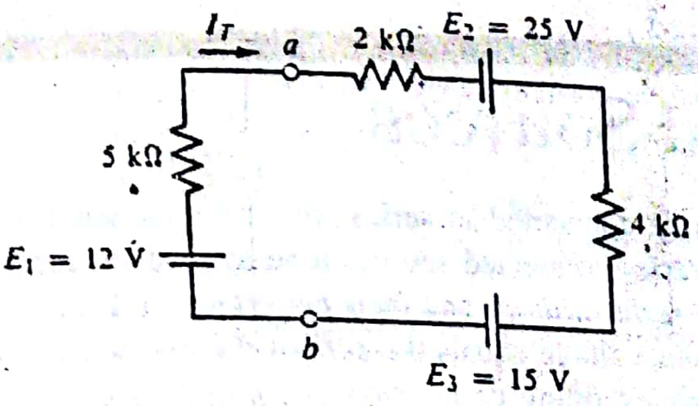

FIGURE 4.16 (Example 4.8)

E_T has the same polarity as E_1 and E_2, as shown in Figure 4.17(a). The total current in the series circuit is then

$$I_T = \frac{E_T}{R_T} = \frac{22\ \text{V}}{11\ \text{k}\Omega} = 2\ \text{mA}$$

(b) To determine V_{ab}, we must restore the original sources to the circuit, as shown in Figure 4.17(b). Since we have already found the current in the circuit, we can find the drop across the 5-kΩ resistor:

$$V_{5\ \text{k}\Omega} = (2\ \text{mA})(5\ \text{k}\Omega) = 10\ \text{V}$$

Figure 4.17(b) shows two closed loops, either one of which can be used to write Kirchhoff's voltage law and find V_{ab}. Using loop 1, we find

$$12 = 10 + V_{ab}$$

or

$$V_{ab} = 2\ \text{V}$$

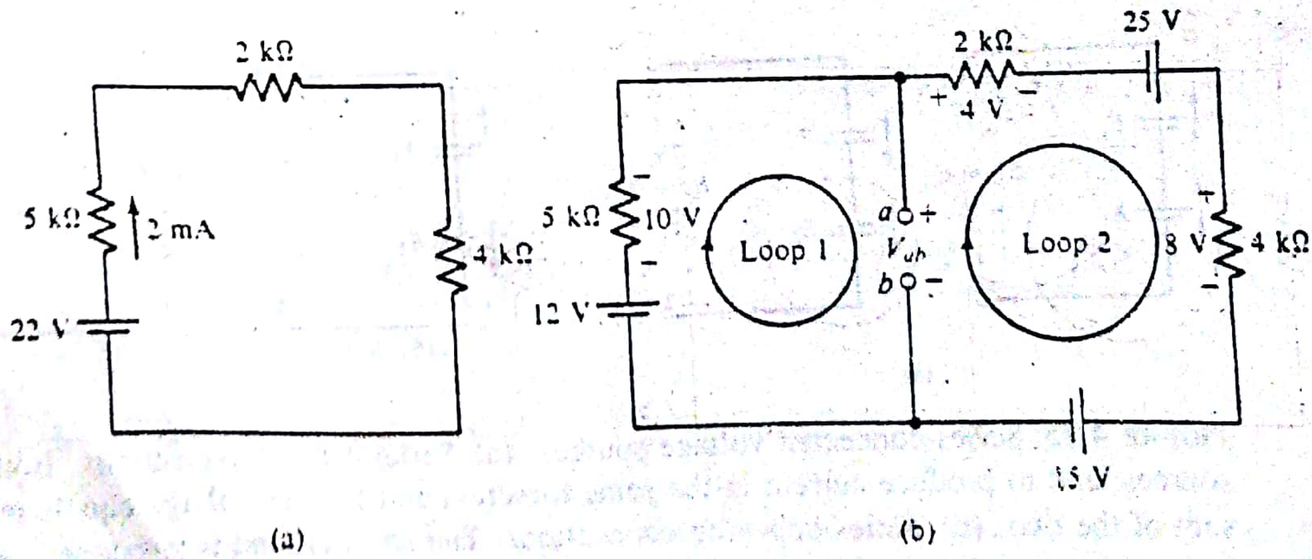

FIGURE 4.17 (Example 4.8)

Using loop 2, we find

$$V_{ab} + 25 = 4 + 8 + 15$$

or

$$V_{ab} = 2 \text{ V}$$

Drill Exercise 4.8

Repeat Example 4.8 when the polarity of E_2 in Figure 4.16 is reversed.

ANSWER: $I_T = 2.545$ mA, $V_{ab} = 24.727$ V. □

Current sources are not connected in series. Recall that an ideal current source produces the same, constant current in any circuit connected to it. It is an obvious contradiction to expect a current source that produces one value of current to maintain it in another current source that maintains a different value.