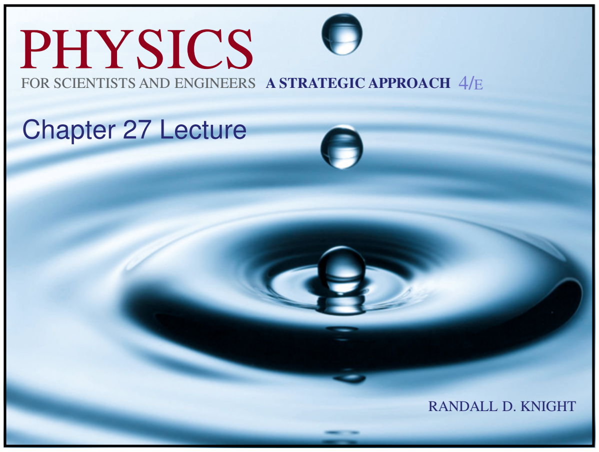
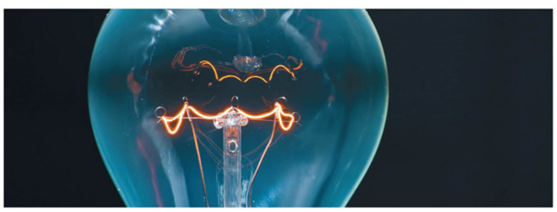


Chapter 27 Current and Resistance



IN THIS CHAPTER, you will learn how and why charge moves through a wire as a current.

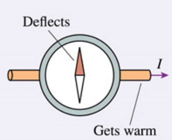
 Slide 27-2

Chapter 27 Preview

What is current?

Current is the flow of charge through a conductor. We can't see charge moving, but two indicators of current are:

- A nearby compass needle is deflected.
- A wire with a current gets warm.



Current I is measured in amperes, a charge flow rate of one coulomb per second. You know this informally as "amps."

« LOOKING BACK Section 23.6 The motion of charges in electric fields

 Slide 27-3

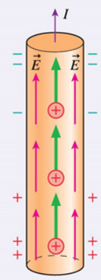
Chapter 27 Preview

How does current flow?

We'll develop a model of conduction:

- Connecting a wire to a battery causes a nonuniform surface charge distribution.
- The surface charges create an electric field inside the wire.
- The electric field pushes the sea of electrons through the metal.
- Electrons are the charge carriers in metals, but it is customary to treat current as the motion of *positive* charges.

Current is I. Current density $J = I/A$ is the amount of current per square meter.

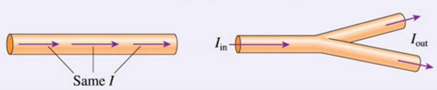


Chapter 27 Preview

What law governs current?

Current is governed by Kirchhoff's junction law.

- The current is the same everywhere in a circuit with no junctions.
- The sum of currents entering a junction equals the sum leaving.

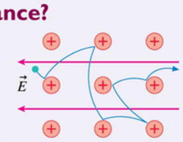


Chapter 27 Preview

What are resistivity and resistance?

Collisions of electrons with atoms cause a conductor to *resist* the motion of charges.

- Resistivity is an electrical property of a material, such as copper.
- Resistance is a property of a specific wire or circuit element based on the material *and* its size and shape.

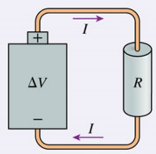


Chapter 27 Preview

What is Ohm's law?

Ohm's law says that the current flowing through a wire or circuit element depends on both the potential difference across it and the element's resistance:

$$I = \Delta V / R$$



« LOOKING BACK Section 26.4 Sources of potential

Slide 27-7

Chapter 27 Reading Questions

Slide 27-8

Reading Question 27.1

What quantity is represented by the symbol J ?

A. Resistivity
B. Conductivity
C. Current density
D. Complex impedance
E. Johnston's constant

Slide 27-9

Reading Question 27.1

What quantity is represented by the symbol J ?

A. Resistivity
B. Conductivity
✔ **C. Current density**
D. Complex impedance
E. Johnston's constant

Reading Question 27.2

The electron drift speed in a typical current-carrying wire is

A. Extremely slow ($\approx 10^{-4}$ m/s).
B. Moderate (≈ 1 m/s).
C. Very fast ($\approx 10^{4}$ m/s).
D. Could be any of A, B, or C.
E. No numerical values were provided.

Reading Question 27.2

The electron drift speed in a typical current-carrying wire is

✔ **A. Extremely slow ($\approx 10^{-4}$ m/s).**
B. Moderate (≈ 1 m/s).
C. Very fast ($\approx 10^{4}$ m/s).
D. Could be any of A, B, or C.
E. No numerical values were provided.

Reading Question 27.3

All other things being equal, current will be larger in a wire that has a larger value of

A. Conductivity.
B. Resistivity.
C. The coefficient of current.
D. Net charge.
E. Potential.

Slide 27-13

Reading Question 27.3

All other things being equal, current will be larger in a wire that has a larger value of

✔**A. Conductivity.**
B. Resistivity.
C. The coefficient of current.
D. Net charge.
E. Potential.

Slide 27-14

Reading Question 27.4

The equation $I = \Delta V/R$ is called

A. Ampère's law.
B. Ohm's law.
C. Faraday's law.
D. Weber's law.

Slide 27-15

Reading Question 27.4

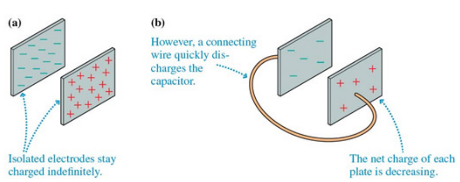
The equation $I = \Delta V/R$ is called

A. Ampère's law.
✔**B. Ohm's law.**
C. Faraday's law.
D. Weber's law.

Chapter 27 Content, Examples, and QuickCheck Questions

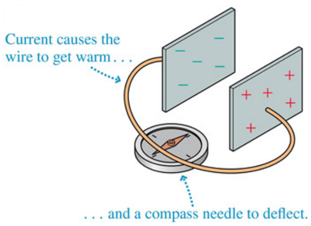
Electric Current

- How does a capacitor get discharged?
- Figure (a) shows a charged capacitor in equilibrium.
- Figure (b) shows a wire discharging the capacitor.
- *As* the capacitor is discharging, there is a *current* in the wire.



Electric Current

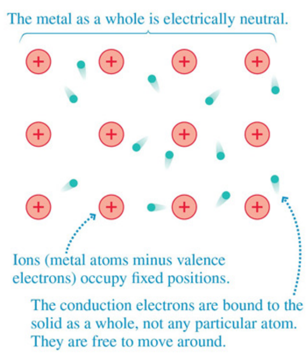
- When a current is flowing, the conductors are *not* in electrostatic equilibrium.
- Though you cannot see current directly, there are certain *indicators* that current is present in a wire.



 Slide 27-19

Charge Carriers

- The outer electrons of metal atoms are only weakly bound to the nuclei.
- In a metal, the outer electrons become detached from their parent nuclei to form a fluid-like *sea of electrons* that can move through the solid.
- **Electrons are the charge carriers in metals.**

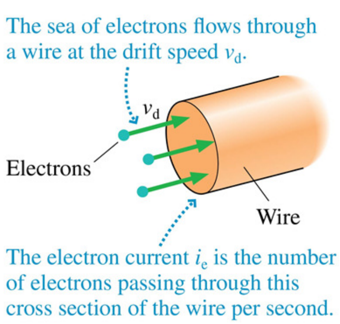


 Slide 27-20

The Electron Current

- We define the **electron current** i_e to be the number of electrons per second that pass through a cross section of the conductor.
- The number N_e of electrons that pass through the cross section during the time interval Δt is

$$N_e = i_e \Delta t$$



 Slide 27-21

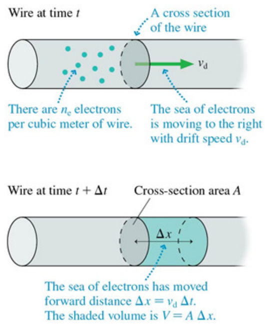
The Electron Current

- If the number density of conduction electrons is n_e, then the total number of electrons in the shaded cylinder is

$$N_e = n_e V = n_e A\Delta x = n_e A v_d \Delta t$$

- So the electron current is

$$i_e = n_e A v_d$$



Slide 27-22

QuickCheck 27.1

A wire carries a current. If both the wire diameter and the electron drift speed are doubled, the electron current increases by a factor of

A. 2.
B. 4.
C. 6.
D. 8.
E. Some other value.

Slide 27-23

QuickCheck 27.1

A wire carries a current. If both the wire diameter and the electron drift speed are doubled, the electron current increases by a factor of

A. 2.
B. 4.
C. 6.
✔ **D. 8.** $i_e \propto A v_d$
E. Some other value.

Slide 27-24

The Electron Density

- In most metals, each atom contributes one valence electron to the sea of electrons.
- Thus the number of conduction electrons n_e is the same as the number of atoms per cubic meter.

TABLE 27.1 Conduction-electron density in metals

Metal	Electron density (m^{-3})
Aluminum	6.0×10^{28}
Copper	8.5×10^{28}
Iron	8.5×10^{28}
Gold	5.9×10^{28}
Silver	5.8×10^{28}

Example 27.1 The Size of the Electron Current

EXAMPLE 27.1 | **The size of the electron current**

What is the electron current in a 2.0-mm-diameter copper wire if the electron drift speed is 1.0×10^{-4} m/s?

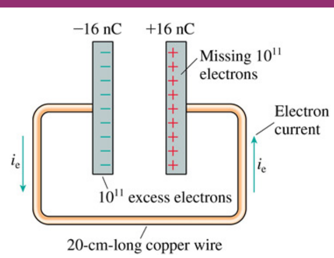
SOLVE This is a straightforward calculation. The wire's cross-section area is $A = \pi r^2 = 3.14 \times 10^{-6}\ m^2$. Table 27.1 gives the electron density for copper as $8.5 \times 10^{28}\ m^{-3}$. Thus we find

$$i_e = n_e A v_d = 2.7 \times 10^{19}\ s^{-1}$$

ASSESS This is an incredible number of electrons to pass through a section of the wire every second. The number is high not because the sea of electrons moves fast—in fact, it moves at literally a snail's pace—but because the density of electrons is so enormous. This is a fairly typical electron current.

Discharging a Capacitor

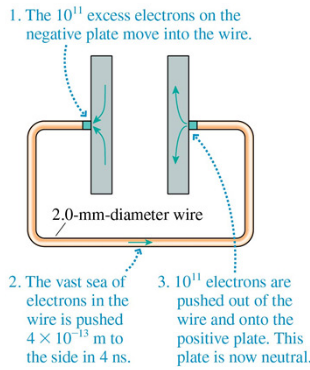
- How long should it take to discharge this capacitor?
- A typical drift speed of electron current through a wire is $v_d \approx 10^{-4}$ m/s.
- At this rate, it would take an electron about 2000 s (over half an hour) to travel 20 cm.



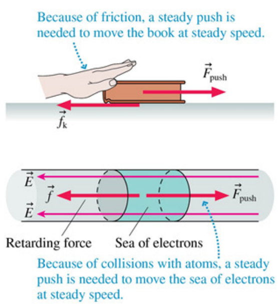
- But real capacitors discharge almost instantaneously!
- What's wrong with our calculation?

Discharging a Capacitor

- The wire is *already full* of electrons!
- We don't have to wait for electrons to move all the way through the wire from one plate to another.
- We just need to slightly rearrange the charges on the plates *and* in the wire.



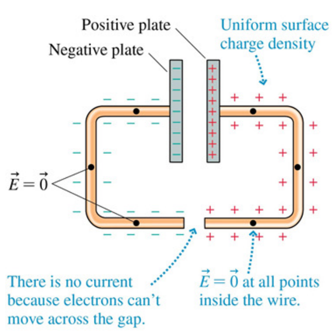
Creating a Current



- A book on a table will slow down and stop unless you continue pushing.
- Analogously, the sea of electrons will slow down and stop unless you continue pushing with an electric field.

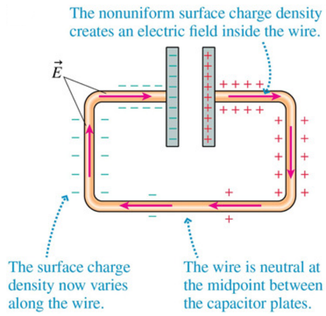
Establishing the Electric Field in a Wire

- The figure shows two metal wires attached to the plates of a charged capacitor.
- This is an electrostatic situation.
- What will happen if we connect the bottom ends of the wires together?



Establishing the Electric Field in a Wire

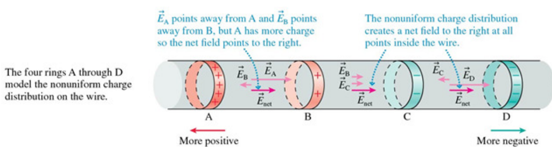
- Within a *very* brief interval of time ($\approx 10^{-9}$ s) of connecting the wires, the sea of electrons shifts slightly.
- The surface charge is rearranged into a *nonuniform* distribution, as shown in the figure.



 Slide 27-31

Establishing the Electric Field in a Wire

- The *nonuniform* distribution of surface charges along a wire creates a net electric field *inside* the wire that points from the more positive end toward the more negative end of the wire.
- This is the internal electric field that pushes the electron current through the wire.



 Slide 27-32

QuickCheck 27.2

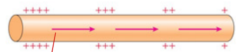
Surface charge is distributed on a wire as shown. Electrons in the wire

A. Drift to the right.
B. Drift to the left.
C. Move upward.
D. Move downward.
E. On average, remain at rest.

 Slide 27-33

QuickCheck 27.2

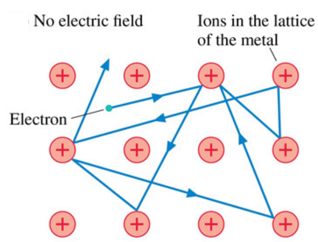
Surface charge is distributed on a wire as shown. Electrons in the wire



A. Drift to the right.
✔**B. Drift to the left.**
C. Move upward.
D. Move downward.
E. On average, remain at rest.

A Model of Conduction

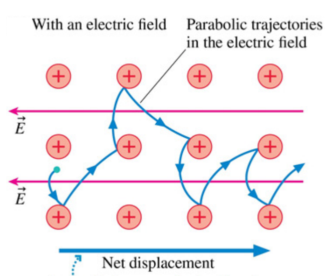
- Within a conductor in electrostatic equilibrium, there is no electric field.
- In this case, an electron bounces back and forth between collisions, but its *average* velocity is zero.



The electron has frequent collisions with ions, but it undergoes no net displacement.

A Model of Conduction

- In the presence of an electric field, the electric force causes electrons to move along parabolic trajectories between collisions.
- Because of the curvature of the trajectories, there is a slow net motion in the "downhill" direction.

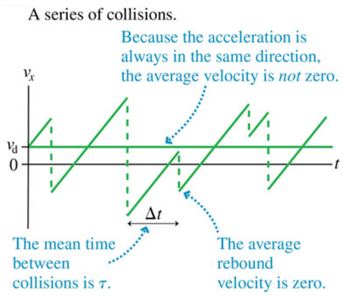


A net displacement in the direction opposite to $\vec{E}$ is superimposed on the random thermal motion.

A Model of Conduction

- The graph shows the speed of an electron during multiple collisions.
- The average drift speed is

$$v_d = \frac{e\tau}{m}E$$



Electron Current

- The electric field strength E in a wire of cross-section A causes an electron current:

$$i_e = \frac{n_e e\tau A}{m}E$$

- The electron density n_e and the mean time between collisions τ are properties of the metal.
- The electron current is directly proportional to the electric field strength.

Example 27.3 Collisions in a Copper Wire

EXAMPLE 27.3 | **Collisions in a copper wire**

Example 27.1 found the electron current to be $2.7 \times 10^{19}\ s^{-1}$ for a 2.0-mm-diameter copper wire in which the electron drift speed is 1.0×10^{-4} m/s. If an internal electric field of 0.020 V/m is needed to sustain this current, a typical value, how many collisions per second, on average, do electrons in copper undergo?

MODEL Use the model of conduction.

Example 27.3 Collisions in a Copper Wire

EXAMPLE 27.3 | **Collisions in a copper wire**

SOLVE From Equation 27.7, the mean time between collisions is

$$\tau = \frac{mv_d}{eE} = 2.8 \times 10^{-14}\ \text{s}$$

The average number of collisions per second is the inverse:

$$\text{Collision rate} = \frac{1}{\tau} = 3.5 \times 10^{13}\ \text{s}^{-1}$$

ASSESS This was another straightforward calculation simply to illustrate the incredibly large collision rate of conduction electrons.

Slide 27-40

Current

- If Q is the total amount of charge that has moved past a point in a wire, we define the current I in the wire to be the rate of charge flow:

$$I \equiv \frac{dQ}{dt} \quad \text{current is the } \textit{rate} \text{ at which charge flows}$$

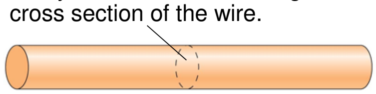
- The SI unit for current is the coulomb per second, which is called the **ampere**.
- 1 ampere = 1 A = 1 C/s
- The conventional current I and the electron current i_e are related by

$$I = \frac{Q}{\Delta t} = \frac{eN_e}{\Delta t} = ei_e$$

Slide 27-41

QuickCheck 27.3

Every minute, 120 C of charge flow through this cross section of the wire.



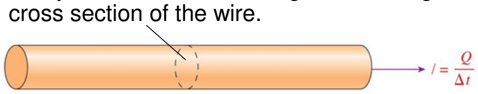
The wire's current is

A. 240 A
B. 120 A
C. 60 A
D. 2 A
E. Some other value.

Slide 27-42

QuickCheck 27.3

Every minute, 120 C of charge flow through this cross section of the wire.



The wire's current is

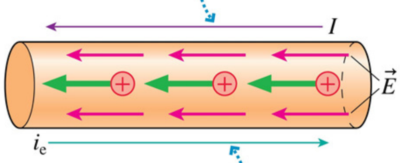
A. 240 A
B. 120 A
C. 60 A
✔ **D. 2 A**
E. Some other value.

 Slide 27-43

Current

- Note that the direction of the current I in a metal is opposite to the direction of the electron current i_e.

The current I is in the direction that positive charges would move. It is in the direction of $\vec{E}$.



The electron current i_e is the motion of actual charge carriers. It is opposite to $\vec{E}$ and I.

 Slide 27-44

The Current Density in a Wire

- The **current density** J in a wire is the current per square meter of cross section:

$$J = \text{current density} \equiv \frac{I}{A} = n_e e v_d$$

- The current density has units of A/m^2.

 Slide 27-45

QuickCheck 27.4

The current density in this wire is

A. 4×10^6 A/m^2
B. 2×10^6 A/m^2
C. 4×10^3 A/m^2
D. 2×10^3 A/m^2
E. Some other value.

Slide 27-46

QuickCheck 27.4

The current density in this wire is

A. 4×10^6 A/m^2
✔**B. 2×10^6 A/m^2**
C. 4×10^3 A/m^2
D. 2×10^3 A/m^2
E. Some other value.

Slide 27-47

Example 27.4 Finding the Electron Drift Speed

EXAMPLE 27.4 | Finding the electron drift speed

A 1.0 A current passes through a 1.0-mm-diameter aluminum wire. What are the current density and the drift speed of the electrons in the wire?

SOLVE We can find the drift speed from the current density. The current density is

$$J = \frac{I}{A} = \frac{I}{\pi r^2} = \frac{1.0\text{ A}}{\pi(0.00050\text{ m})^2} = 1.3 \times 10^6\text{ A/m}^2$$

The electron drift speed is thus

$$v_d = \frac{J}{n_e e} = 1.3 \times 10^{-4}\text{ m/s} = 0.13\text{ mm/s}$$

where the conduction-electron density for aluminum was taken from Table 27.1.

ASSESS We earlier used 1.0×10^{-4} m/s as a typical electron drift speed. This example shows where that value comes from.

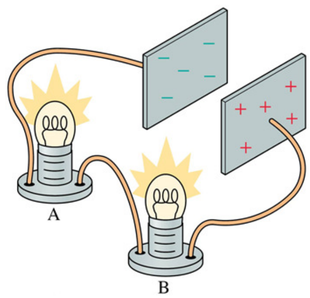
Slide 27-48

Slide 46

11 fix symbol (4x)
System_1300, 2/3/2016

Conservation of Current

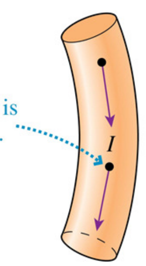
- The figure shows two lightbulbs in the wire connecting two charged capacitor plates.
- As the capacitor discharges, the current through both bulbs is *exactly the same!*
- The rate of electrons *leaving* a lightbulb (or any other device) is exactly the same as the rate of electrons *entering* the lightbulb.



 Slide 27-49

Charge Conservation and Current

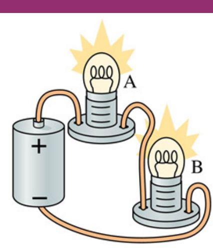
- Due to conservation of charge, the current must be the same at all points in a current-carrying wire.



 Slide 27-50

QuickCheck 27.5

A and B are identical lightbulbs connected to a battery as shown. Which is brighter?

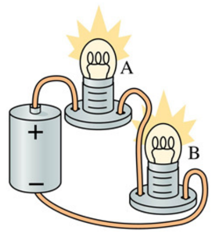


A. Bulb A
B. Bulb B
C. The bulbs are equally bright.

 Slide 27-51

QuickCheck 27.5

A and B are identical lightbulbs connected to a battery as shown. Which is brighter?



A. Bulb A

B. Bulb B

✔**C. The bulbs are equally bright.**

Conservation of current

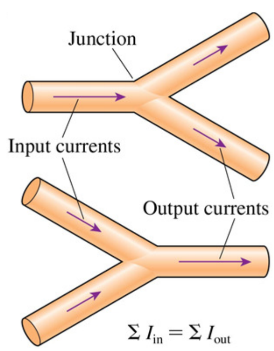
Kirchhoff's Junction Law

- For a *junction*, the law of conservation of current requires that

$$\sum I_{in} = \sum I_{out}$$

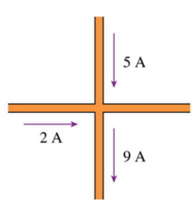
where the Σ symbol means summation.

- This basic conservation statement is called **Kirchhoff's junction law**.



QuickCheck 27.6

The current in the fourth wire is



A. 16 A to the right.

B. 4 A to the left.

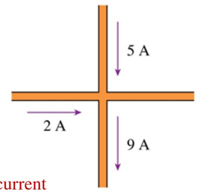
C. 2 A to the right.

D. 2 A to the left.

E. Not enough information to tell.

QuickCheck 27.6

The current in the fourth wire is



A. 16 A to the right.
B. 4 A to the left.
C. 2 A to the right.
✔**D. 2 A to the left.** Conservation of current
E. Not enough information to tell.

Conductivity and Resistivity

- The conductivity of a material is

$$\sigma = \text{conductivity} = \frac{n_e e^2 \tau}{m}$$

- Conductivity, like density, characterizes a material as a whole.
- The current density J is related to the electric field E by

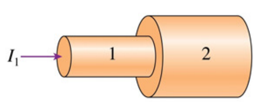
$$J = \sigma E$$

- The resistivity tells us how reluctantly the electrons move in response to an electric field:

$$\rho = \text{resistivity} = \frac{1}{\sigma} = \frac{m}{n_e e^2 \tau}$$

QuickCheck 27.7

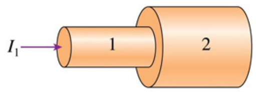
Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does current I_1 in segment 1 compare to current I_2 in segment 2?



A. $I_1 > I_2$
B. $I_1 = I_2$
C. $I_1 < I_2$
D. There's not enough information to compare them.

QuickCheck 27.7

Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does current I_1 in segment 1 compare to current I_2 in segment 2?



A. $I_1 > I_2$

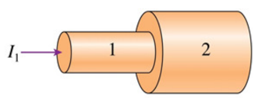
✔**B.** $\boldsymbol{I_1 = I_2}$ Conservation of current

C. $I_1 < I_2$

D. There's not enough information to compare them.

QuickCheck 27.8

Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does current density J_1 in segment 1 compare to current density J_2 in segment 2?



A. $J_1 > J_2$

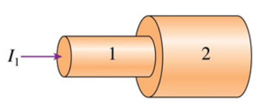
B. $J_1 = J_2$

C. $J_1 < J_2$

D. There's not enough information to compare them.

QuickCheck 27.8

Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does current density J_1 in segment 1 compare to current density J_2 in segment 2?



✔**A.** $\boldsymbol{J_1 > J_2}$ Smaller cross-section area

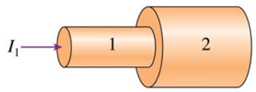
B. $J_1 = J_2$

C. $J_1 < J_2$

D. There's not enough information to compare them.

QuickCheck 27.9

Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does the electric field E_1 in segment 1 compare to the electric field E_2 in segment 2?



A. $E_1 > E_2$

B. $E_1 = E_2$ but not zero

C. $E_1 < E_2$

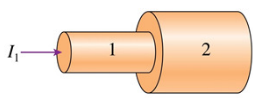
D. Both are zero because metal is a conductor.

E. There's not enough information to compare them.

 Slide 27-61

QuickCheck 27.9

Both segments of the wire are made of the same metal. Current I_1 flows into segment 1 from the left. How does the electric field E_1 in segment 1 compare to the electric field E_2 in segment 2?



✔ **A.** $\mathbf{E_1 > E_2}$ $J = \sigma E$

B. $E_1 = E_2$ but not zero

C. $E_1 < E_2$

D. Both are zero because metal is a conductor.

E. There's not enough information to compare them.

 Slide 27-62

Conductivity and Resistivity

This woman is measuring her percentage body fat by gripping a device that sends a small electric current through her body. Because muscle and fat have different resistivities, the amount of current allows the fat-to-muscle ratio to be determined.

 Slide 27-63

Conductivity and Resistivity

TABLE 27.2 Resistivity and conductivity of conducting materials

Material	Resistivity (Ω m)	Conductivity (Ω^{-1} m^{-1})
Aluminum	2.8×10^{-8}	3.5×10^{7}
Copper	1.7×10^{-8}	6.0×10^{7}
Gold	2.4×10^{-8}	4.1×10^{7}
Iron	9.7×10^{-8}	1.0×10^{7}
Silver	1.6×10^{-8}	6.2×10^{7}
Tungsten	5.6×10^{-8}	1.8×10^{7}
Nichrome*	1.5×10^{-6}	6.7×10^{5}
Carbon	3.5×10^{-5}	2.9×10^{4}

*Nickel-chromium alloy used for heating wires.

Example 27.5 The Electric Field in a Wire

EXAMPLE 27.5 The electric field in a wire

A 2.0-mm-diameter aluminum wire carries a current of 800 mA. What is the electric field strength inside the wire?

SOLVE The electric field strength is

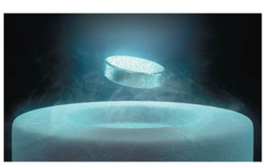
$$E = \frac{J}{\sigma} = \frac{I}{\sigma \pi r^2} = \frac{0.80\ \text{A}}{(3.5 \times 10^7\ \Omega^{-1}\ \text{m}^{-1})\pi(0.0010\ \text{m})^2} = 0.0073\ \text{V/m}$$

where the conductivity of aluminum was taken from Table 27.2.

ASSESS This is a *very* small field in comparison with those we calculated in Chapters 22 and 23. This calculation justifies the claim in Table 23.1 that a typical electric field strength inside a current-carrying wire is ≈ 0.01 V/m. It takes *very few* surface charges on a wire to create the weak electric field necessary to push a considerable current through the wire. The reason, once again, is the enormous value of the charge-carrier density n_e. Even though the electric field is very tiny and the drift speed is agonizingly slow, a wire can carry a substantial current due to the vast number of charge carriers able to move.

Superconductivity

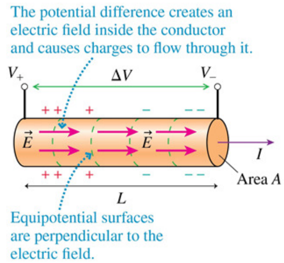
- In 1911, the Dutch physicist Kamerlingh Onnes discovered that certain materials suddenly and dramatically lose *all* resistance to current when cooled below a certain temperature.
- This complete loss of resistance at low temperatures is called **superconductivity**.



Superconductors have unusual magnetic properties. Here a small permanent magnet levitates above a disk of the high temperature superconductor $YBa_2Cu_3O_7$ that has been cooled to liquid-nitrogen temperature.

Resistance and Ohm's Law

- The figure shows a section of a conductor in which an electric field $\vec{E}$ is creating current I by pushing the charge carriers.
- The field strength is
$$E = \frac{\Delta V}{\Delta s} = \frac{\Delta V}{L}$$
- The current density is
$$J = I/A = E/\rho$$
- So the current is related to ΔV by
$$I = \frac{A}{\rho L}\Delta V$$



 Slide 27-67

Resistance and Ohm's Law

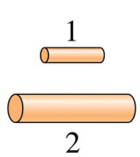
- The current through a conductor is proportional to the potential difference between its ends.
- We define the **resistance** R of a long, thin conductor of length L and cross-sectional area A to be
$$R = \frac{\rho L}{A}$$
- The SI unit of resistance is the *ohm*.
- 1 ohm = 1 Ω = 1 V/A
- The current through a conductor is determined by the potential difference ΔV along its length:

$$I = \frac{\Delta V}{R} \quad \text{(Ohm's law)}$$

 Slide 27-68

QuickCheck 27.10

Wire 2 is twice the length and twice the diameter of wire 1. What is the ratio R_2/R_1 of their resistances?

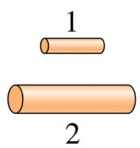


A. 1/4
B. 1/2
C. 1
D. 2
E. 4

 Slide 27-69

QuickCheck 27.10

Wire 2 is twice the length and twice the diameter of wire 1. What is the ratio R_2/R_1 of their resistances?



A. 1/4

✔**B. 1/2**

C. 1

D. 2

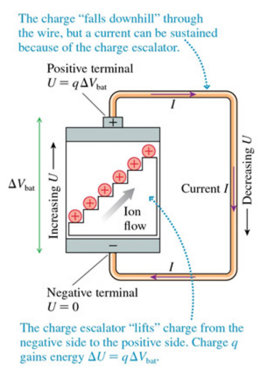
E. 4

Slide 27-70

Batteries and Current

- A battery is a source of potential difference ΔV_{bat}.
- The battery creates a potential difference between the ends of the wire.
- The potential difference in the wire creates an electric field in the wire.
- The electric field pushes a current I through the wire.
- The current in the wire is

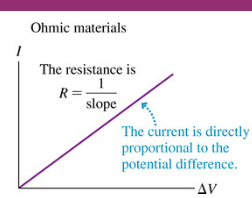
$$I = \Delta V_{wire}/R$$



Slide 27-71

Ohm's Law

- Ohm's law is limited to those materials whose resistance R remains constant—or very nearly so—during use.

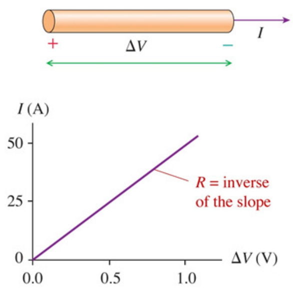


- The materials to which Ohm's law applies are called *ohmic*.
- The current through an ohmic material is directly proportional to the potential difference; doubling the potential difference doubles the current.
- Metal and other conductors are ohmic devices.

Slide 27-72

QuickCheck 27.11

The current through a wire is measured as the potential difference ΔV is varied. What is the wire's resistance?

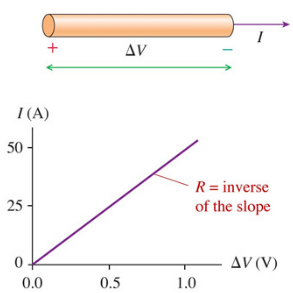


A. 0.01 Ω
B. 0.02 Ω
C. 50 Ω
D. 100 Ω
E. Some other value

Slide 27-73

QuickCheck 27.11

The current through a wire is measured as the potential difference ΔV is varied. What is the wire's resistance?

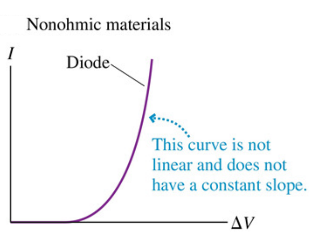


A. 0.01 Ω
✔**B. 0.02 Ω**
C. 50 Ω
D. 100 Ω
E. Some other value

Slide 27-74

Nonohmic Materials

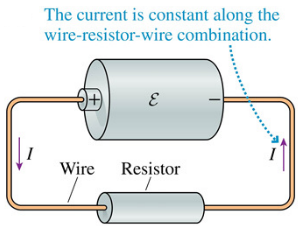
- Some materials and devices are *nonohmic*, meaning that the current through the device is *not* directly proportional to the potential difference.
- Diodes, batteries, and capacitors are all nonohmic devices.



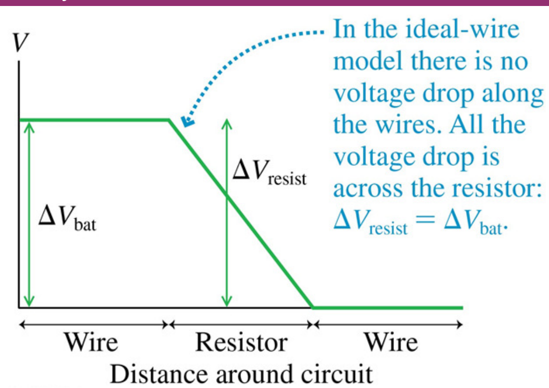
Slide 27-75

Battery-Wire-Resistor-Wire Circuit

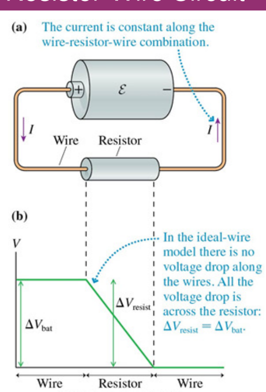
- The figure shows a resistor connected to a battery with current-carrying wires.
- Current must be conserved; hence the current I through the resistor is the same as the current in each wire.
- The next two slides show how the electric potential varies through the circuit.



Battery-Wire-Resistor-Wire Circuit



Battery-Wire-Resistor-Wire Circuit



Example 27.7 A Battery and a Resistor

EXAMPLE 27.7 A battery and a resistor

What resistor would have a 15 mA current if connected across the terminals of a 9.0 V battery?

MODEL Assume the resistor is connected to the battery with ideal wires.

SOLVE Connecting the resistor to the battery with ideal wires makes $\Delta V_{resist} = \Delta V_{bat} = 9.0$ V. From Ohm's law, the resistance giving a 15 mA current is

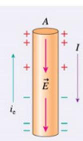
$$R = \frac{\Delta V_{resist}}{I} = \frac{9.0 \text{ V}}{0.015 \text{ A}} = 600\ \Omega$$

ASSESS Currents of a few mA and resistances of a few hundred ohms are quite typical of real circuits.

Chapter 27 Summary Slides

General Principles

Current is a nonequilibrium motion of charges sustained by an electric field. Nonuniform surface charge density creates an electric field in a wire. The electric field pushes the electron current i_e in a direction opposite to $\vec{E}$. The conventional current I is in the direction in which positive charge *seems* to move.



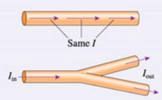
General Principles

Conservation of Charge

The current is the same at any two points in a wire.
At a junction,

$$\sum I_{in} = \sum I_{out}$$

This is **Kirchhoff's junction law.**



Slide 27-82

General Principles

Electron current

i_e = rate of electron flow
$N_e = i_e \Delta t$

Conventional current

I = rate of charge flow $= ei_e$
$Q = I \Delta t$

Current density

$J = I/A$

Slide 27-83

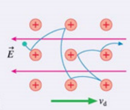
Important Concepts

Sea of electrons

Conduction electrons move freely around the positive ions that form the atomic lattice.

Conduction

An electric field causes a slow drift at speed v_d to be superimposed on the rapid but random thermal motions of the electrons.



Collisions of electrons with the ions transfer energy to the atoms. This makes the wire warm and lightbulbs glow. More collisions mean a higher resistivity ρ and a lower conductivity σ.

Slide 27-84

Important Concepts

The **drift speed** is $v_d = \frac{e\tau}{m}E$, where τ is the mean time between collisions.

The electron current is related to the drift speed by

$$i_e = n_e A v_d$$

where n_e is the electron density.

Important Concepts

An electric field E in a conductor causes a current density $J = n_e e v_d = \sigma E$, where the **conductivity** is

$$\sigma = \frac{n_e e^2 \tau}{m}$$

The **resistivity** is $\rho = 1/\sigma$.

Applications

Resistors

A potential difference ΔV_{wire} between the ends of a wire creates an electric field inside the wire:

$$E_{wire} = \frac{\Delta V_{wire}}{L}$$

The electric field causes a current in the direction of decreasing potential.

The size of the current is

$$I = \frac{\Delta V_{wire}}{R}$$

where $R = \frac{\rho L}{A}$ is the wire's **resistance.**

This is **Ohm's law.**