Chapter 25

Current, Resistance, and Electromotive Force

PowerPoint® Lectures for
University Physics, Thirteenth Edition
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Goals for Chapter 25

- To understand current and how charges move in a conductor
- To understand resistivity and conductivity
- To calculate the resistance of a conductor
- To learn how an emf causes current in a circuit
- To calculate energy and power in circuits

Introduction

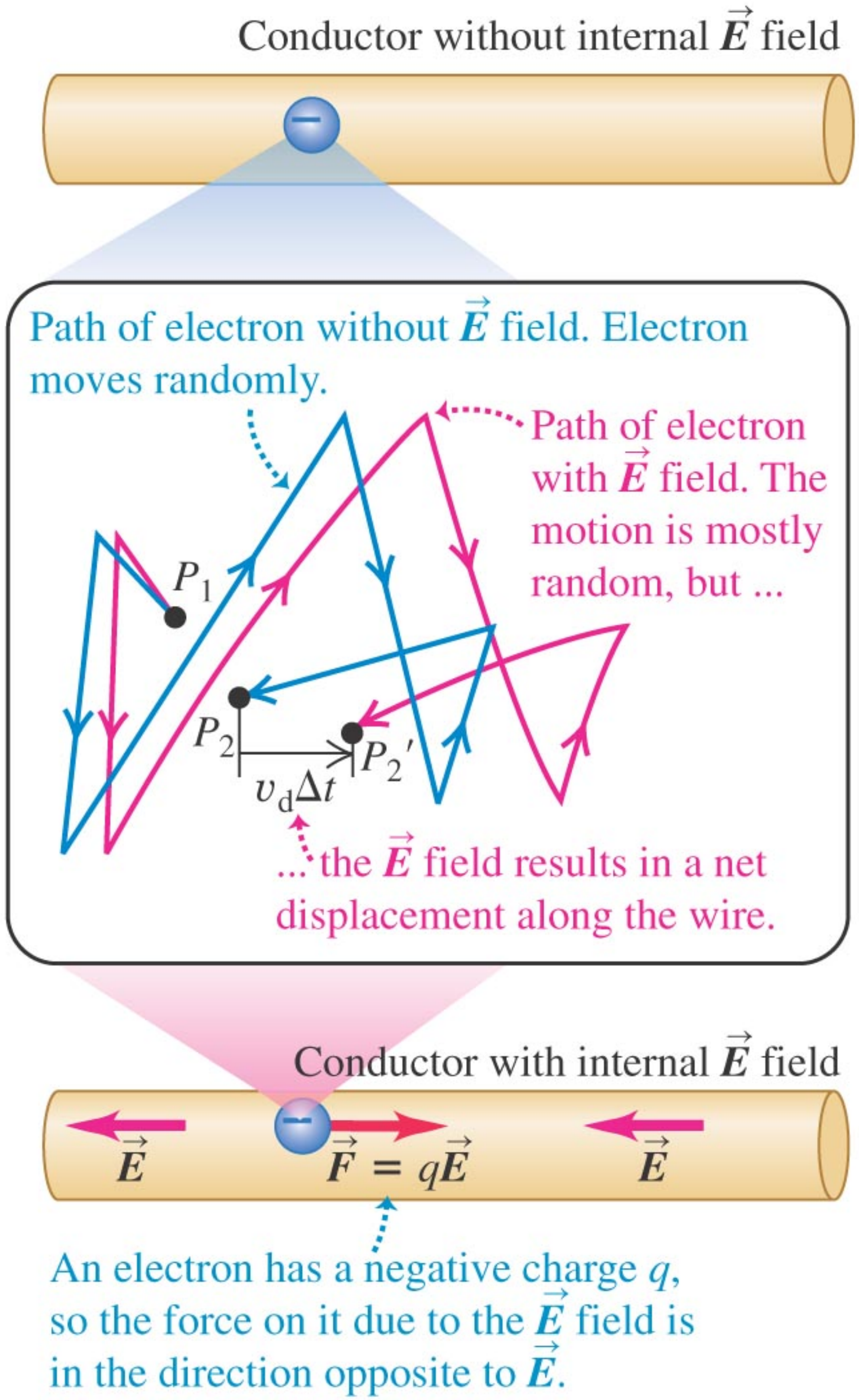
- Electric currents flow through light bulbs.
- Electric circuits contain charges in motion.
- Circuits are at the heart of modern devices such as computers, televisions, and industrial power systems.

Current

- A *current* is any motion of charge from one region to another. Current is defined as

  $$I = dQ/dt.$$

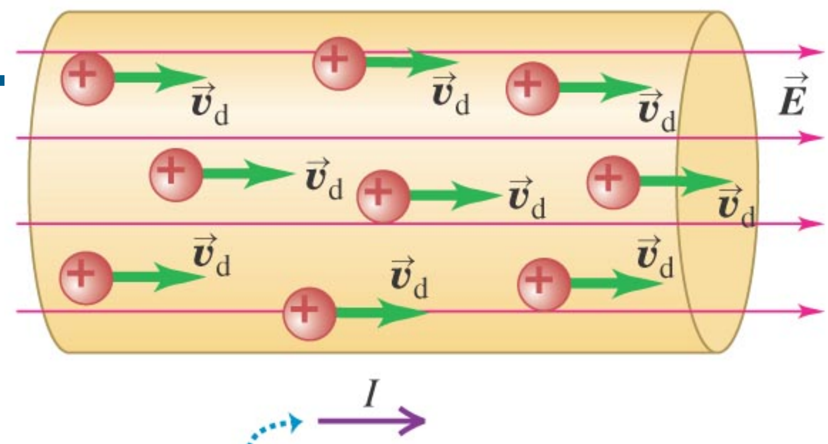
- An electric field in a conductor causes charges to flow.



Direction of current flow

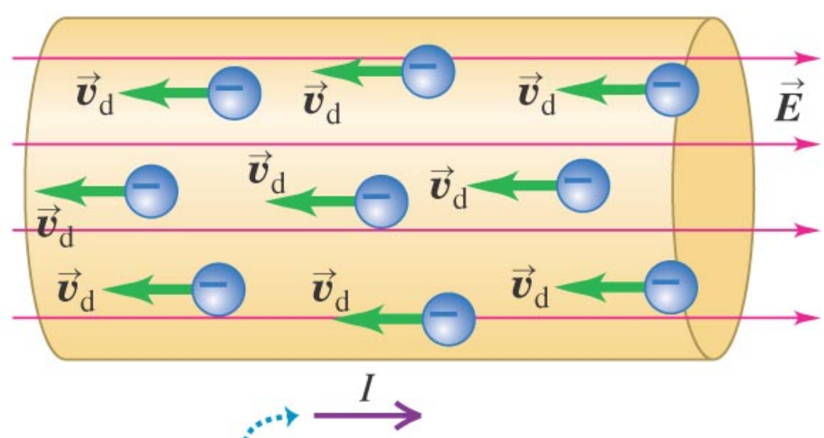
- A current can be produced by positive or negative charge flow.
- *Conventional current* is treated as a flow of positive charges. Same as direction of the electric field
- The moving charges in metals are electrons (see figure below).

(a)



A **conventional current** is treated as a flow of positive charges, regardless of whether the free charges in the conductor are positive, negative, or both.

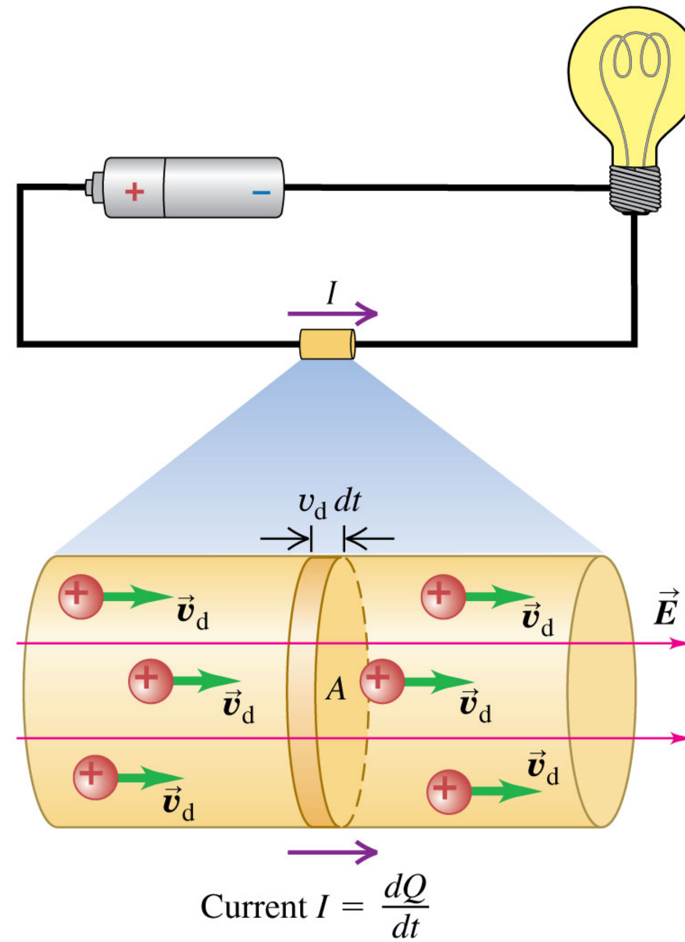
(b)



In a metallic conductor, the moving charges are electrons — but the *current* still points in the direction positive charges would flow.

Current, drift velocity, and current density

- Follow the discussion of current, drift velocity, and current density.
- The positive charges moving in the direction of the electric field.
- Example 25.1 An 18-gauge copper wire has a nominal diameter of 1.02 mm. This wire carries a constant current of 1.67A to a 200W lamp. The density of free electrons is 8.5E28/m^3.
  Find the magnitudes of current density and drift velocity.
  How long it takes for the electrons to travel length of a 1m wire?



Q25.1

Two copper wires of different diameter are joined end to end, and a current flows in the wire combination.

When electrons move from the larger-diameter wire into the smaller-diameter wire,

A. their drift speed increases.

B. their drift speed decreases.

C. their drift speed stays the same.

D. not enough information given to decide

Resistivity

- The ***resistivity*** of a material is the ratio of the electric field in the material to the current density it causes:

$$\rho = \frac{E}{J}; \quad \text{SI unit:} \frac{V/m}{A/m^2} = \frac{V}{A}m = \ \Omega.\text{m}$$

- The ***conductivity*** is the reciprocal of the resistivity.

Resistivity of different material

Table 25.1 Resistivities at Room Temperature (20 °C)

Substance		$\rho\,(\Omega \cdot m)$	Substance	$\rho\,(\Omega \cdot m)$
Conductors			**Semiconductors**	
Metals	Silver	1.47×10^{-8}	Pure carbon (graphite)	3.5×10^{-5}
	Copper	1.72×10^{-8}	Pure germanium	0.60
	Gold	2.44×10^{-8}	Pure silicon	2300
	Aluminum	2.75×10^{-8}	**Insulators**	
	Tungsten	5.25×10^{-8}	Amber	5×10^{14}
	Steel	20×10^{-8}	Glass	10^{10}–10^{14}
	Lead	22×10^{-8}	Lucite	$>10^{13}$
	Mercury	95×10^{-8}	Mica	10^{11}–10^{15}
Alloys	Manganin (Cu 84%, Mn 12%, Ni 4%)	44×10^{-8}	Quartz (fused)	75×10^{16}
	Constantan (Cu 60%, Ni 40%)	49×10^{-8}	Sulfur	10^{15}
	Nichrome	100×10^{-8}	Teflon	$>10^{13}$
			Wood	10^{8}–10^{11}

Do you recognize any connection between electrical Resistivity and thermal resistivity of the material?

Q25.2

Electrons in an electric circuit pass through a resistor. The wire has the same diameter on each side of the resistor.

Compared to the drift speed of the electrons before entering the resistor, the drift speed of the electrons after leaving the resistor is

A. faster.

B. slower.

C. the same.

D. not enough information given to decide

Q25.3

Electrons in an electric circuit pass through a resistor. The wire has the same diameter on each side of the resistor.

Compared to the potential energy of an electron before entering the resistor, the potential energy of an electron after leaving the resistor is

A. greater.

B. less.

C. the same.

D. not enough information given to decide

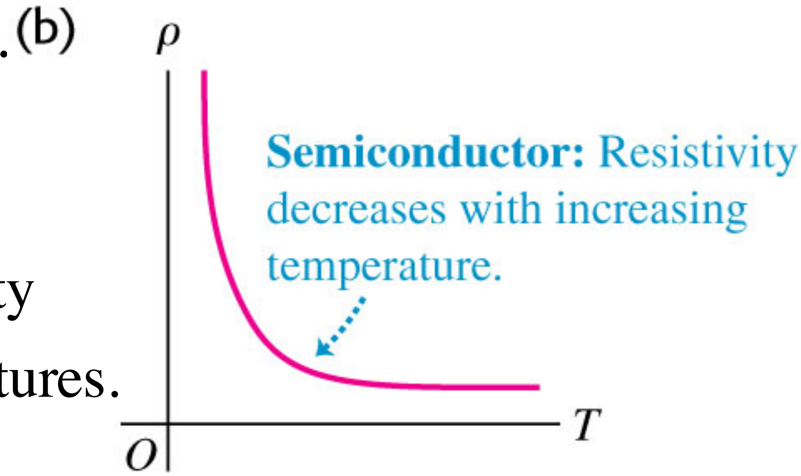
Resistivity and temperature

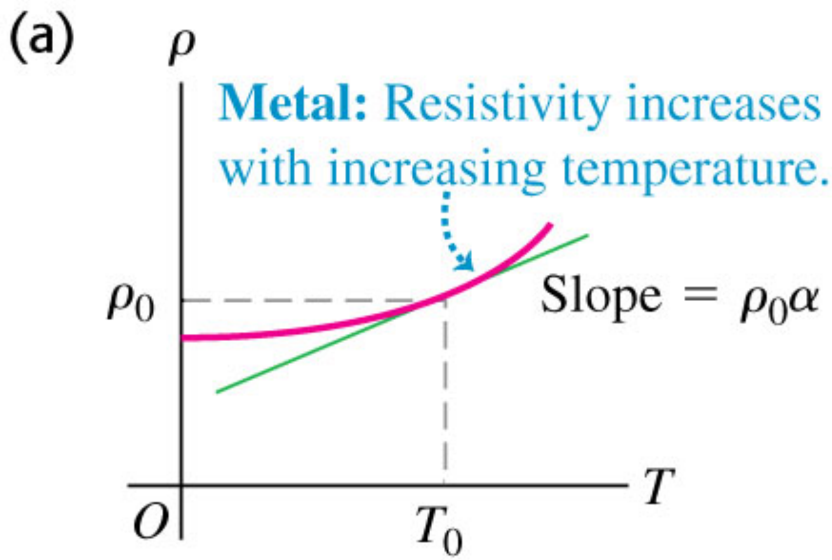
- Resistivity depends on temperature.

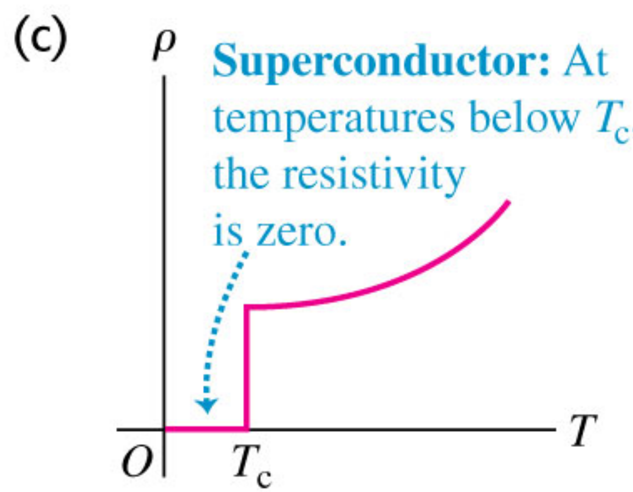
$$\rho(T) = \rho_0\left(1+\alpha\left(T-T_0\right)\right)$$

α is the temperature coefficient of resistivity

Linear only for a limitted range of temperatures.







Resistivity and temperature

- Some temperature coefficients of resistivity.

Table 25.2 Temperature Coefficients of Resistivity (Approximate Values Near Room Temperature)

Material	$\alpha\,[(°C)^{-1}]$	Material	$\alpha\,[(°C)^{-1}]$
Aluminum	0.0039	Lead	0.0043
Brass	0.0020	Manganin	0.00000
Carbon (graphite)	−0.0005	Mercury	0.00088
Constantan	0.00001	Nichrome	0.0004
Copper	0.00393	Silver	0.0038
Iron	0.0050	Tungsten	0.0045

Resistance

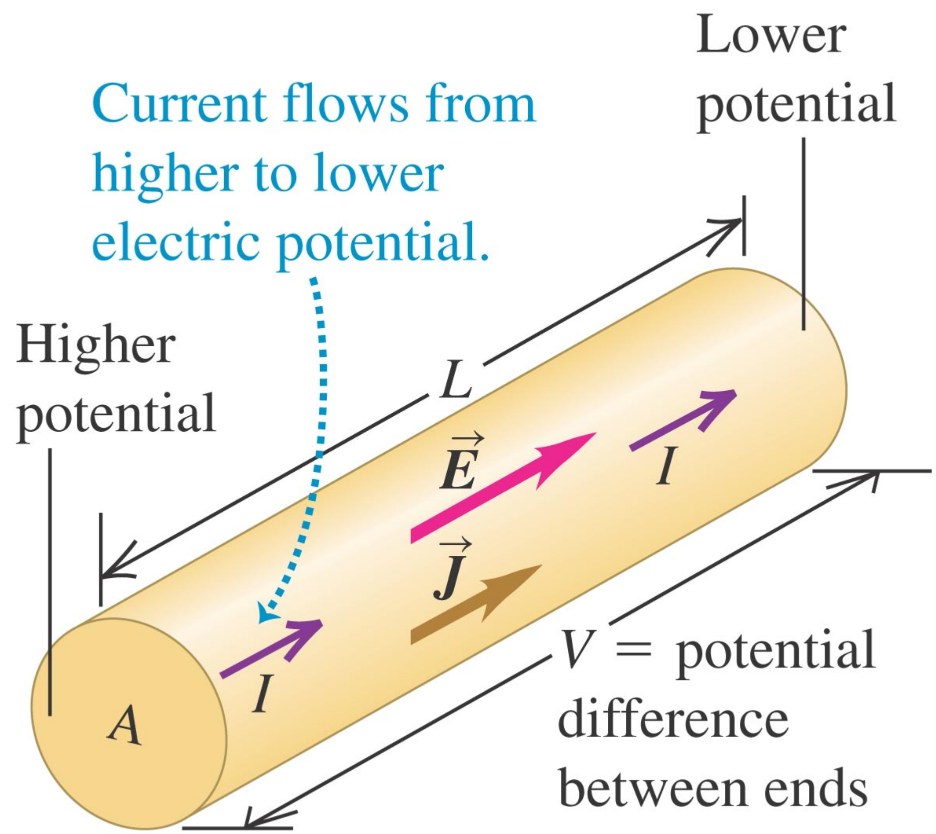
- The *resistance* of a conductor is

$$R = \rho \frac{L}{A}$$

- The potential across a conductor is

$$V = IR.$$

- If V is directly proportional to I (that is, if R is constant), the equation $V = IR$ is called *Ohm's law*.

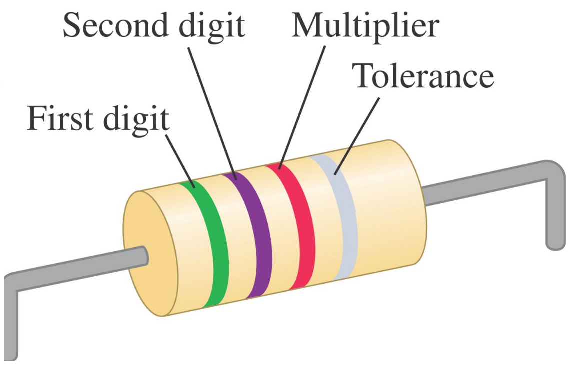


Resistors are color-coded for easy identification

- This resistor has a resistance of 5.7 kΩ with a tolerance of ±10%.

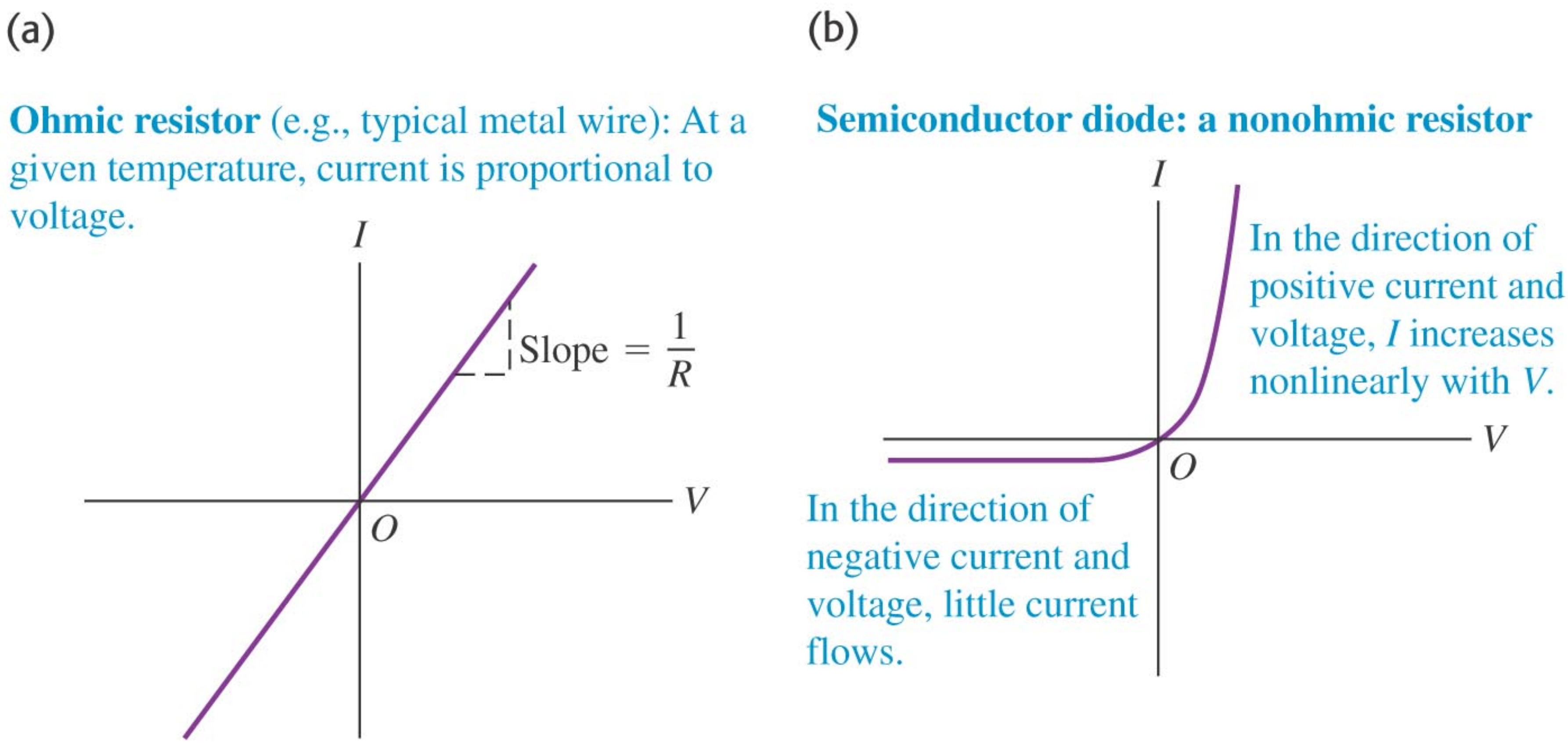
Table 25.3 Color Codes for Resistors

Color	Value as Digit	Value as Multiplier
Black	0	1
Brown	1	10
Red	2	10^2
Orange	3	10^3
Yellow	4	10^4
Green	5	10^5
Blue	6	10^6
Violet	7	10^7
Gray	8	10^8
White	9	10^9



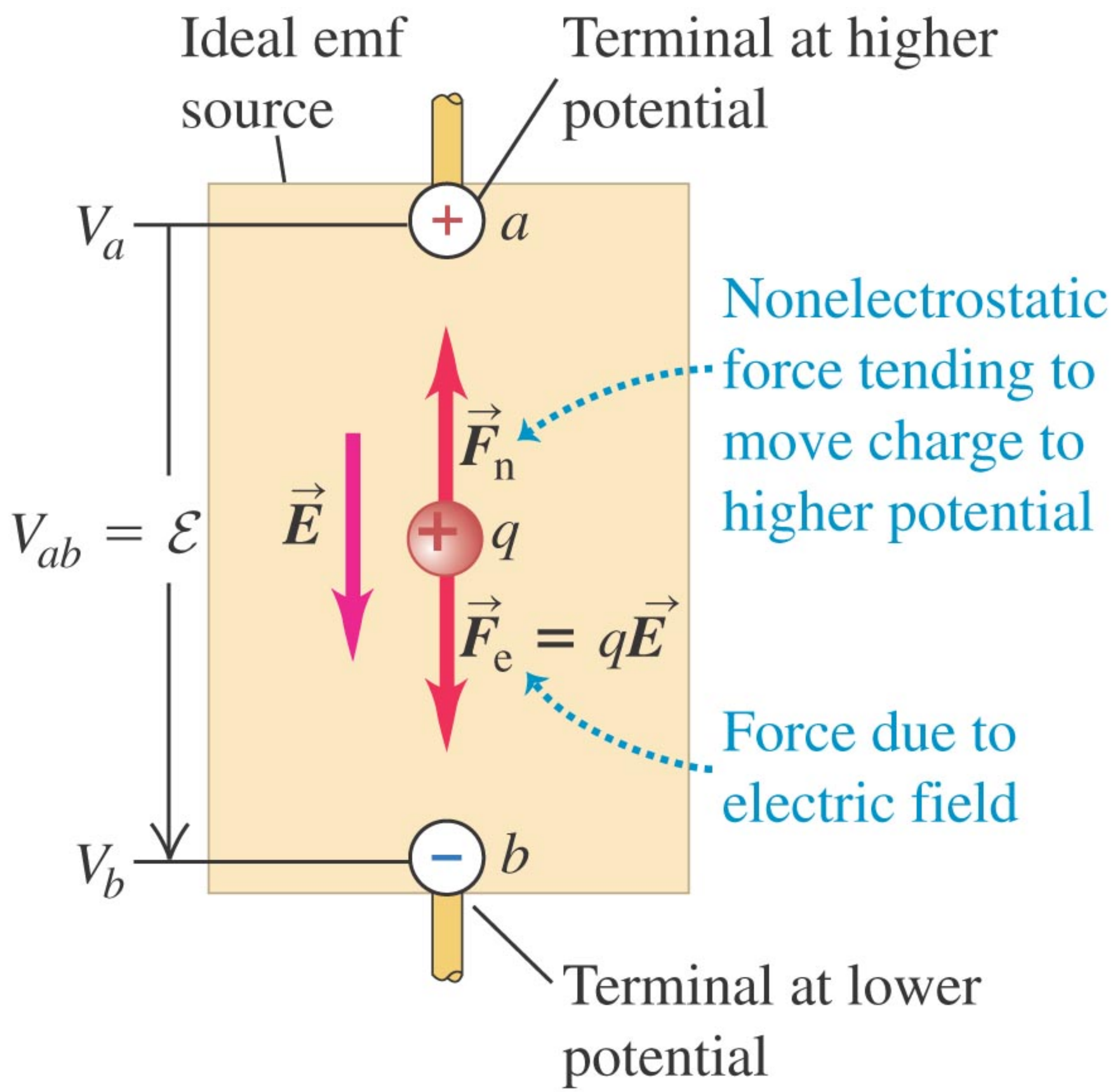
Ohmic and nonohmic resistors

- Only the resistor in Figure 25.10(a) below obeys Ohm's law.



Electromotive force and circuits

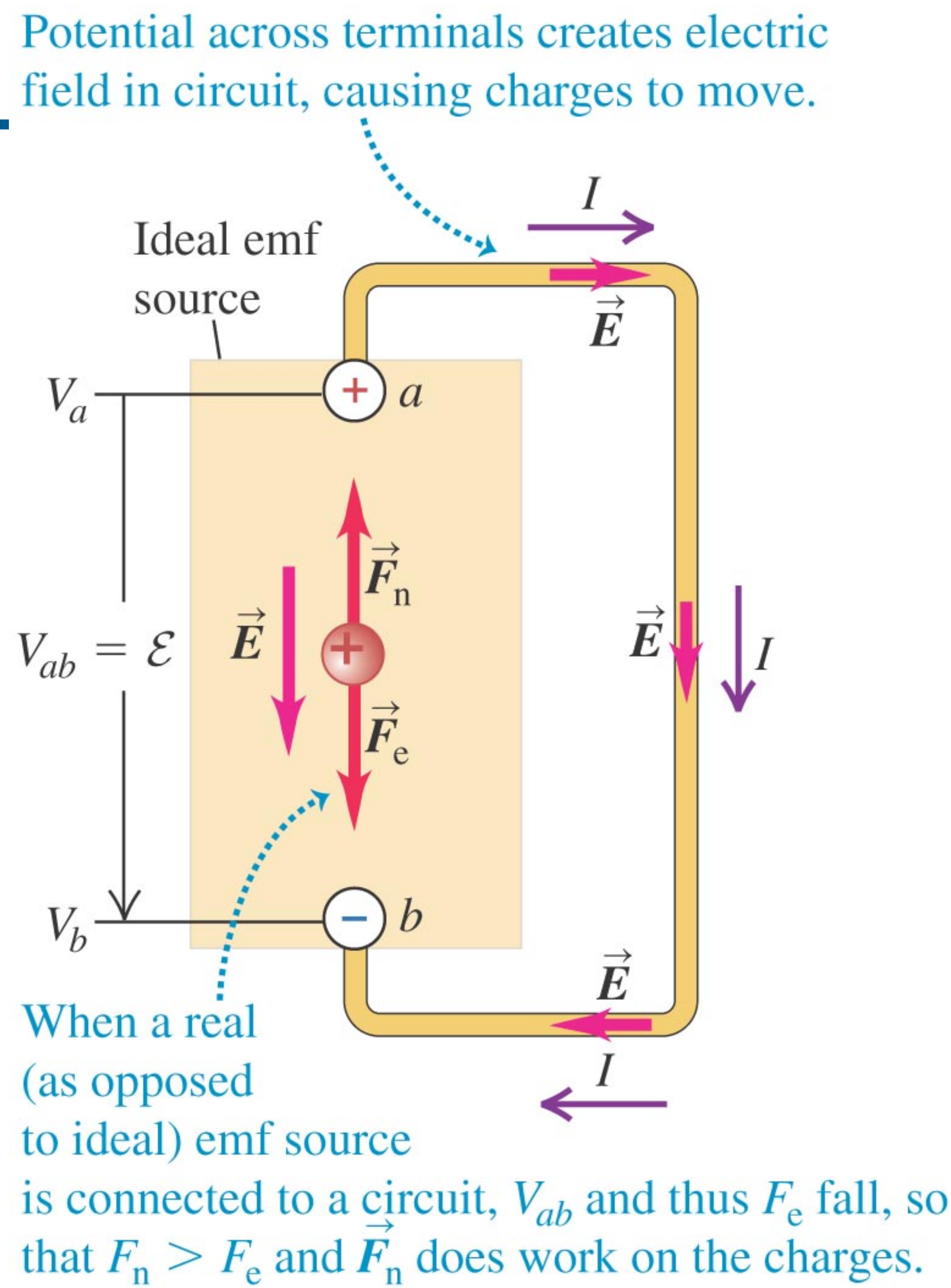
- ***Effect of an electric field on a conductor:*** **Current flows for a short time** until the internal field opposing the external field are equal in magnitude
- An *electromotive force* (*emf*) makes current flow. In spite of the name, an emf is *not* a force.
- Source of emf in an open circuit



When the emf source is not part of a closed circuit, $F_n = F_e$ and there is no net motion of charge between the terminals.

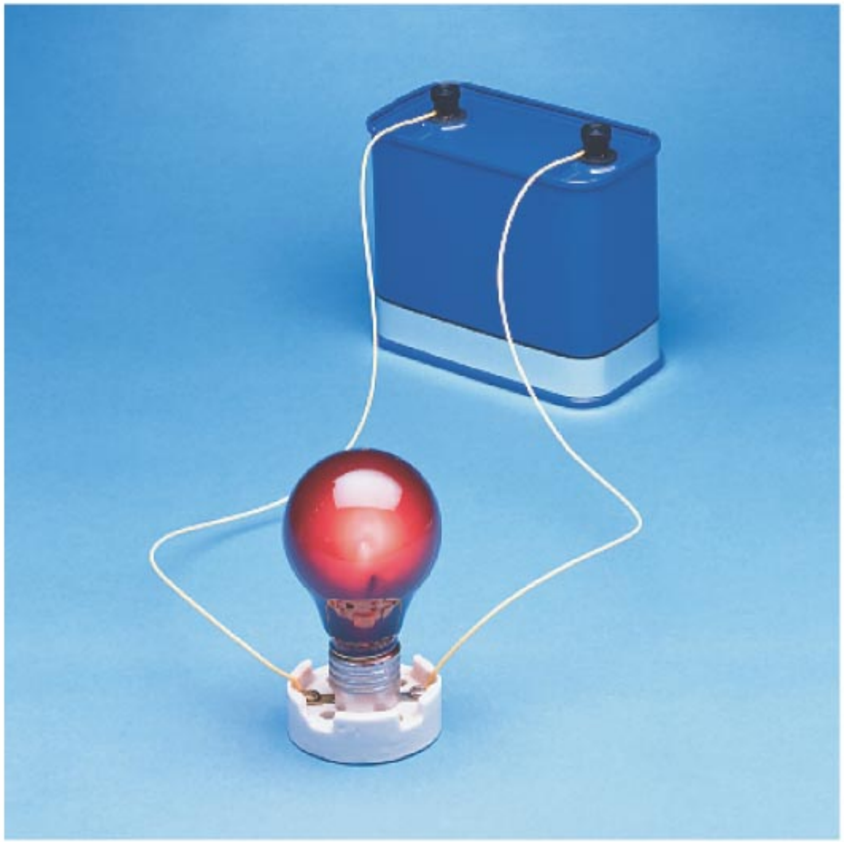
Electromotive force and circuits

- For a steady current we need a closed loop.
- An *electromotive force* (*emf*) makes current flow. In spite of the name, an emf is *not* a force.
- Source of emf a complete circuit (right).



Internal resistance

- Ideal sources of emf have no internal resistance. The *terminal voltage* of an ideal emf source is $V_{ab} = \varepsilon$
- Real sources of emf actually contain some *internal resistance* r. The *terminal voltage* of areal emf source is $V_{ab} = \varepsilon - Ir$.
- The terminal voltage of the 12-V battery shown at the right is **12 V when the circuit is open** but is less than 12 V when the circuit is closed.



Internal resistance

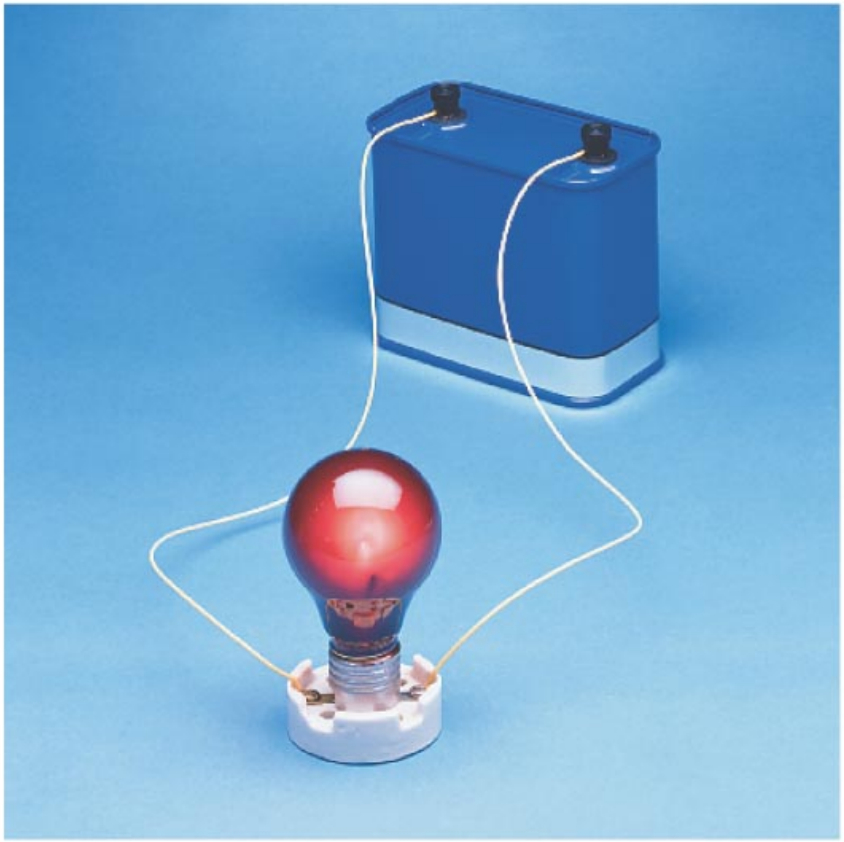
SI unit for emf: $1V = 1\dfrac{J}{C}$

Amount of work the battery does to move one Coulomb of charge through itself.

A battery does not generate the charges. A battery moves the charges around.

A circuit does not consume the current.

1.5 V battery does 1.5 J of work to move one Coulomb of charge.



$$\varepsilon - Ir = IR \rightarrow I = \frac{\varepsilon}{R + r}$$

Symbols for circuit diagrams

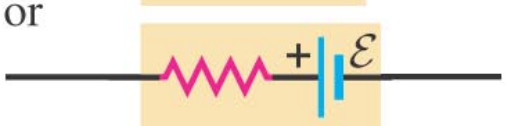
Table 25.4 Symbols for Circuit Diagrams

Conductor with negligible resistance

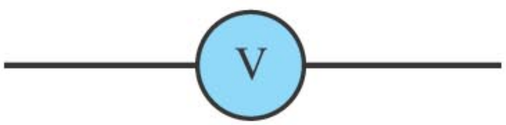
Resistor

Source of emf (longer vertical line always represents the positive terminal, usually the terminal with higher potential)

or



Source of emf with internal resistance r (r can be placed on either side)

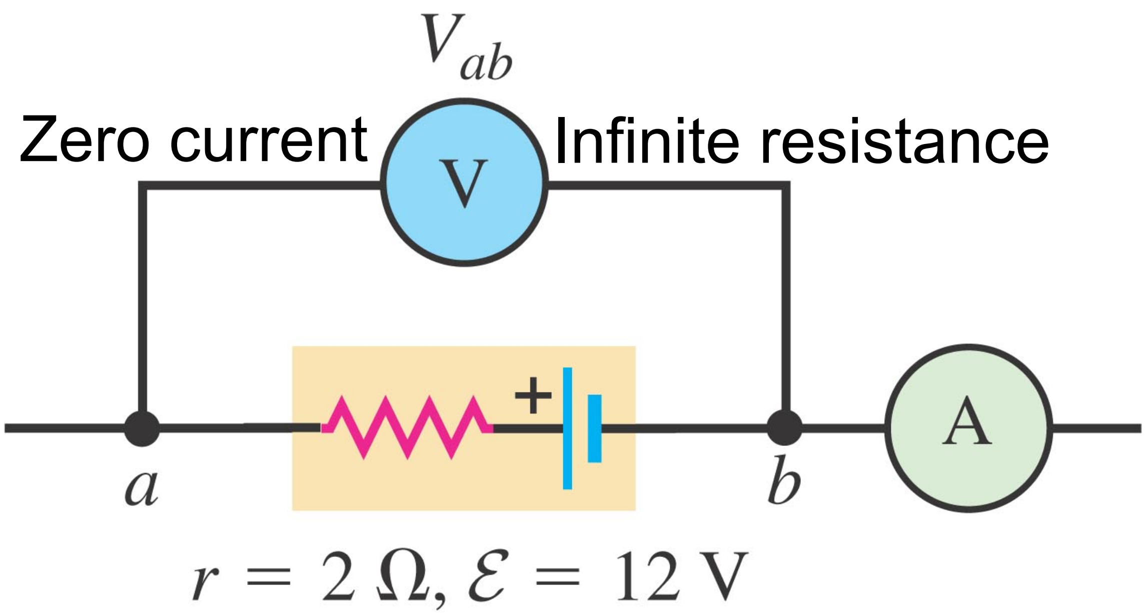


Voltmeter (measures potential difference between its terminals)

Ammeter (measures current through it)

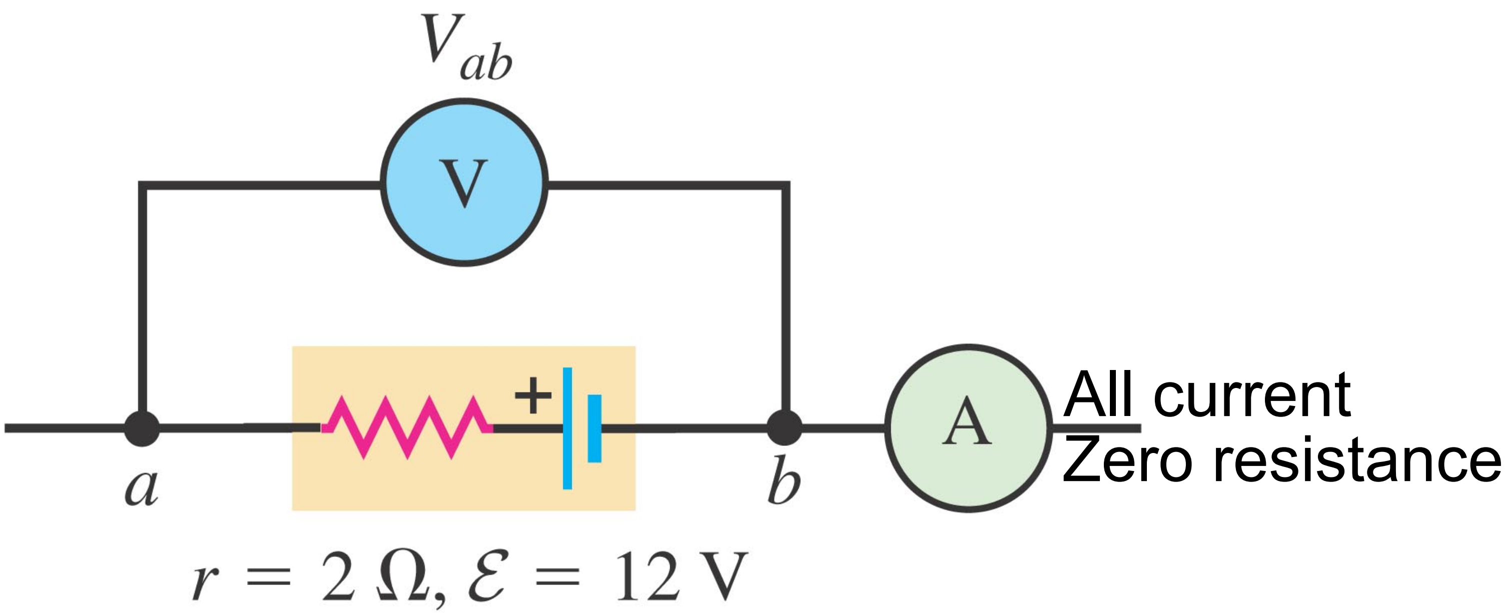
Ideal voltmeter

- Voltmeters will be covered in chapter 26
- For now we use **ideal voltmeter** which has infinite resistance and does not allow any current through. Voltmeters are always connected in parallel with the circuit element that voltage across is desired.



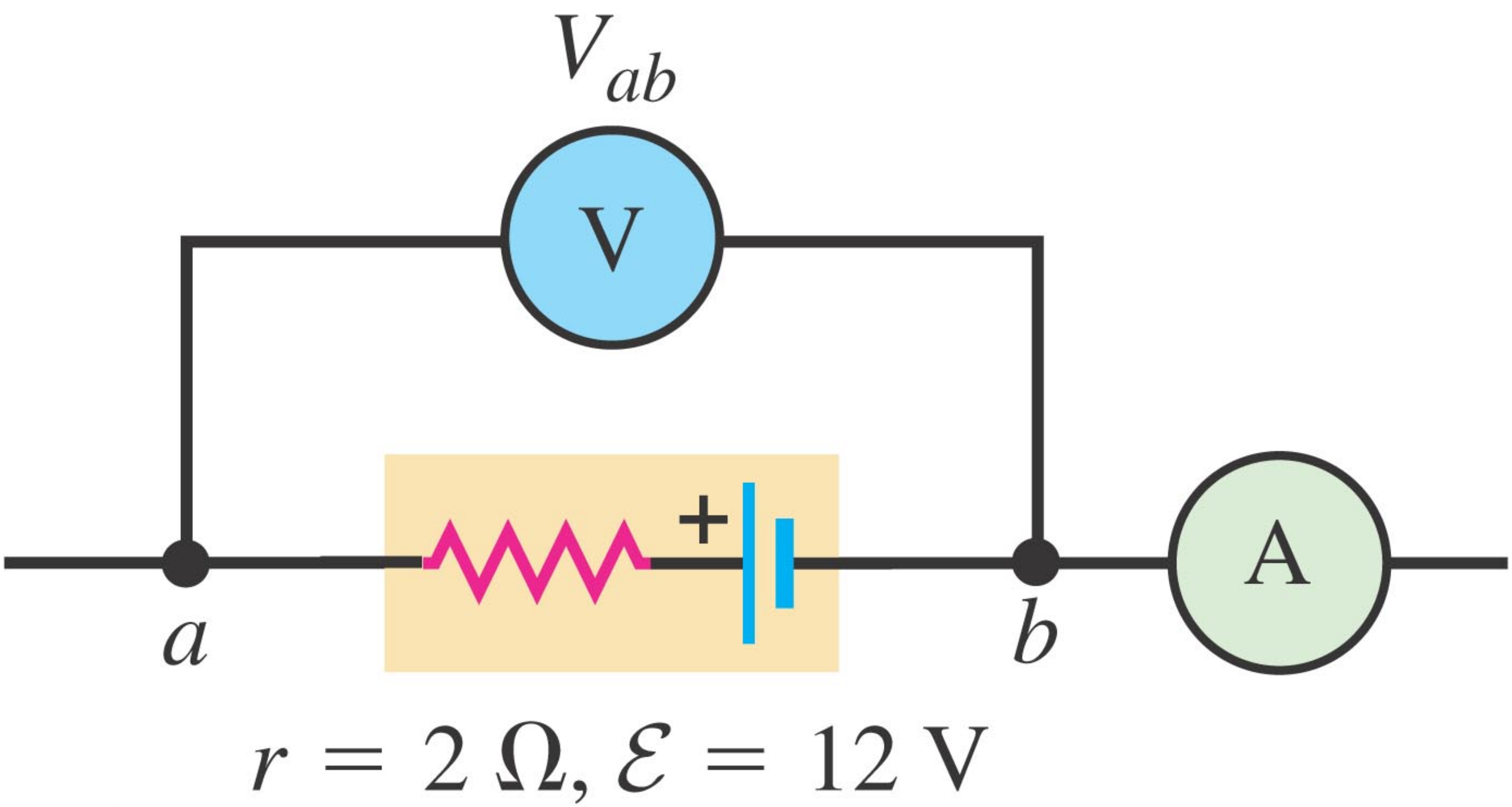
Ideal ammeter

- Real ammeters will be covered in chapter 26
- For now we use an **ideal ammeter** which has near zero resistance and does allow all the current through. Ammeters are always inserted in series with the circuit that current through it is desired.



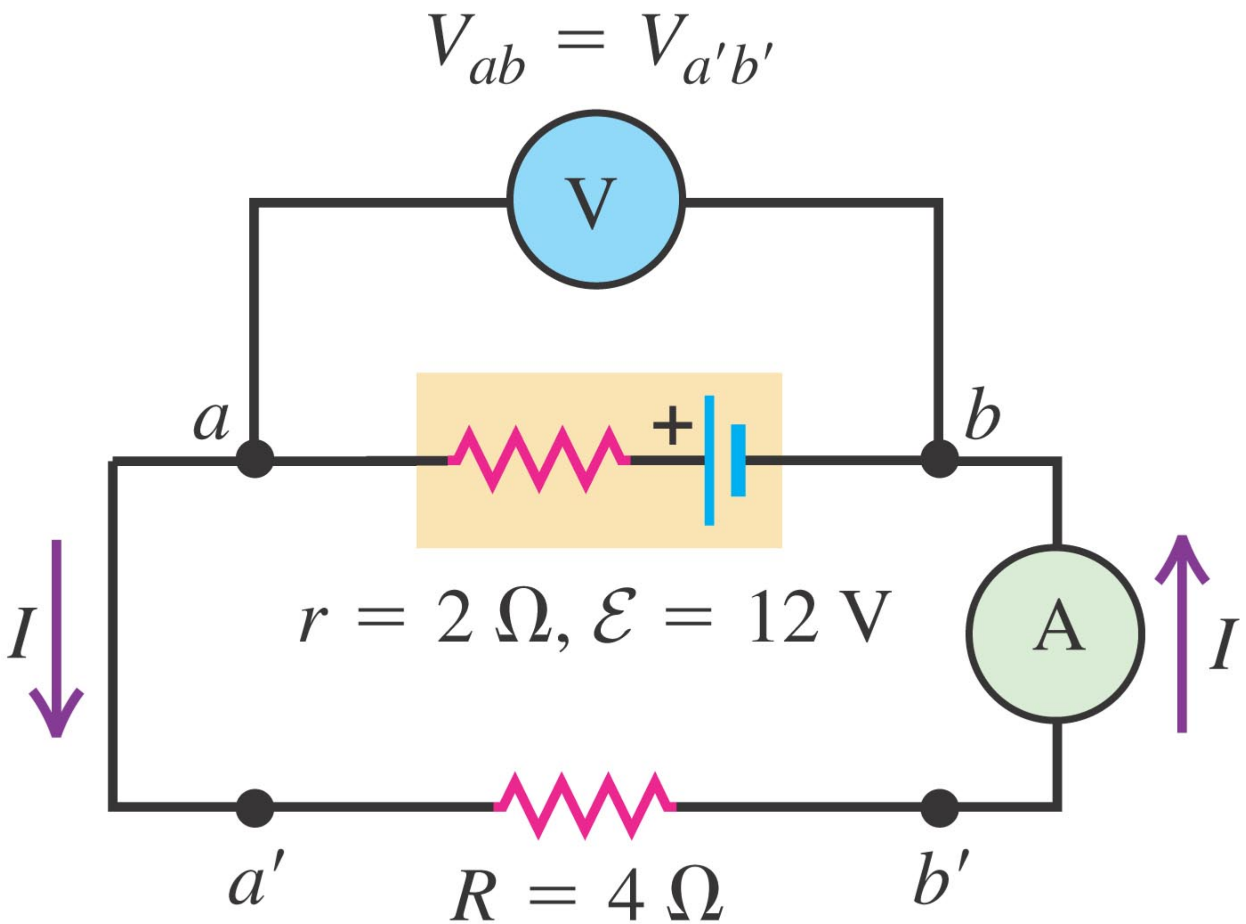
A source in an open circuit

- Example 25.4: determine the readings of the idealized voltmeter and the idealized ammeter.



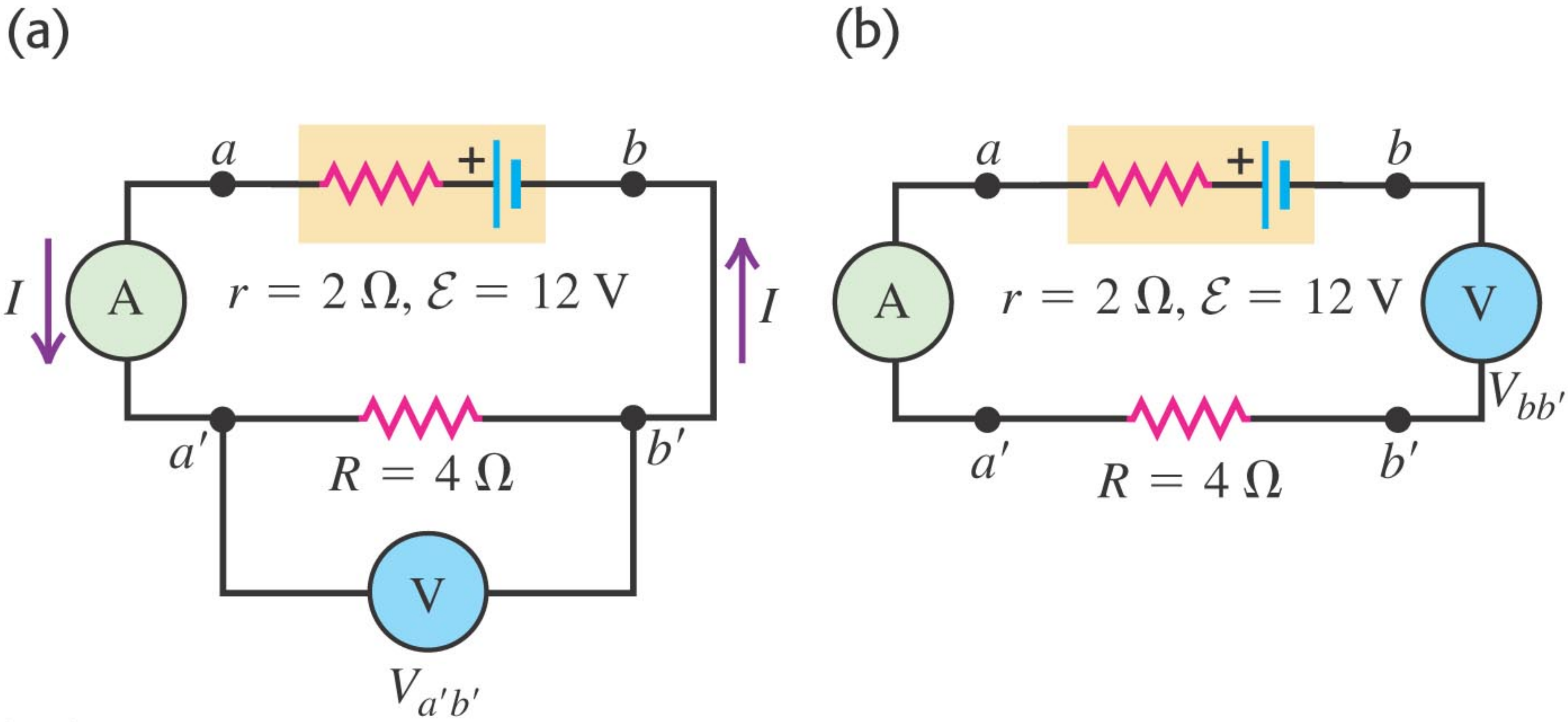
Source in a complete circuit

- Example 25.5 determine the readings of the idealized voltmeter and the idealized ammeter.



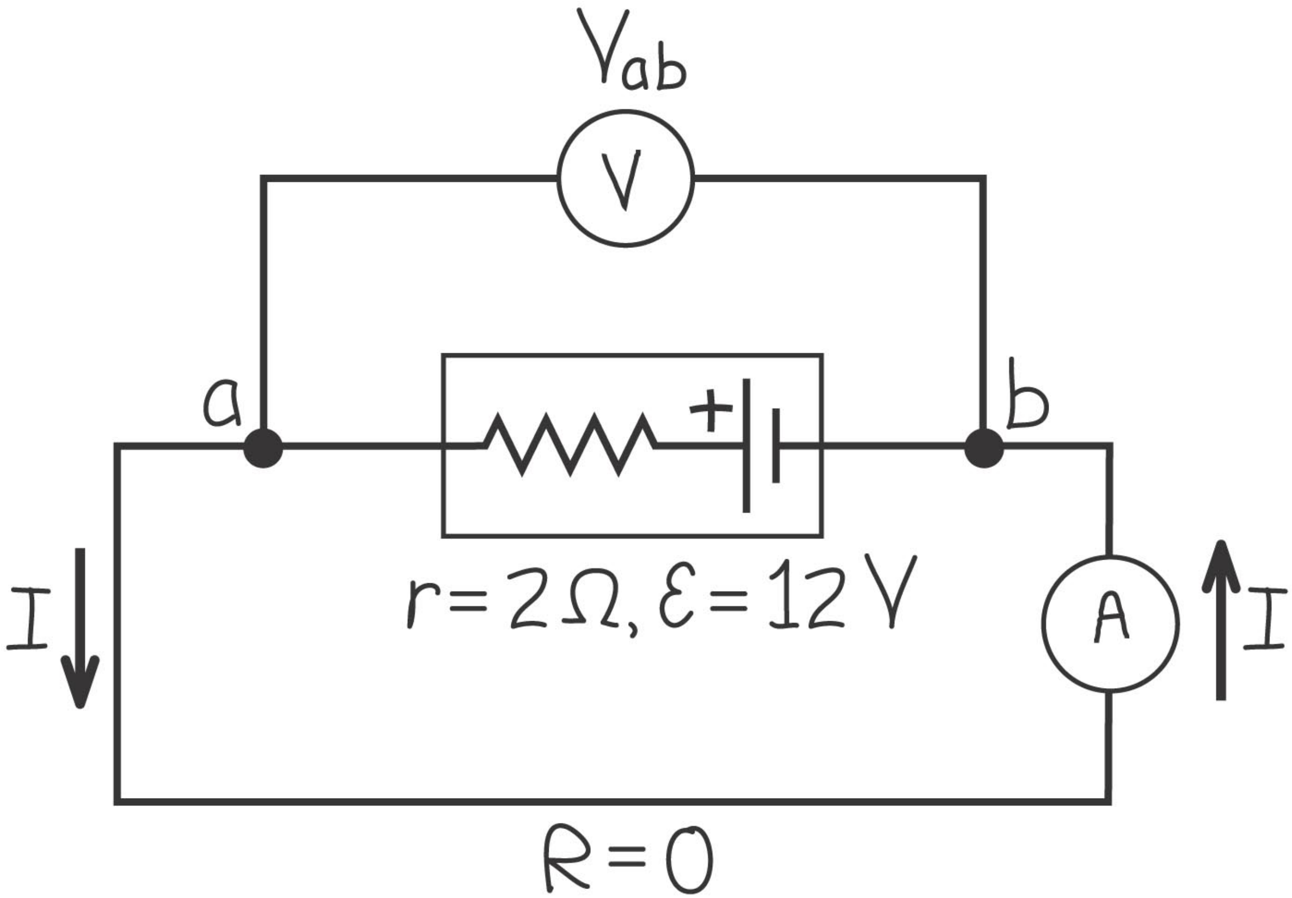
Using voltmeters and ammeters

- Example 25.6: The meters of the previous circuit have been moved. What are the readings of the meters in a and b?



A source with a short circuit

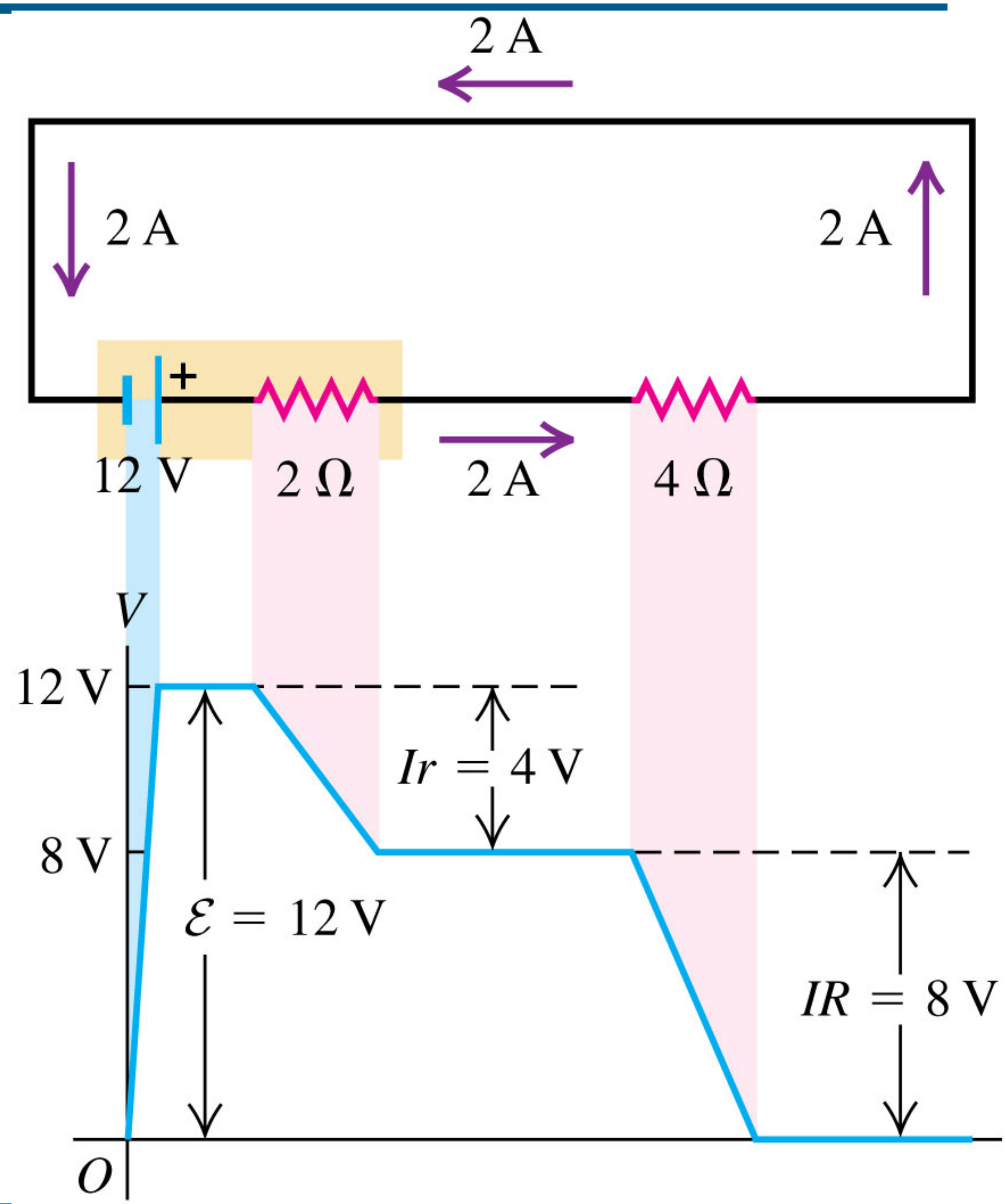
- Example 25.7: what are the meter readings?



Potential changes around a circuit

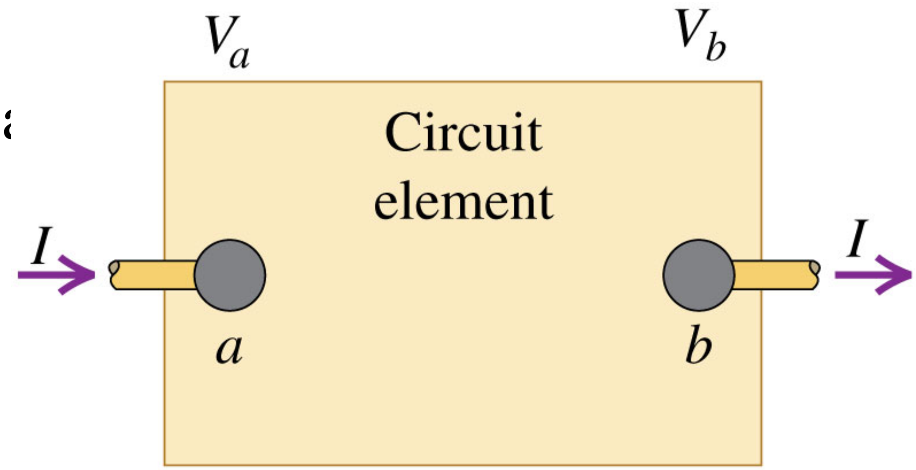
- The net change in potential must be zero for a round trip in a circuit.

$$\varepsilon - Ir - IR = 0$$



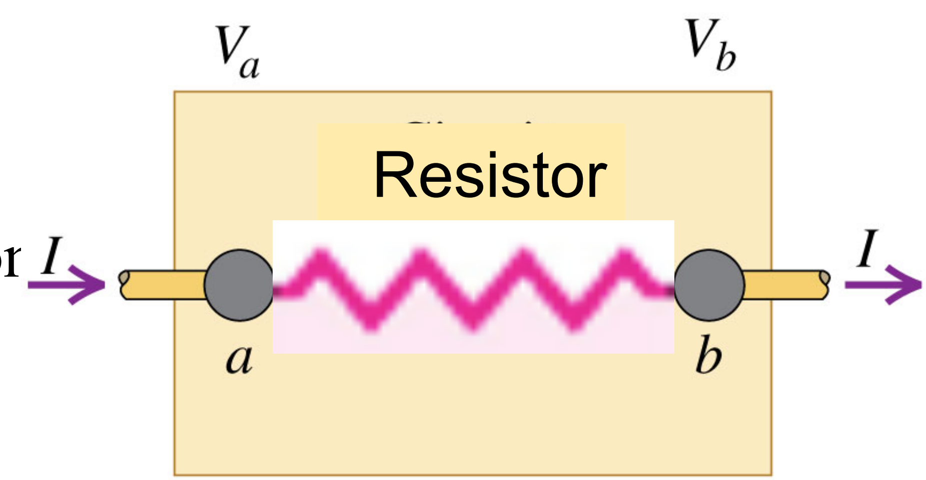
Energy and power in electric circuits

- The rate at which energy is delivered to (or extracted from) a circuit element is:
  $P = V_{ab}I.$

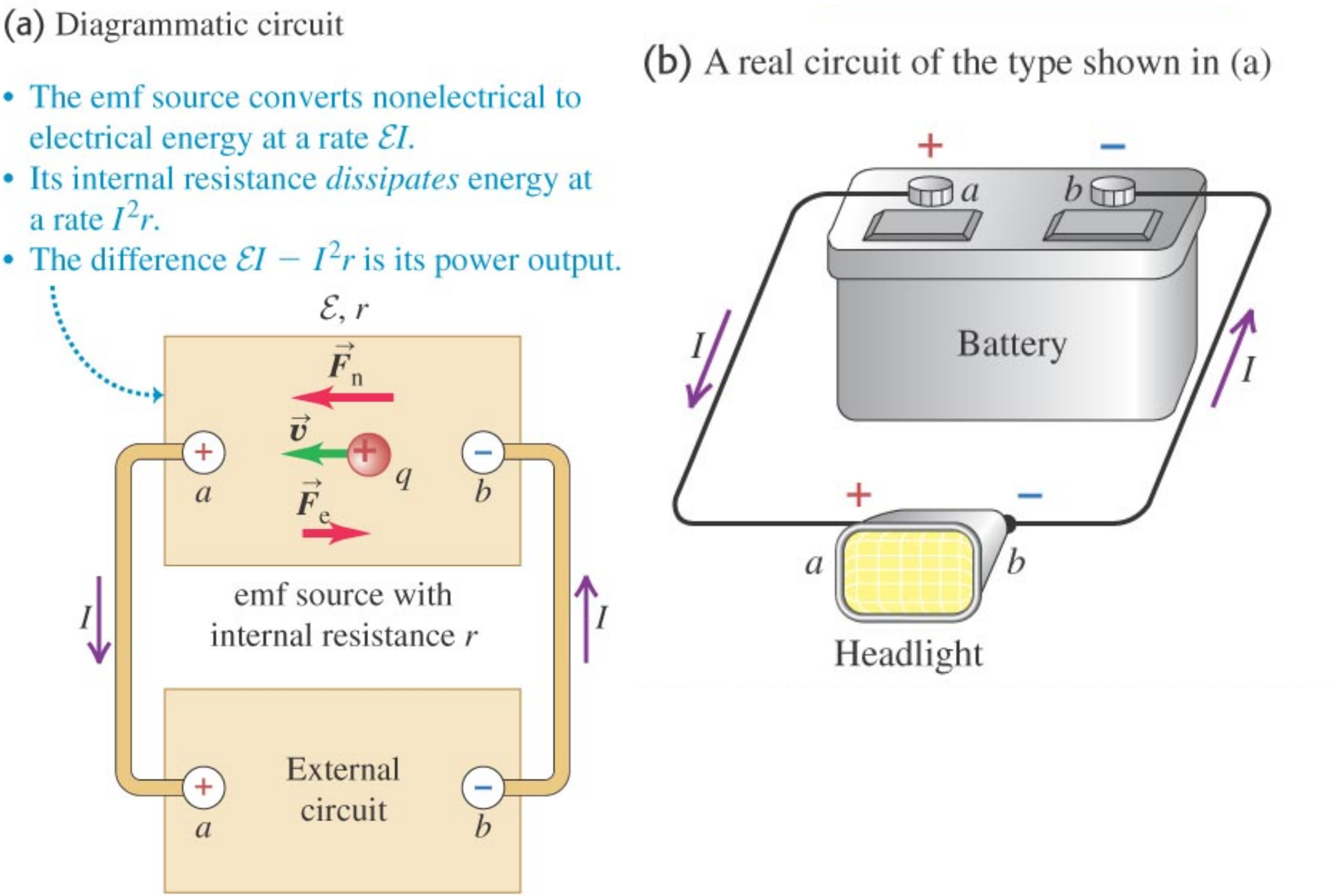


- The power delivered to a pure resistor is:
  $P = V_R\, I = (IR)I = I^2R = V_{ab}{}^2/R.$

- Power consumed by a resistor or letting current I to pass through is:
  $P = I^2R$



Energy and power output of a emf source



Problem solving strategy: Identify and Set Up

1. Make a drawing of the circuit.
2. Identify the circuit elements, including sources of emf, resistors, capacitors (Chapter 26), and inductors (Chapter 30).
3. Identify the target variables. Typically they will be the power input or output for each circuit element, or the total amount of energy put into or taken out of a circuit element in a given time.

Problem solving strategy: EXECUTE

1. A source of emf ε delivers power εI into a circuit when current I flows through the source in the direction from – to +. (For example, energy is converted from chemical energy in a battery, or from mechanical energy in a generator.) In this case there is a ***positive* power output to the circuit** or, equivalently, a ***negative* power input to the source**.

2. A source of emf takes power εI from a circuit when current passes through the source from + to – . (This occurs in **charging a storage battery**, when electrical energy is converted to chemical energy.) In this case there is a *negative* power output to the circuit or, equivalently, a *positive* power input to the source.

3. There is **always a *positive* power input to a resistor** (including internal resistors) through which current flows, irrespective of the direction of current flow. This process **removes energy** from the circuit, converting it to heat at the rate $VI = I^2R = V^2/R$, where V is the potential difference across the resistor.

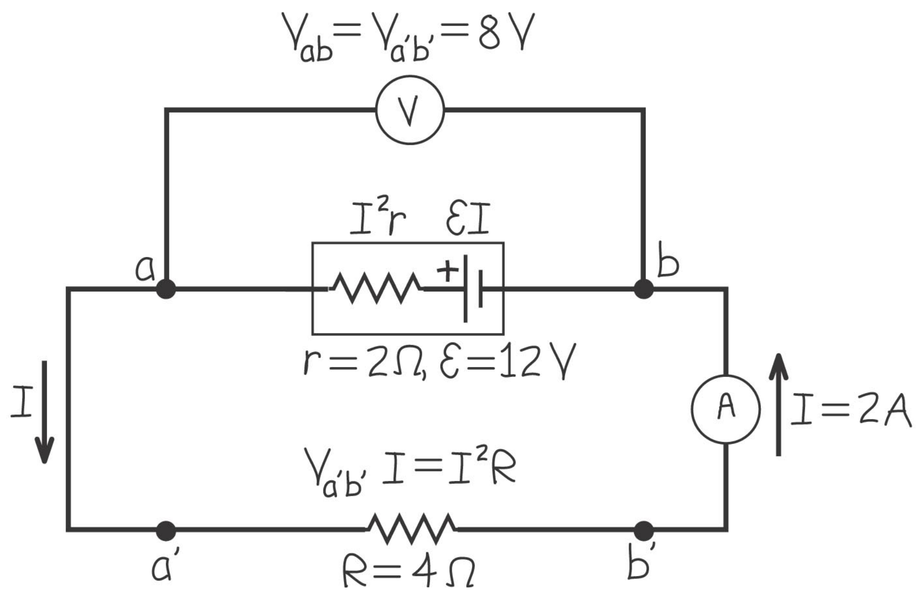
4. If the **power into or out of a circuit element is constant**, the **energy delivered to or extracted from that element is the product of power and elapsed time**. When the power is not constant, calculating the total energy requires an integral over the relevant time interval.

Problem solving strategy: Evaluate

1. **EVALUATE** *your answer:* Check your results; in particular, check that energy is conserved. This conservation can be expressed in either of two forms: “net power input = net power output” or “the algebraic sum of the power inputs to the circuit elements is zero.”

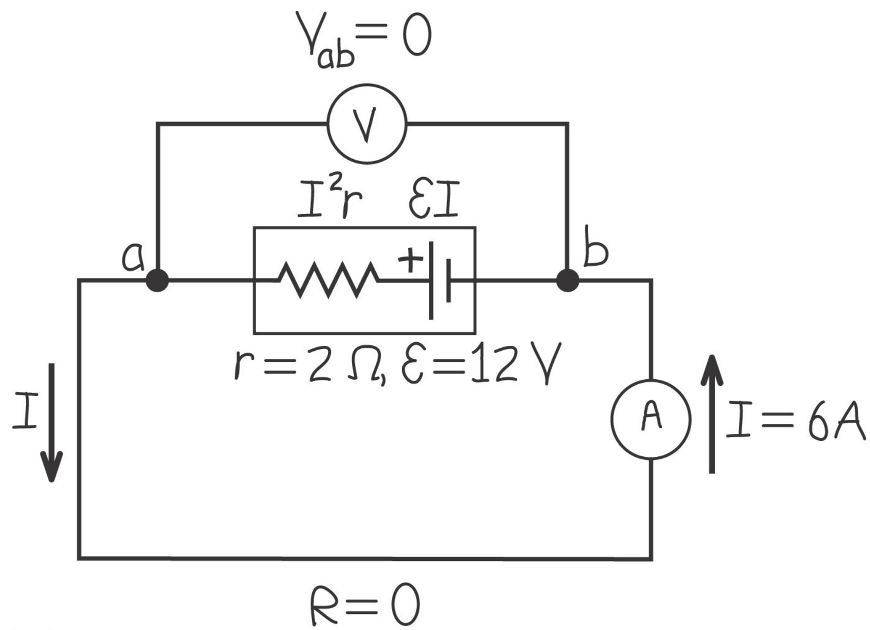
Power input and output

- 25.9: Find the rate of energy conversion (chemical to electrical) and the rate of dissipation of energy in the battery and the power output of the battery.



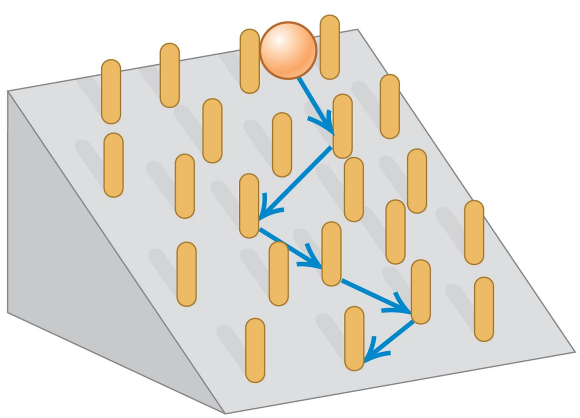
Power in a short circuit

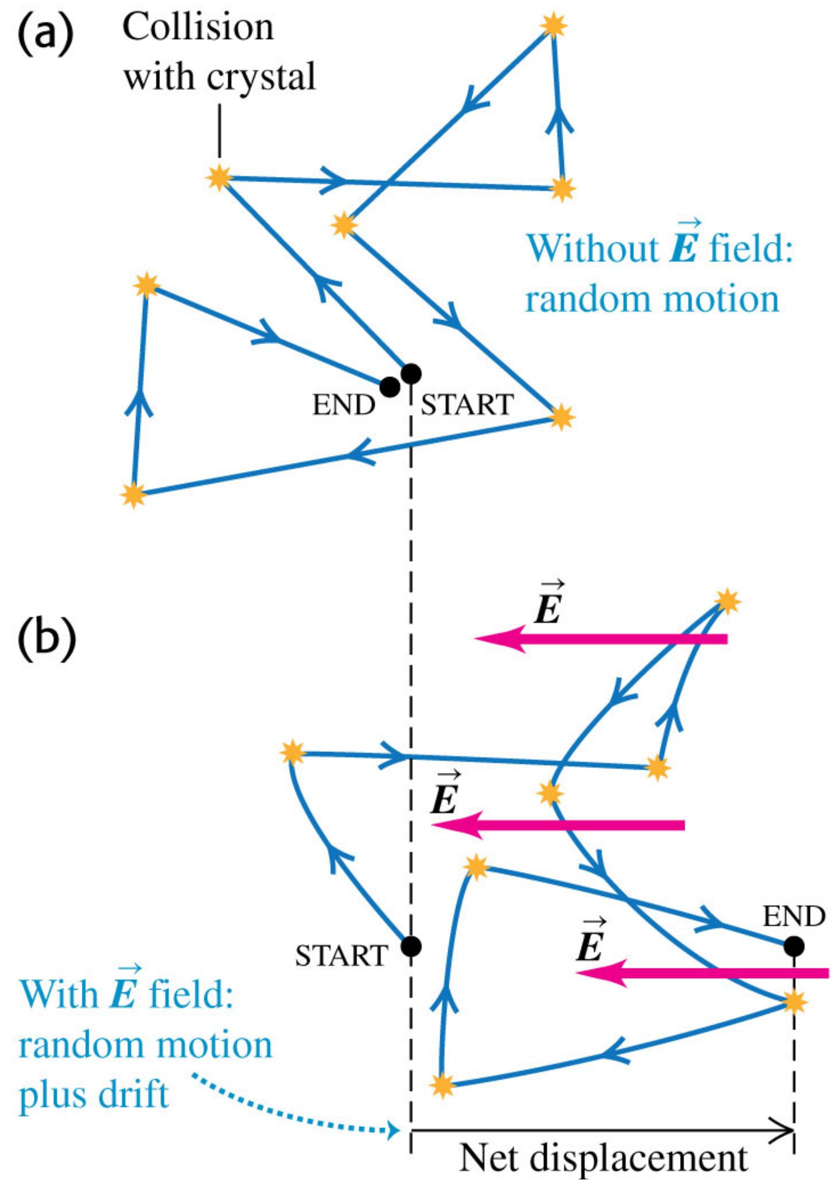
- Find the rate of energy conversion (chemical to electrical) and the rate of dissipation of energy in the battery and the power output of the battery.



Theory of metallic conduction

- Follow the discussion in the text using Figures 25.26 (right) and 25.27 (below). Both illustrate the random motion of electrons in a conductor.
- Follow Example 25.11.





Q25.4

Electrons in an electric circuit pass through a source of emf. The wire has the same diameter on each side of the source of emf.

Compared to the drift speed of the electrons before entering the source of emf, the drift speed of the electrons after leaving the source of emf is

A. faster.

B. slower.

C. the same.

D. not enough information given to decide

Q25.5

Electrons in an electric circuit pass through a source of emf. The wire has the same diameter on each side of the source of emf.

Compared to the potential energy of an electron before entering the source of emf, the potential energy of an electron after leaving the source of emf is

A. greater.

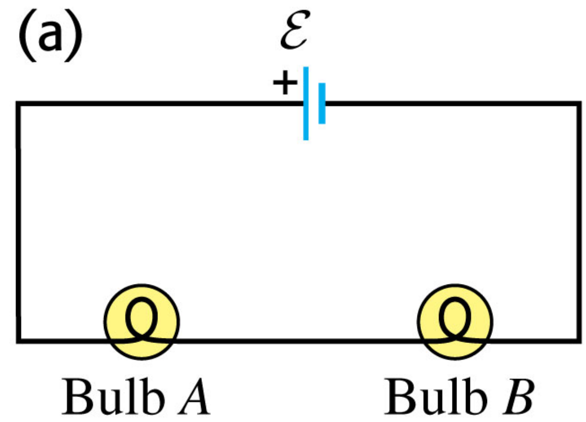
B. less.

C. the same.

D. not enough information given to decide

Q25.6

In the circuit shown, the two bulbs *A* and *B* are identical. Compared to bulb *A*,



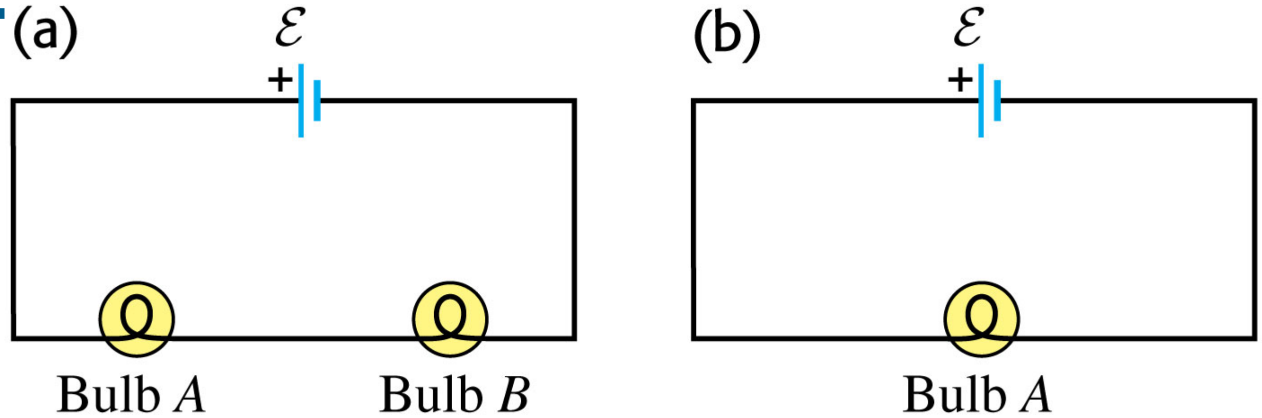
A. bulb *B* glows more brightly.

B. bulb *B* glows less brightly.

C. bulb *B* glows just as brightly.

D. The answer depends on whether the mobile charges in the wires are positively or negatively charged.

Q25.7



In the circuit shown in (a), the two bulbs *A* and *B* are identical. Bulb *B* is removed and the circuit is completed as shown in (b). Compared to the brightness of bulb *A* in (a), bulb *A* in (b) is

A. brighter.

B. less bright.

C. just as bright.

D. Any of the above, depending on the rated wattage of the bulb.

Q25.8

An ideal voltmeter

A. has zero resistance and should be connected in parallel with the circuit element being measured.

B. has zero resistance and should be connected in series with the circuit element being measured.

C. has infinite resistance and should be connected in parallel with the circuit element being measured.

D. has infinite resistance and should be connected in series with the circuit element being measured.

Q25.9

An ideal ammeter

A. has zero resistance and should be connected in parallel with the circuit element being measured.

B. has zero resistance and should be connected in series with the circuit element being measured.

C. has infinite resistance and should be connected in parallel with the circuit element being measured.

D. has infinite resistance and should be connected in series with the circuit element being measured.