

Chapter 26

Direct-Current Circuits

PowerPoint® Lectures for
University Physics, Thirteenth Edition
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Lectures by Wayne Anderson

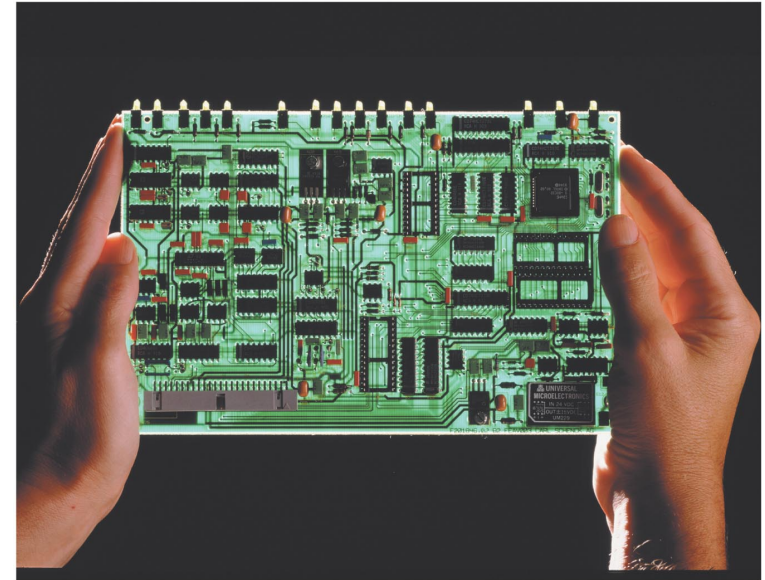
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Goals for Chapter 26

- To analyze circuits having resistors in series and parallel
- To apply Kirchhoff's rules to multiloop circuits
- To learn how to use various types of meters in a circuit
- To analyze circuits containing capacitors and resistors
- To study power distribution in the home

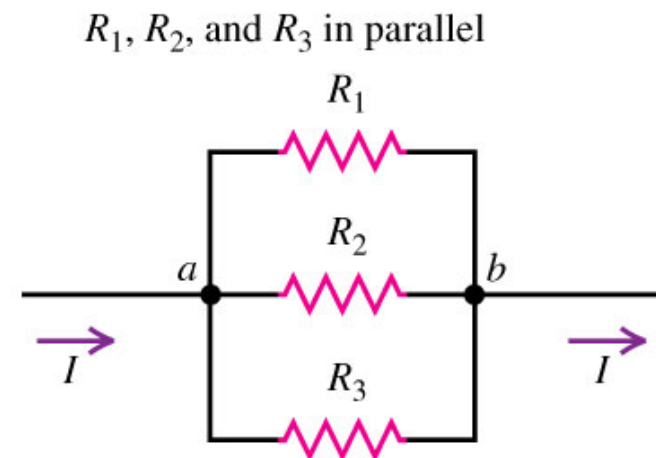
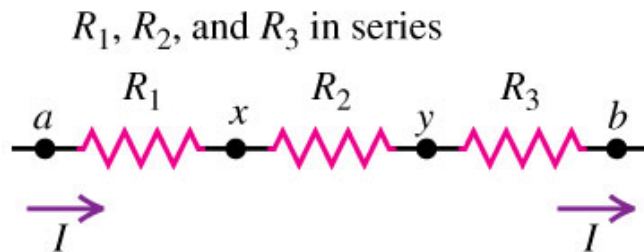
Introduction

- How can we apply series/parallel combinations of resistors to a complex circuit board?
- In this chapter, we will learn general methods for analyzing more complex networks.
- We shall look at various instruments for measuring electrical quantities in circuits.



Resistors in series and parallel

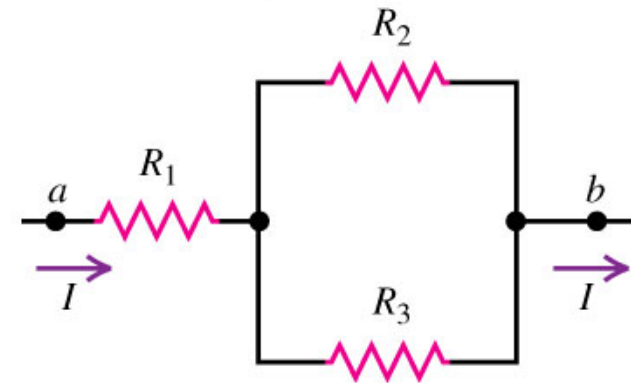
- Resistors are in *series* if they are connected one after the other so the current is the same in all of them (see left figure below).
- The *equivalent resistance* of a series combination is the *sum* of the individual resistances: $R_{\text{eq}} = R_1 + R_2 + R_3 + \dots$
- Resistors are in *parallel* if they are connected so that the potential difference must be the same across all of them (see right figure below).
- The *equivalent resistance* of a parallel combination is given by $\frac{1}{R_{\text{eq}}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$



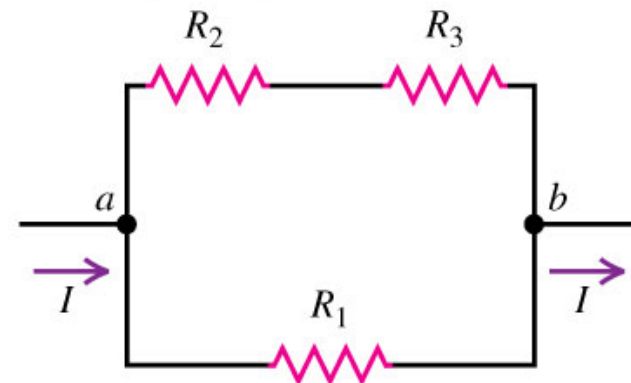
Series and parallel combinations

- Resistors can also be connected in combinations of series and parallel, as shown in Figure 26.1(c) and (d) at the right.

(c) R_1 in series with parallel combination of R_2 and R_3



(d) R_1 in parallel with series combination of R_2 and R_3



Problem solving strategy for resistor combinations

IDENTIFY many resistor networks are made up of resistors in series, in parallel, or a combination. Need to find a single equivalent resistor (same as capacitors).

SET UP

- **Make a drawing of the resistor network.**
- **Identify groups of resistors connected in series or parallel.**
- Identify the target variables such as **equivalent resistance of the network, the potential difference across each resistor or the current through each resistor.**

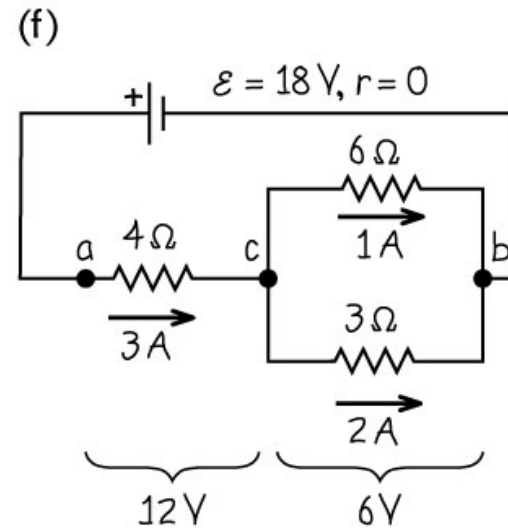
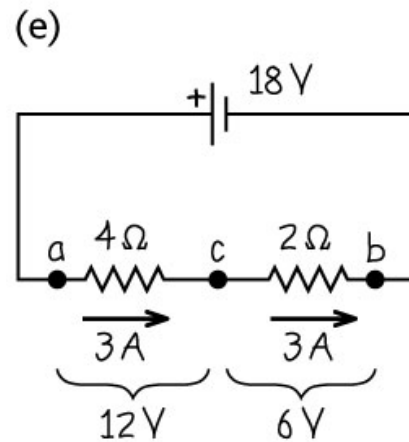
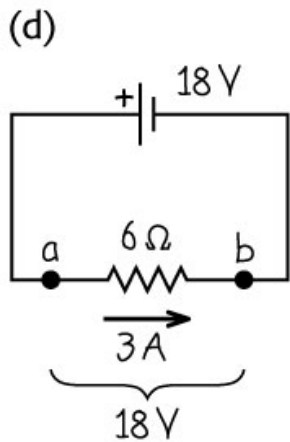
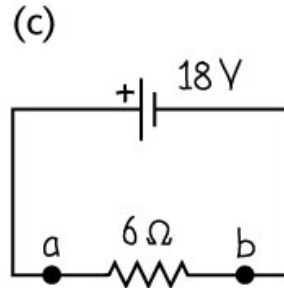
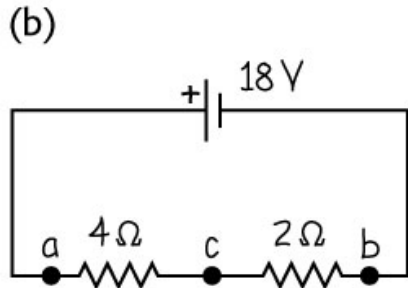
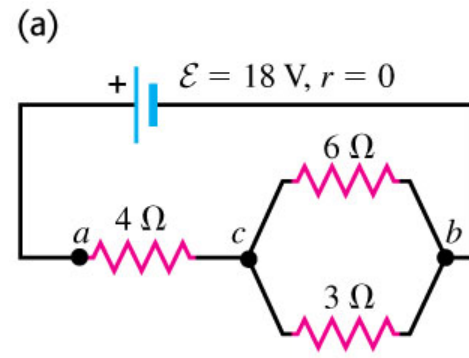
EXECUTE Use Eq. (26.1) or (26.2), respectively, to find the equivalent resistance for series or parallel combinations.

- **If the network is more complex**, try reducing it to series and parallel combinations.
- **Total potential difference across resistors connected in series is the sum of the individual potential differences. The potential difference across resistors connected in parallel is the same for every resistor and equals the potential difference across the combination.**
- **The current through resistors connected in series is the same through every resistor and equals the current through the combination. The total current through resistors connected in parallel is the sum of the currents through the individual resistors.**

EVALUATE *your answer*: Check whether your results are consistent. The equivalent resistance of resistors connected in series should be greater than that of any individual resistor; that of resistors in parallel should be less than that of any individual resistor.

Equivalent resistance

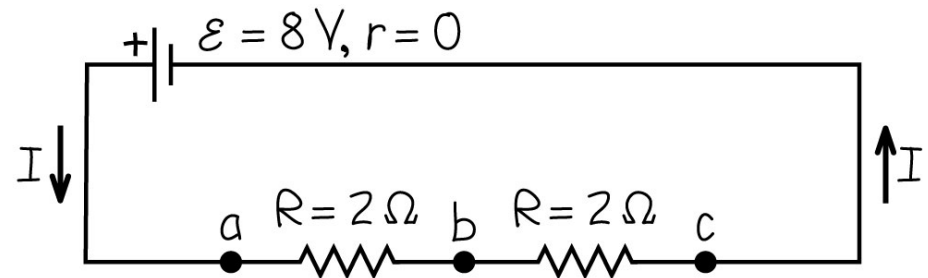
- Example 26.1



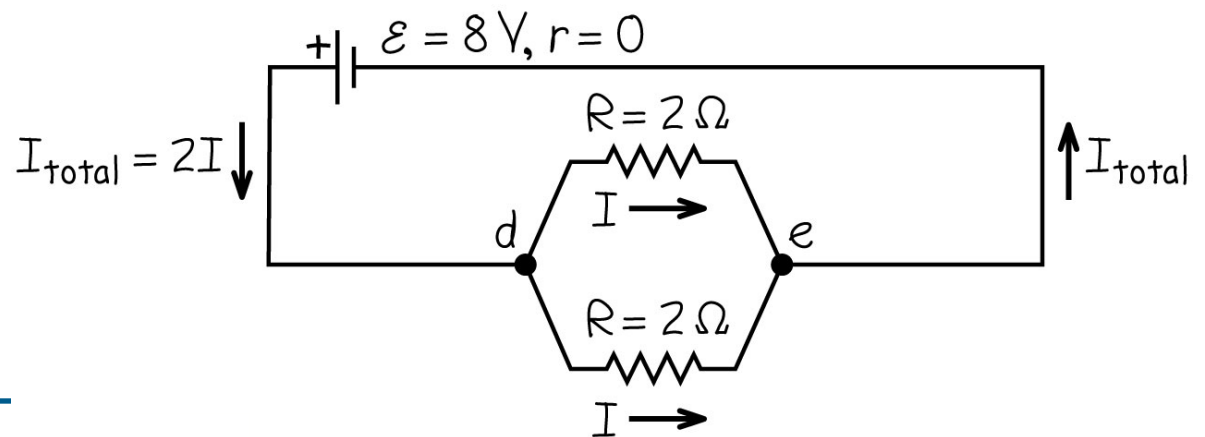
Series versus parallel combinations

- Example 26.2 Find the current through the bulbs and power delivered to each bulb and the network in each case.
- What happens in each case if one of the bulbs burn out?

(a) Light bulbs in series

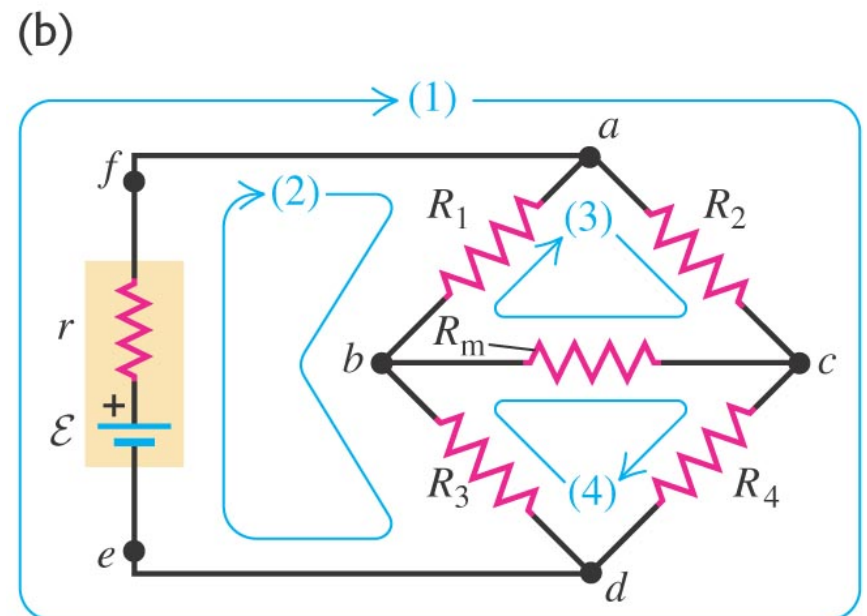
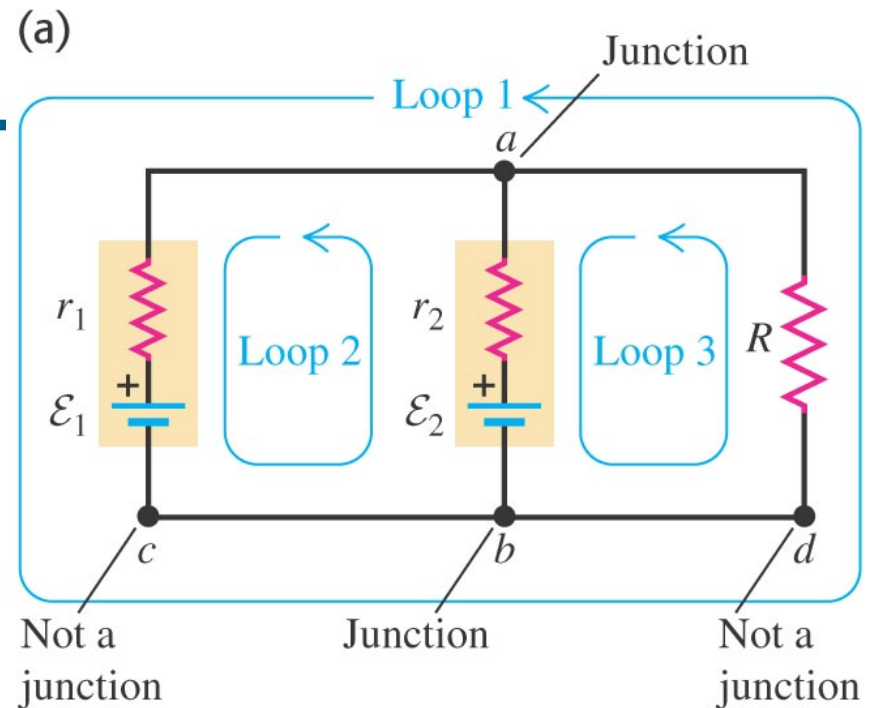


(b) Light bulbs in parallel



Kirchhoff's Rules I

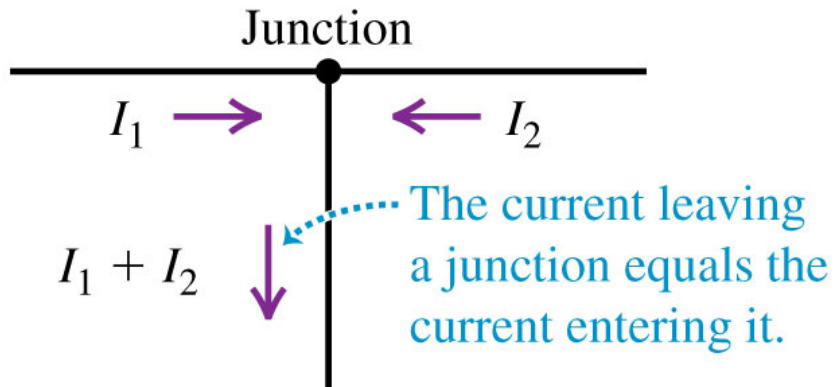
- A *junction* is a point where three or more conductors meet.
- A *loop* is any closed conducting path.



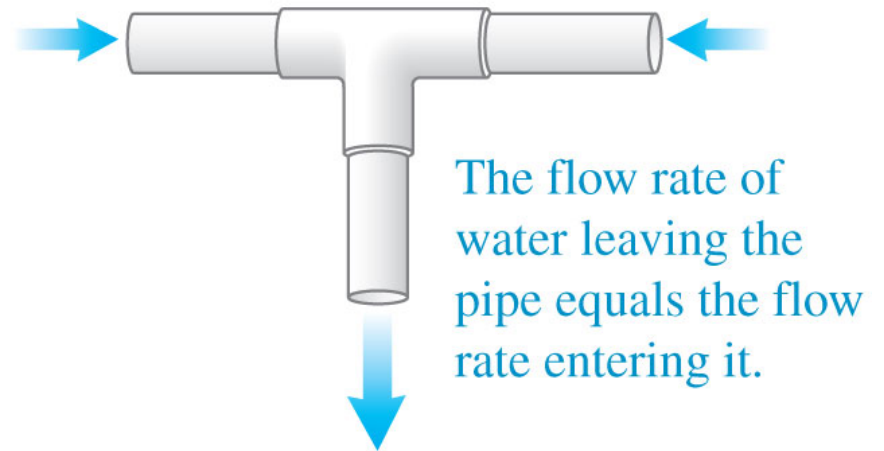
Kirchoff's Junctions

- Kirchoff's *junction rule*: The algebraic sum of the currents into any junction is zero: $\Sigma I = 0$.

(a) Kirchoff's junction rule

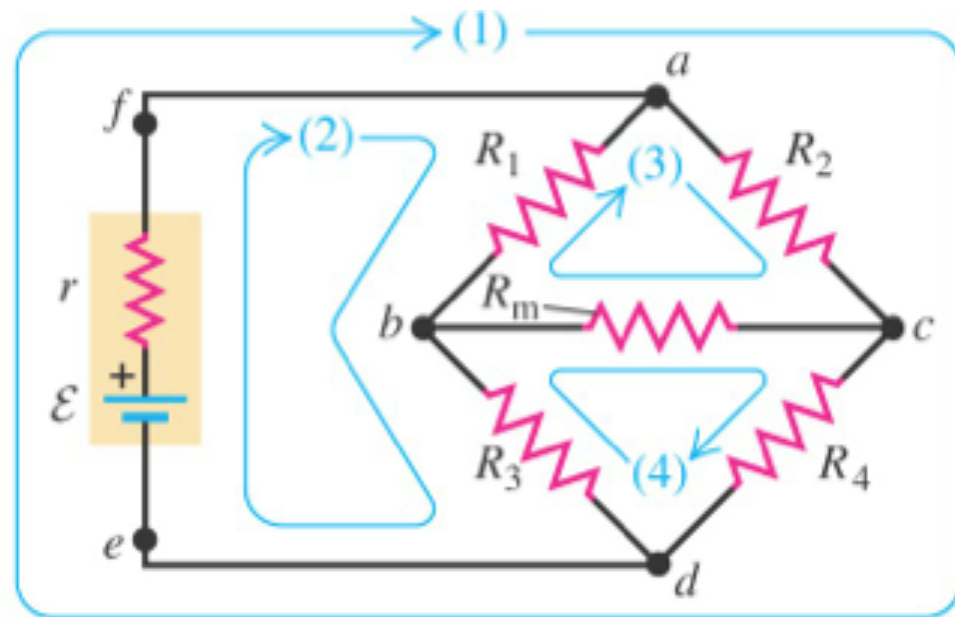


(b) Water-pipe analogy



Kirchoff's loop rule

- Kirchoff's *loop rule*: The algebraic sum of the potential differences in any loop must equal zero: $\Sigma V = 0$.

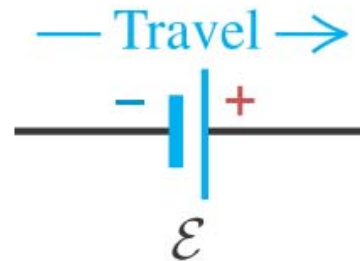


Sign convention for the loop rule

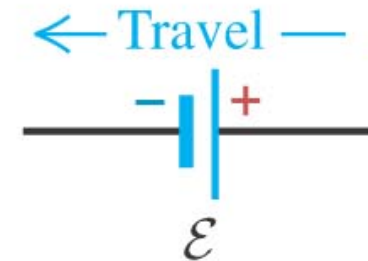
- **Sign of the exit pole**

(a) Sign conventions for emfs

$+\mathcal{E}$: Travel direction from $-$ to $+$:



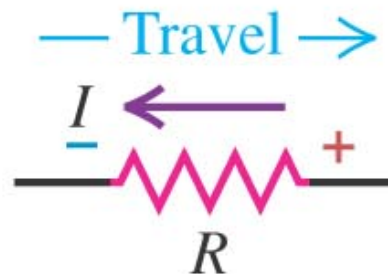
$-\mathcal{E}$: Travel direction from $+$ to $-$:



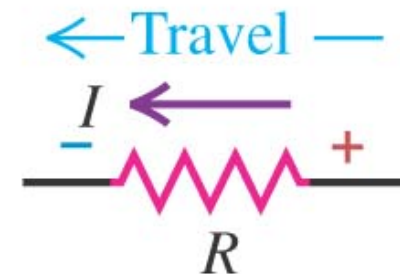
- **Voltage of the resistor drops along the current**

(b) Sign conventions for resistors

$+IR$: Travel *opposite* to current direction:



$-IR$: Travel *in* current direction:



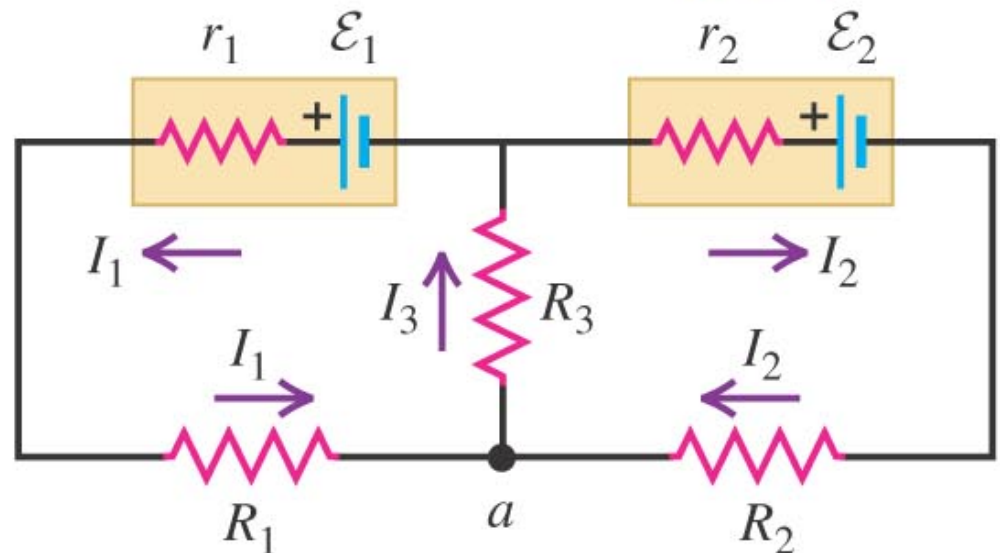
Reducing the number of unknown currents

IDENTIFY concepts: Kirchhoff's rules are useful for analyzing any electric circuit.

SET UP *the problem* using the following steps:

- 1. Draw a circuit diagram**, leaving room to label all quantities, known and unknown. Indicate an assumed direction for each unknown current and emf. (Don't worry about the direction of currents. If the actual direction of a quantity is opposite to your assumption, the resulting quantity will have a negative sign.)
- 2. As you label currents**, it helpful to use Kirchhoff's junction rule, so as to **reduce number of unknown quantities**.
- 3. Identify the target variables.**

(a) Three unknown currents: I_1, I_2, I_3



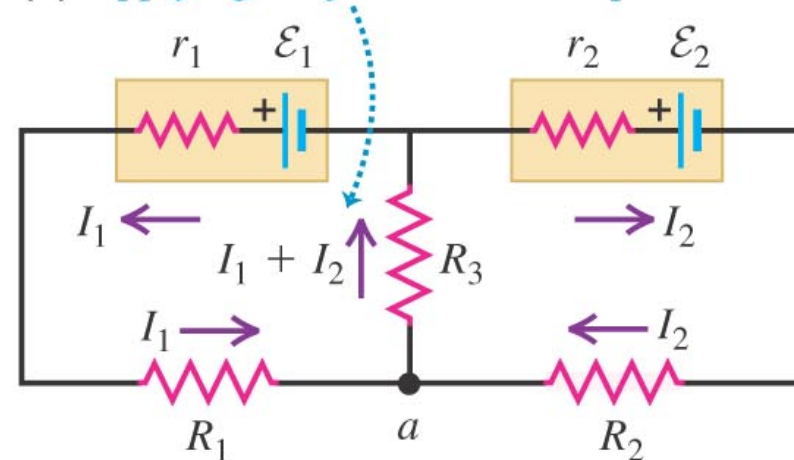
Reducing the number of unknown currents

EXECUTE *the solution* as follows:

1. Choose any loop in the network and any direction to travel around the loop as you apply Kirchhoff's loop rule. The direction can differ from the current direction.
2. Travel around the loop in the chosen direction, adding potential differences algebraically as you cross them. Use the sign conventions of Fig. 26.8.
3. Equate the sum obtained in step 2 to zero in accordance with the loop rule.
4. You need as many independent equations as unknowns so keep creating equations using the junction and loop rules until you have enough.
5. Solve the equations simultaneously to determine the unknowns.

6. To find the potential V_{ab} of any point a with respect to any other point b . Start at b and add the potential changes you encounter in going from b to a , using the same sign rules as in step 2.

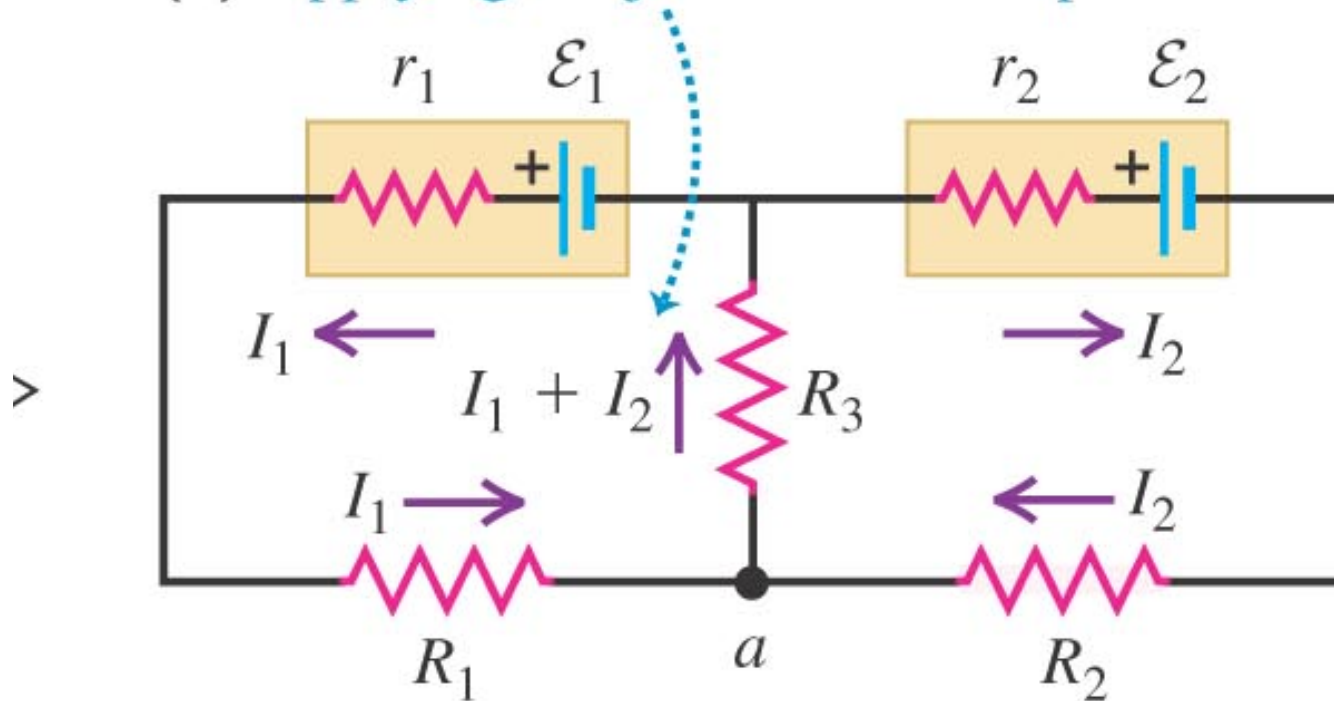
(b) Applying the junction rule to point a eliminates I_3 .



Reducing the number of unknown currents

- EVALUATE** *your answer*: Check all the steps in your algebra. **Apply steps 1 and 2 to a loop you have not yet considered; if the sum of potential drops isn't zero, you've made an error somewhere.**

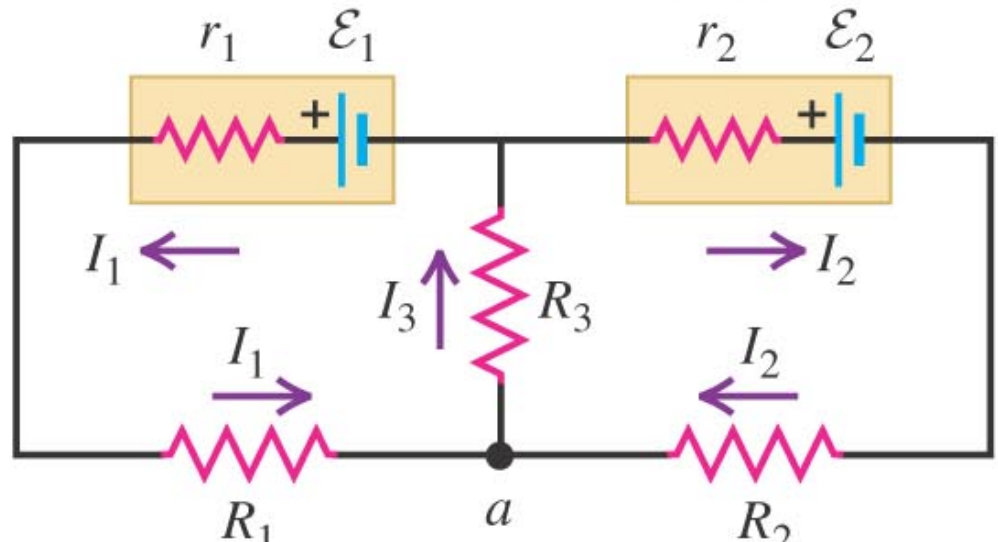
(b) Applying the junction rule to point a eliminates I_3 .



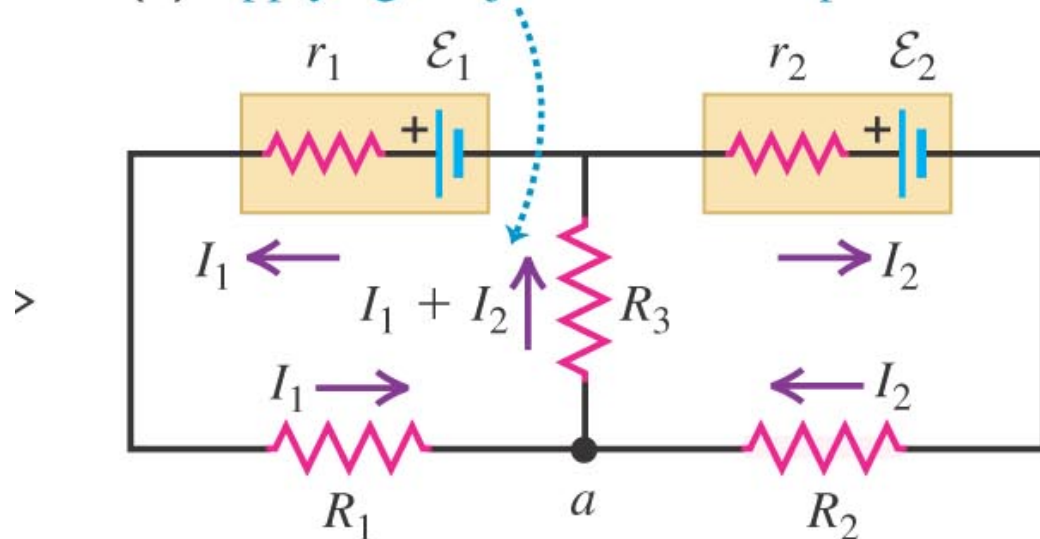
Reducing the number of unknown currents

- Figure below shows how to use the junction rule to reduce the number of unknown currents.

(a) Three unknown currents: I_1, I_2, I_3

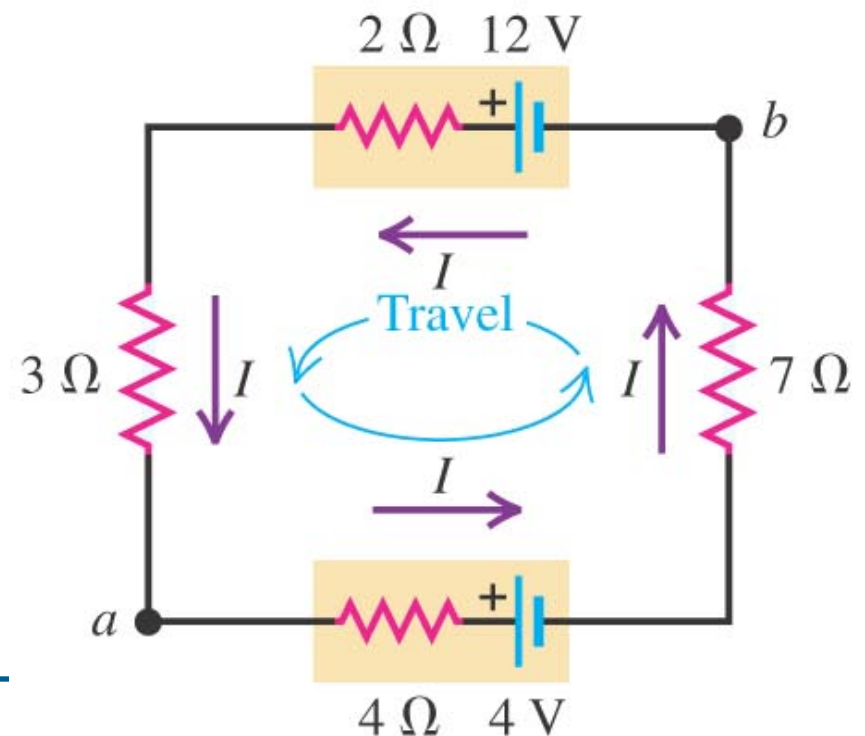
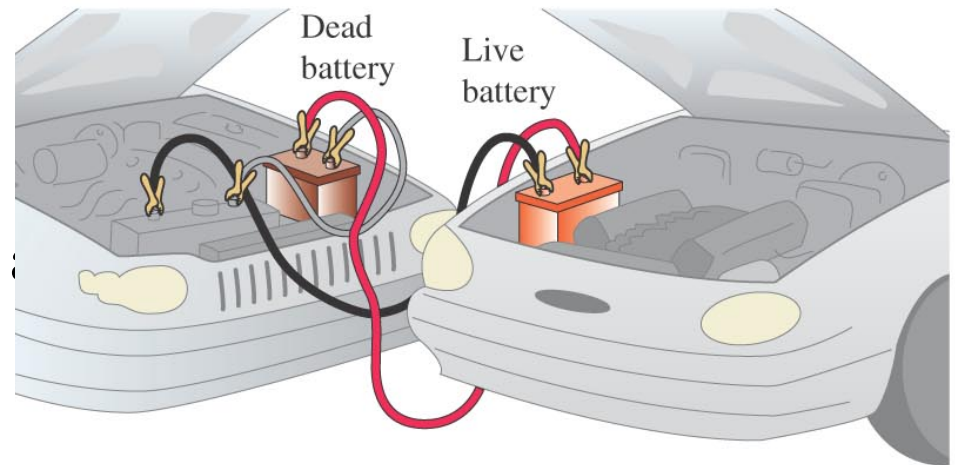


(b) Applying the junction rule to point a eliminates I_3 .



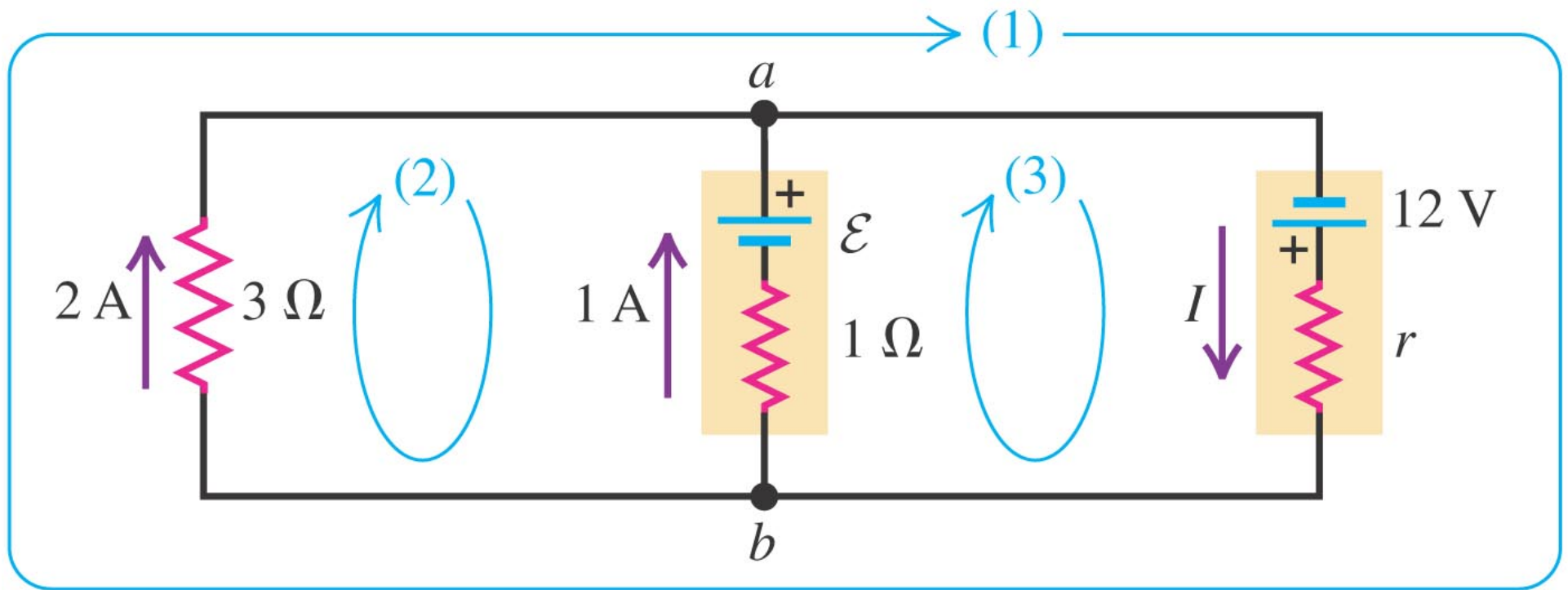
A single-loop circuit

- Example 26.3 Find
- The current
- Potential difference between a
- Power output of each battery



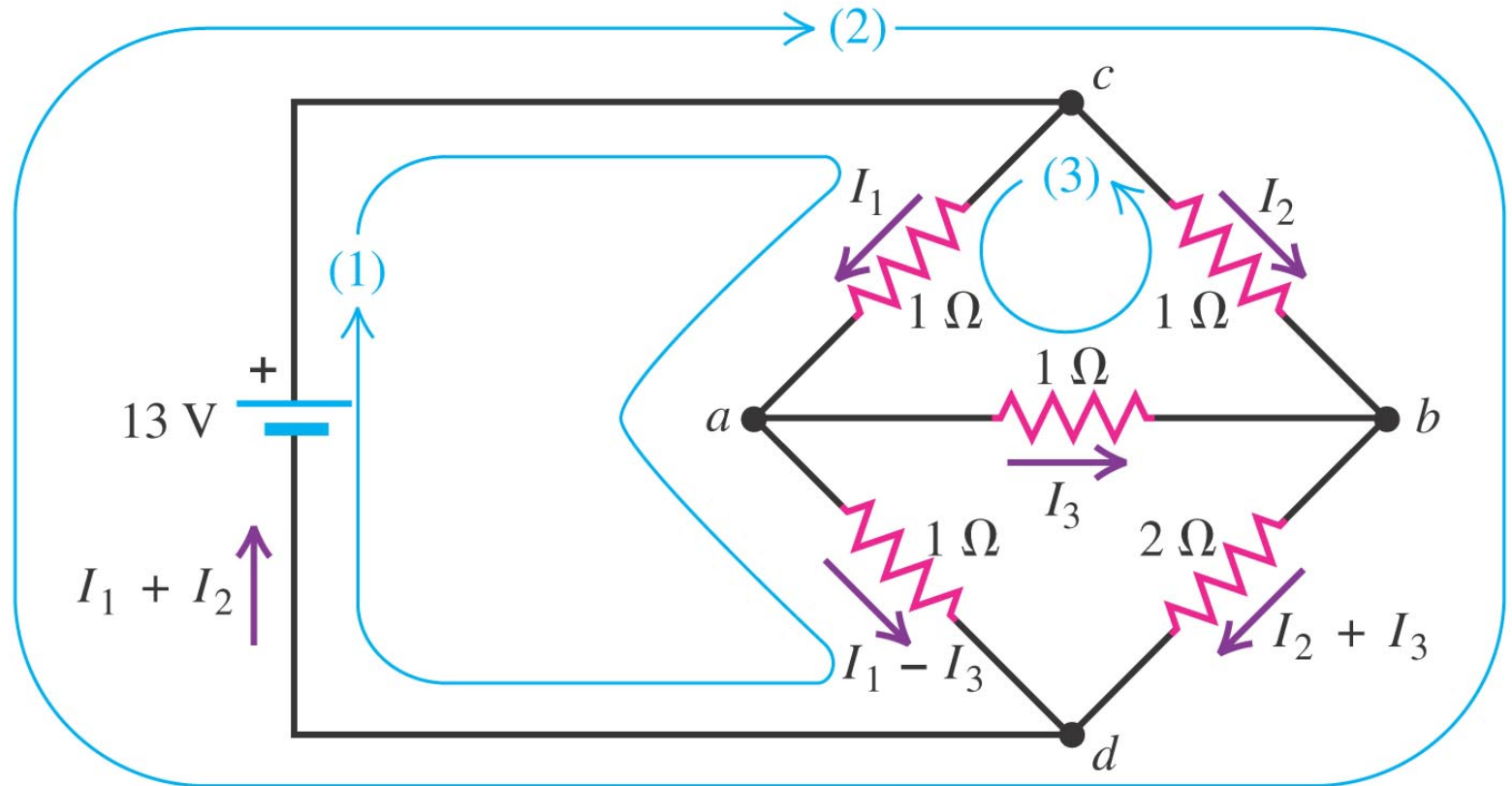
Charging a battery

- Example 26.4, which shows how to charge a battery. Find the unknown current, r and ε .
- Example 26.5, calculate the power delivered by the power supply to the chargeable battery. Do the power accounting



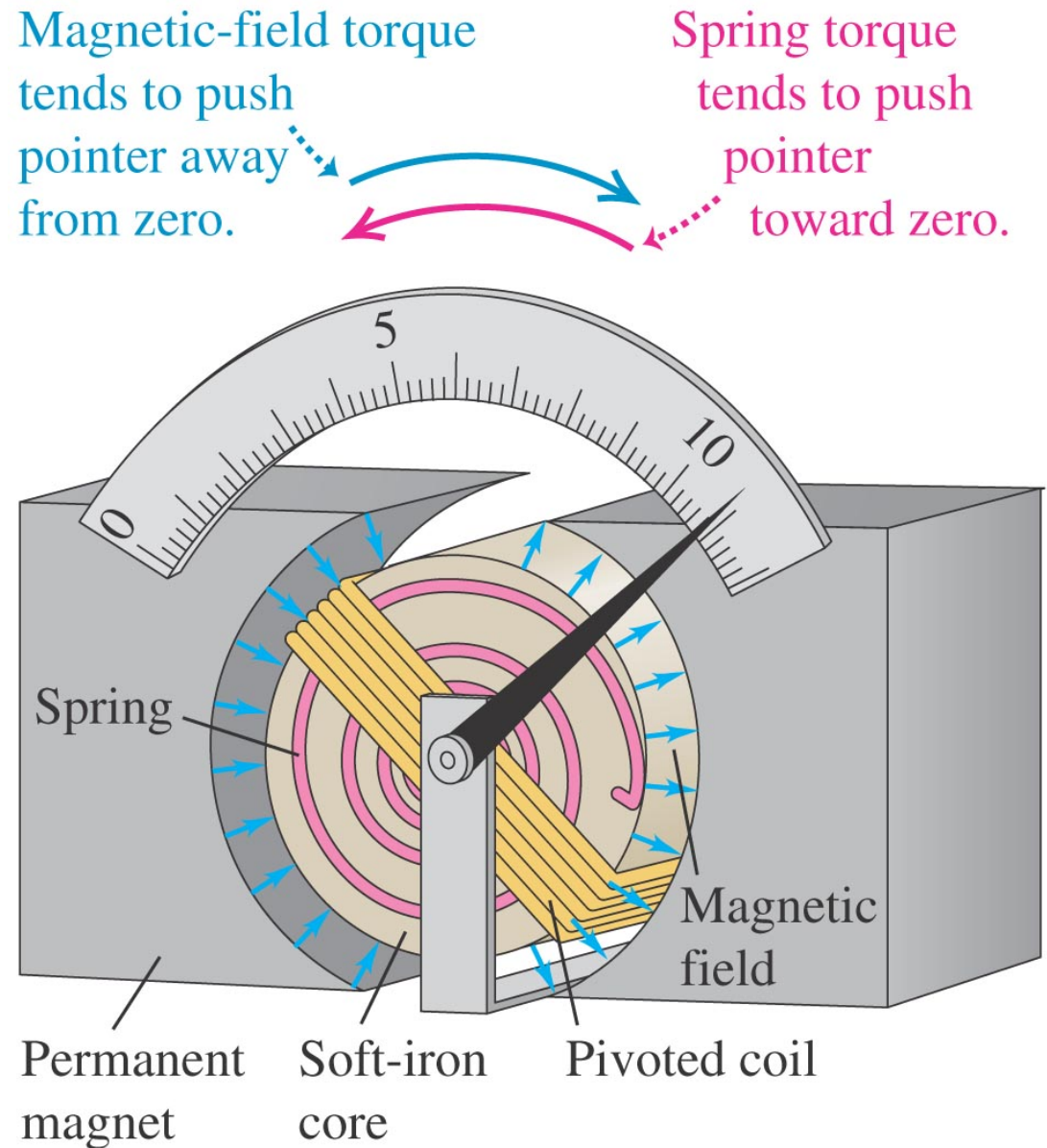
A complex network

- Example 26.6 Find the current in each resistor and the equivalent resistance.
- Example 26.7 Find the potential difference between points a and b



D'Arsonval galvanometer

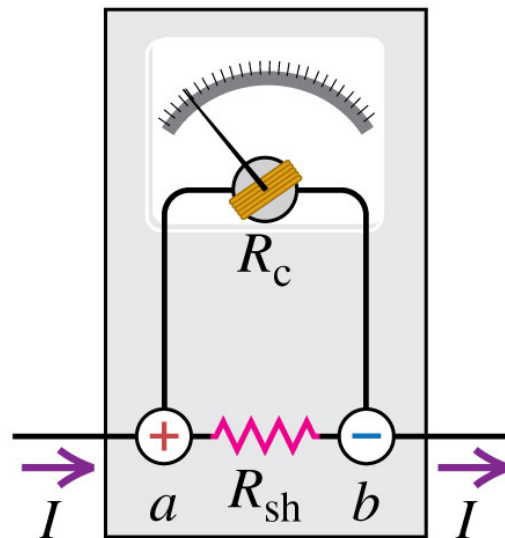
- A *d'Arsonval galvanometer* measures the current through it
- Many electrical instruments, such as ammeters and voltmeters, use a galvanometer in their design.



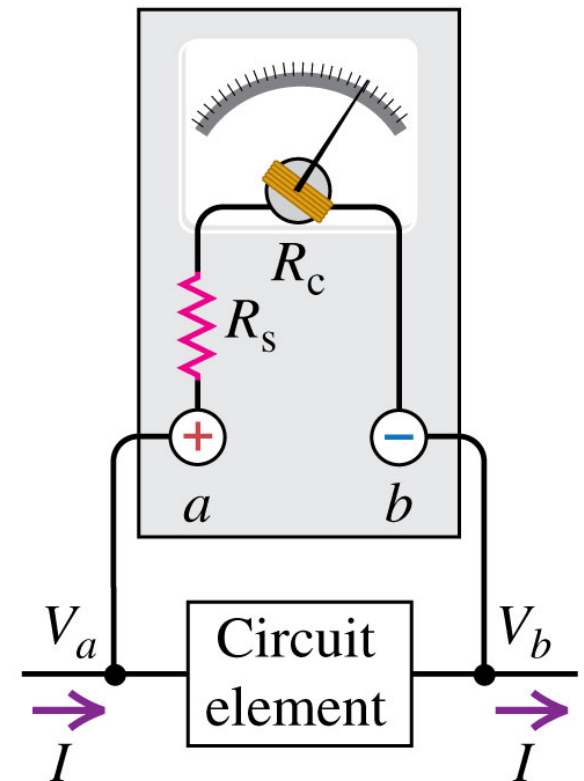
Ammeters and voltmeters

- An *ammeter* measures the current passing through it.
- A *voltmeter* measures the potential difference between two points.
- Figure shows how to use a galvanometer to make an ammeter and a voltmeter.

(a) Moving-coil ammeter



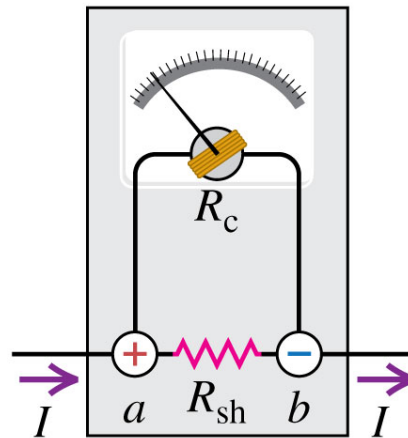
(b) Moving-coil voltmeter



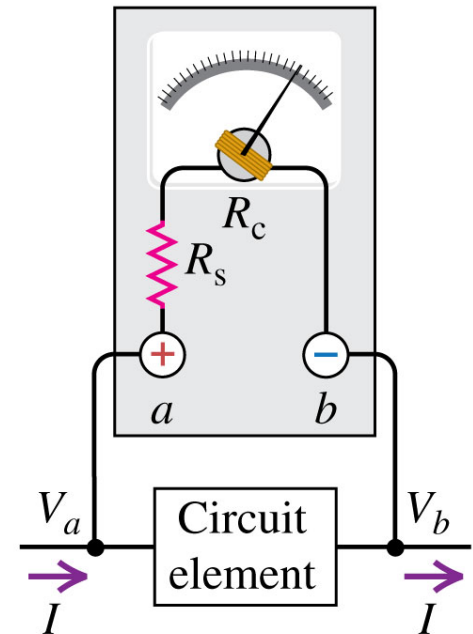
Ammeters and voltmeters

- Examples 26.8 (ammeter) and 26.9 (ammeter).

(a) Moving-coil ammeter

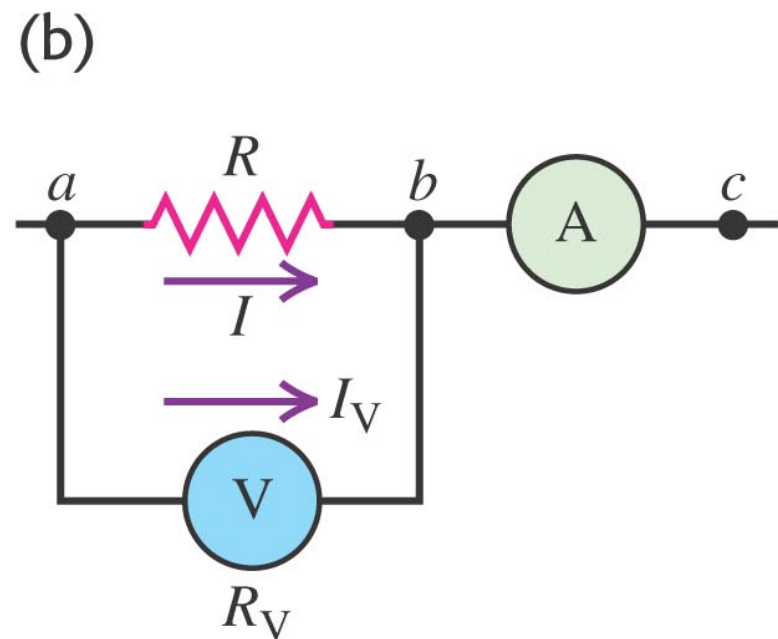
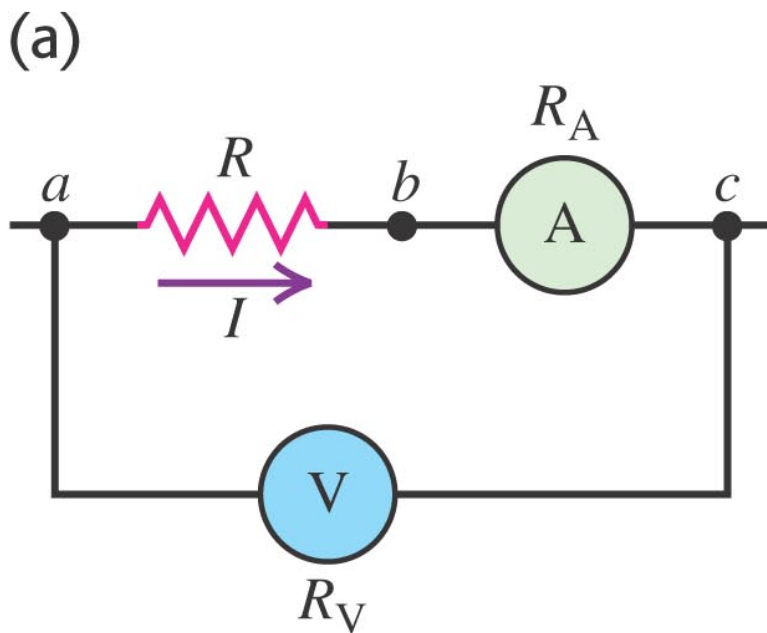


(b) Moving-coil voltmeter



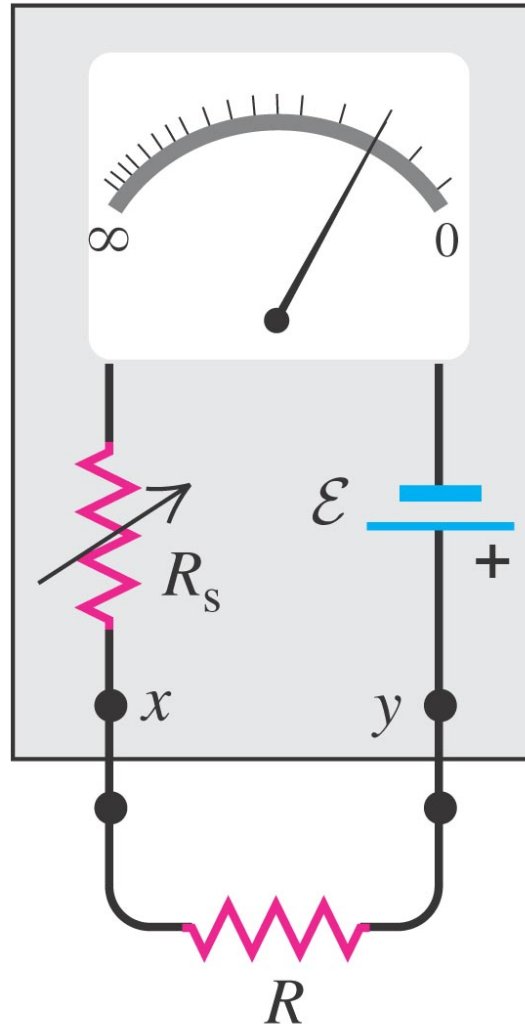
Ammeters and voltmeters in combination

- An ammeter and a voltmeter may be used together to measure resistance and power. Figure illustrates how this can be done.
- Example 26.10
- Example 26.11



Ohmmeters

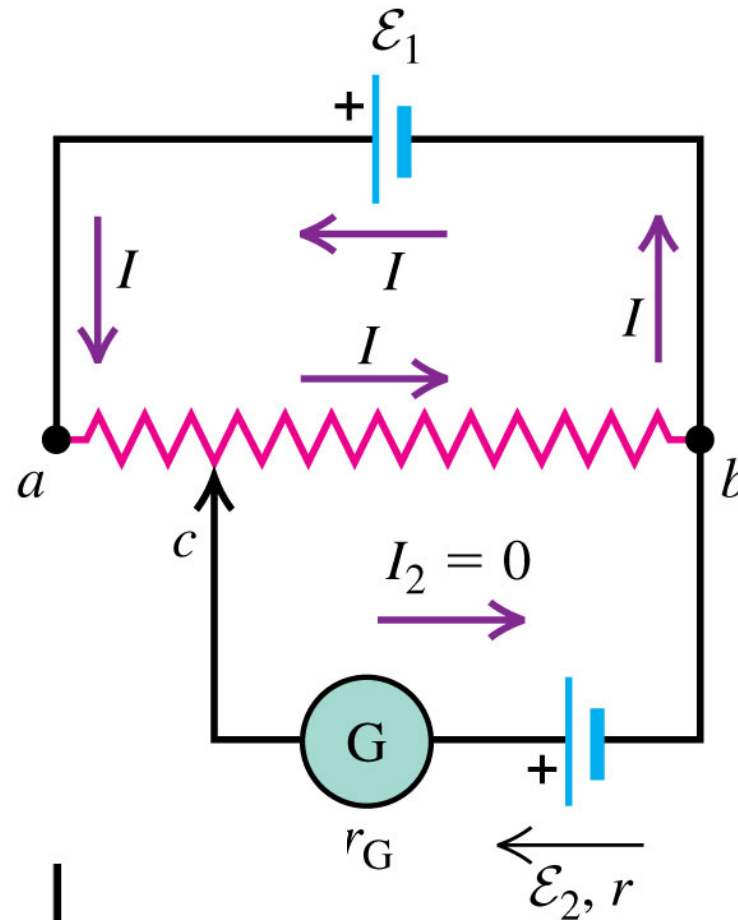
An *ohmmeter* is designed to measure resistance.



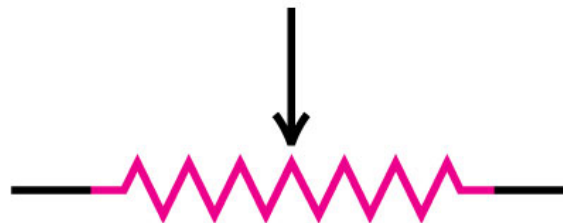
Potentiometers

A potentiometer measures the emf of a source without drawing any current from the source.

(a) Potentiometer circuit



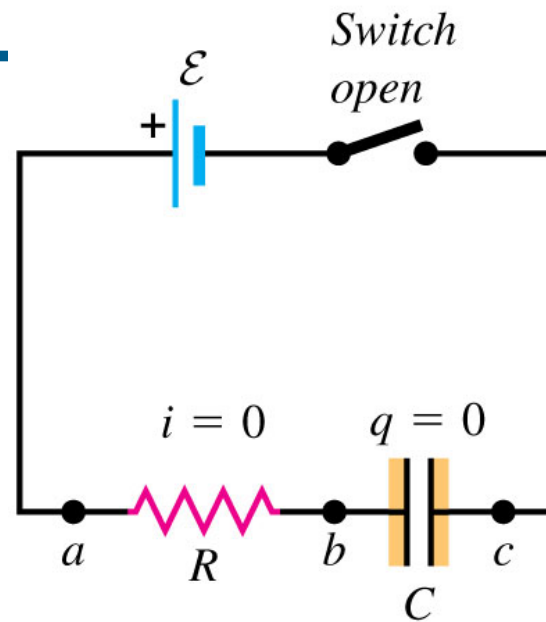
(b) Circuit symbol for potentiometer (variable resistor)



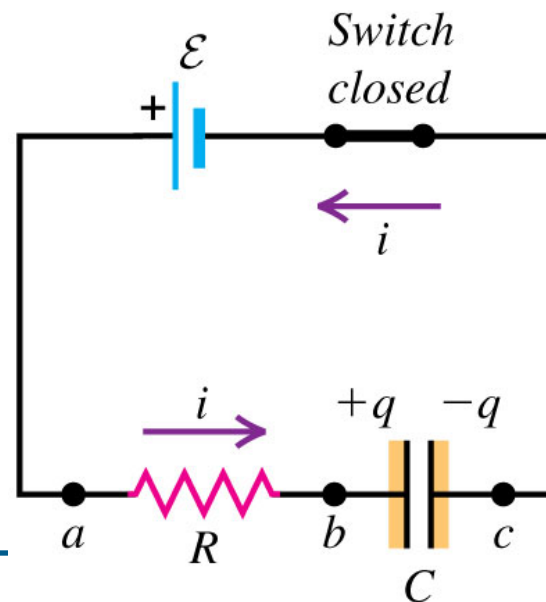
Charging a capacitor

- The *time constant* is $\tau = RC$.

(a) Capacitor initially uncharged



(b) Charging the capacitor

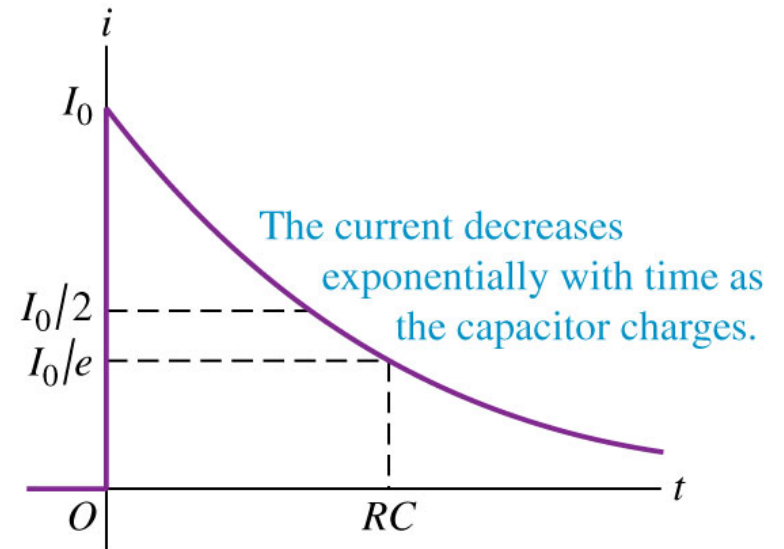


When the switch is closed, the charge on the capacitor increases over time while the current decreases.

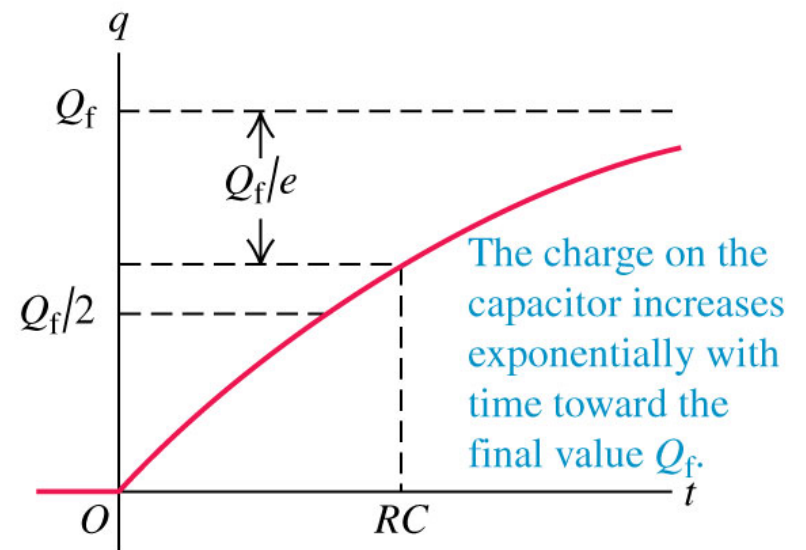
Charging a capacitor

- The *time constant* is $\tau = RC$.

(a) Graph of current versus time for a charging capacitor



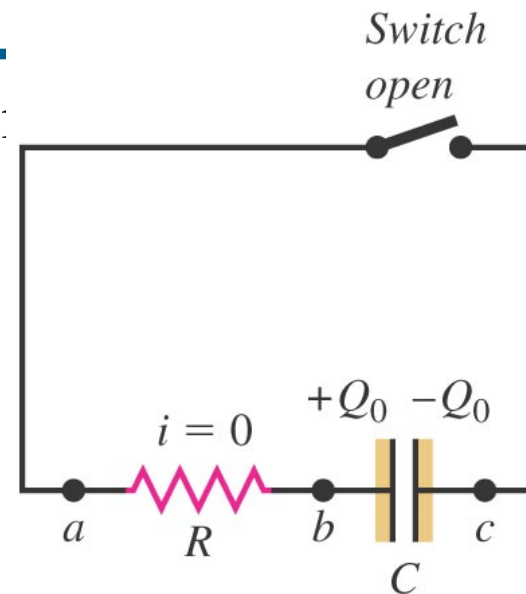
(b) Graph of capacitor charge versus time for a charging capacitor



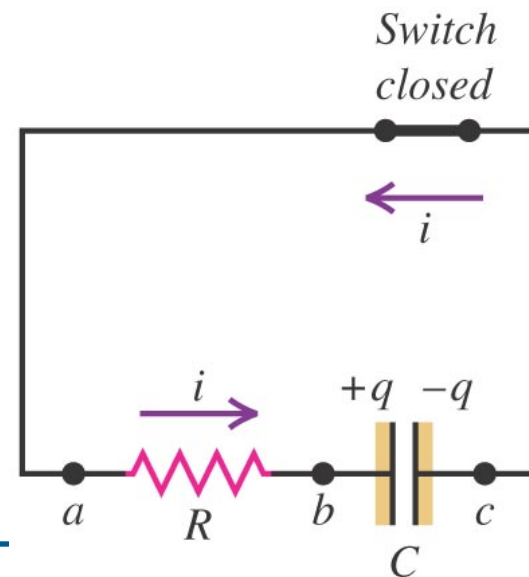
Discharging a capacitor

- Read the discussion of discharging. Figures 26.22 and 26.23 below.
- Examples 26.12 and 26.13.

(a) Capacitor initially charged



(b) Discharging the capacitor

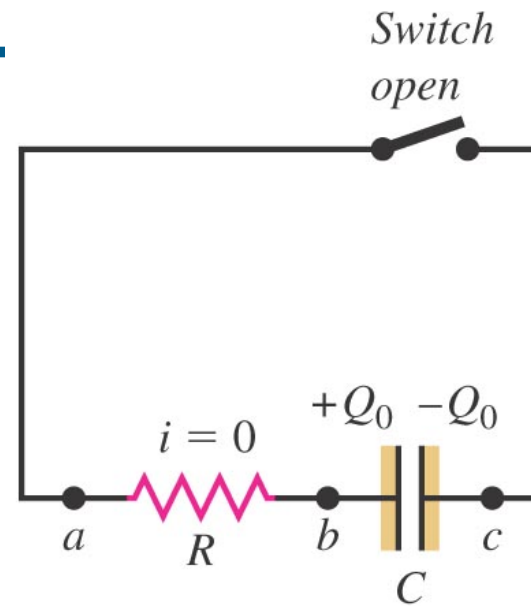


When the switch is closed, the charge on the capacitor and the current both decrease over time.

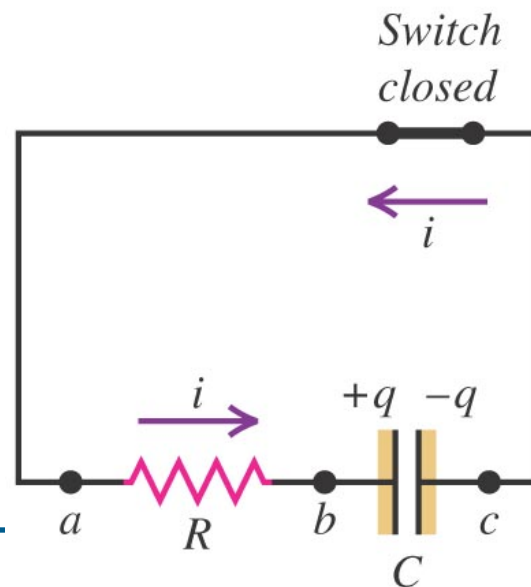
Discharging a capacitor

- Examples 26.12 and 26.13.

(a) Capacitor initially charged



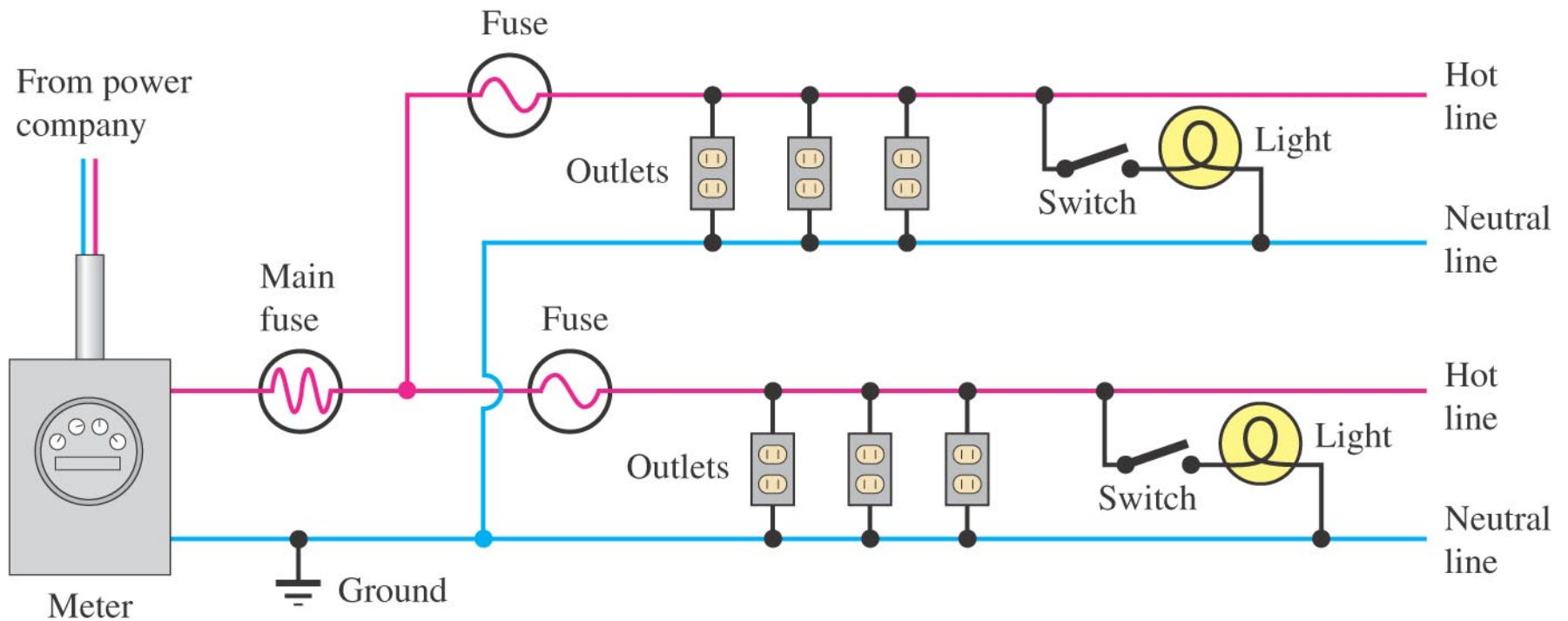
(b) Discharging the capacitor



When the switch is closed, the charge on the capacitor and the current both decrease over time.

Power distribution systems

- Follow the text discussion using Figure 26.24 below.



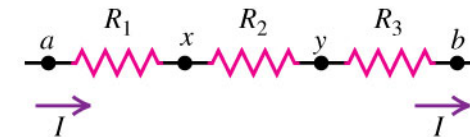


Q26.1

Which of the two arrangements shown has the *smaller* equivalent resistance between points a and b ?

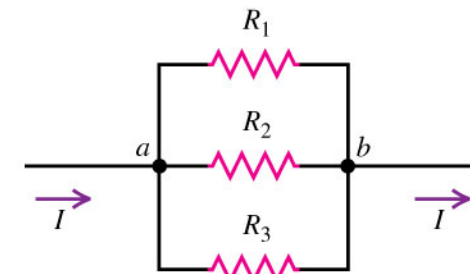
- A. the series arrangement
- B. the parallel arrangement
- C. The equivalent resistance is the same for both arrangements.
- D. The answer depends on the values of the individual resistances R_1 , R_2 , and R_3 .

(a) R_1 , R_2 , and R_3 in series



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(b) R_1 , R_2 , and R_3 in parallel

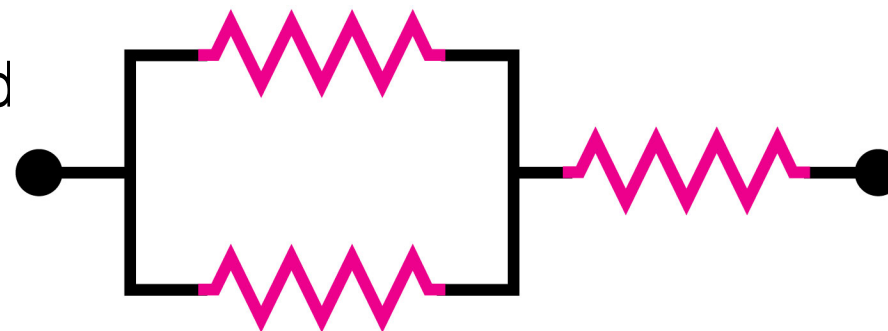


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Q26.2



Three identical resistors, each of resistance R , are connected as shown. What is the equivalent resistance of this arrangement of three resistors?



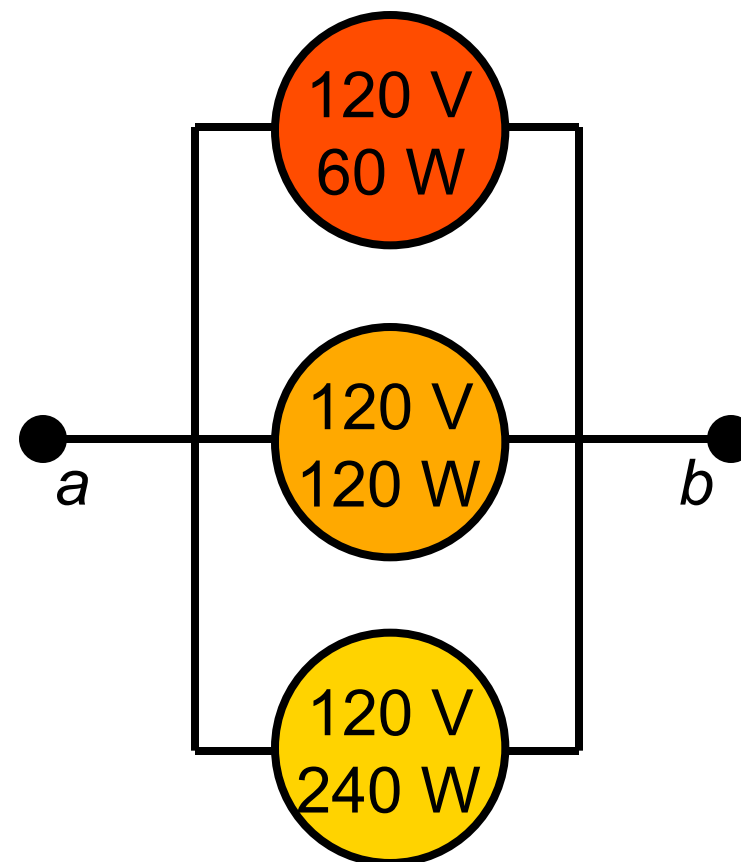
- A. $3R$
- B. $2R$
- C. $3R/2$
- D. $2R/3$
- E. $R/3$

Q26.3



A 120-V, 60-W light bulb, a 120-V, 120-W light bulb, and a 120-V, 240-W light bulb are connected in parallel as shown.

The voltage between points *a* and *b* is 120 V. Through which bulb is there the greatest voltage drop?



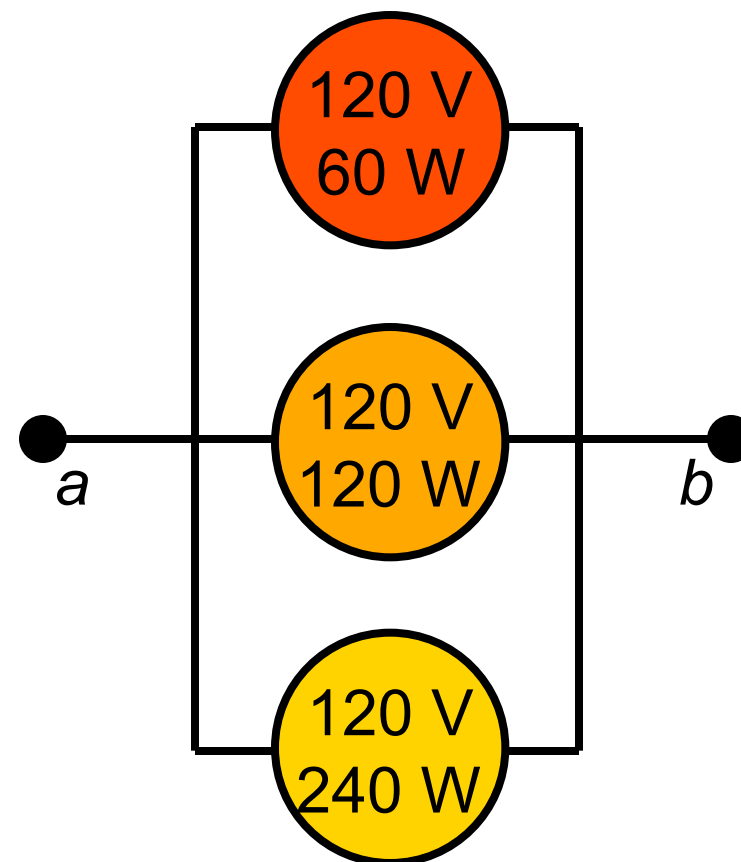
- A. the 120-V, 60-W light bulb
- B. the 120-V, 120-W light bulb
- C. the 120-V, 240-W light bulb
- D. All three light bulbs have the same voltage drop.

Q26.4



A 120-V, 60-W light bulb, a 120-V, 120-W light bulb, and a 120-V, 240-W light bulb are connected in parallel as shown.

The voltage between points *a* and *b* is 120 V. Which bulb glows the brightest?



- A. the 120-V, 60-W light bulb
- B. the 120-V, 120-W light bulb
- C. the 120-V, 240-W light bulb
- D. All three light bulbs glow with equal brightness.

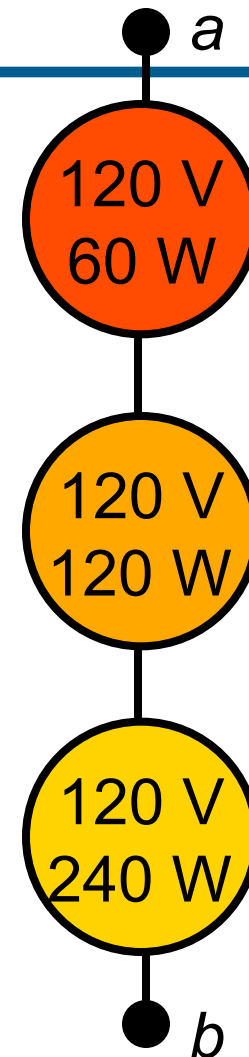
Q26.5



A 120-V, 60-W light bulb, a 120-V, 120-W light bulb, and a 120-V, 240-W light bulb are connected in series as shown.

The voltage between points a and b is 120 V. Through which bulb is there the greatest voltage drop?

- A. the 120-V, 60-W light bulb
- B. the 120-V, 120-W light bulb
- C. the 120-V, 240-W light bulb
- D. All three light bulbs have the same voltage drop.



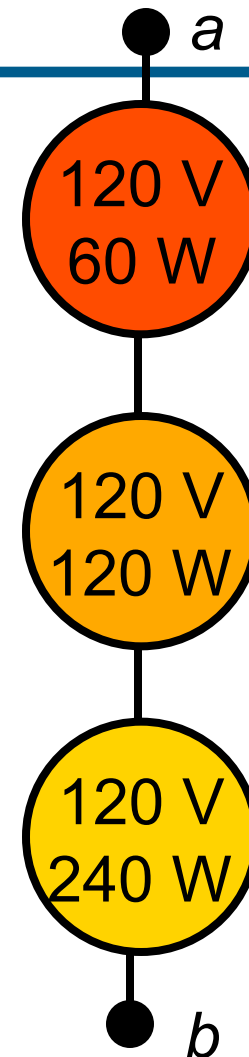
Q26.6



A 120-V, 60-W light bulb, a 120-V, 120-W light bulb, and a 120-V, 240-W light bulb are connected in series as shown.

The voltage between points a and b is 120 V. Which bulb glows the brightest?

- A. the 120-V, 60-W light bulb
- B. the 120-V, 120-W light bulb
- C. the 120-V, 240-W light bulb
- D. All three light bulbs glow with equal brightness.

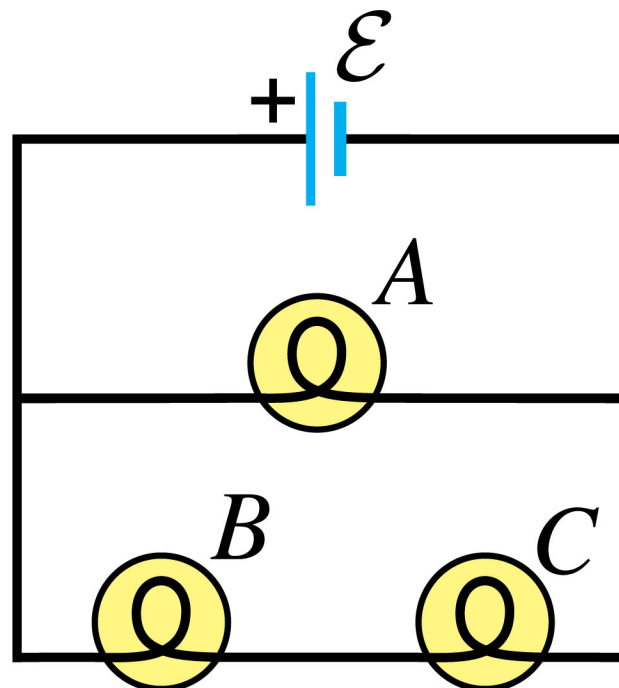


Q26.7



Three identical light bulbs are connected to a source of emf as shown. Which bulb is brightest?

- A. light bulb *A*
- B. light bulb *B*
- C. light bulb *C*
- D. both light bulbs *B* and *C*
(Both are equally bright and are brighter than light bulb *A*.)
- E. All bulbs are equally bright.



Q26.8



You wish to study a resistor in a circuit. To simultaneously measure the current in the resistor and the voltage across the resistor, you would place

- A. an ammeter in series and an voltmeter in series.
- B. an ammeter in series and an voltmeter in parallel.
- C. an ammeter in parallel and an voltmeter in series.
- D. an ammeter in parallel and an voltmeter in parallel.

Q26.9



A battery, a capacitor, and a resistor are connected in series. Which of the following affect(s) the maximum charge stored on the capacitor?

- A. the emf e of the battery
- B. the capacitance C of the capacitor
- C. the resistance R of the resistor
- D. both e and C
- E. all three of e , C , and R

Q26.10



A battery, a capacitor, and a resistor are connected in series. Which of the following affect(s) the rate at which the capacitor charges?

- A. the emf e of the battery
- B. the capacitance C of the capacitor
- C. the resistance R of the resistor
- D. both C and R
- E. all three of e , C , and R