UFUG 1504: Honors General Physics II

Chapter 26

Current and Resistance

Honors General Physics II Module 1 exam

添加时间 受影响时段 修改预定 取消预定

教学区, 实验楼W1, 1楼, 101, Honor

预定时段：2024-10-19 星期六 09:00-12:00

• 已预定

编辑 取消

M1 exam 9:30-11:30，10月19号， 星期六，

记得带计算器， 常数会给， 公式不会

26 Summary (1 of 6)

Current

- The electric current i in a conductor is defined by

$$i = \frac{dq}{dt}.$$

Equation 26-1

Current Density

- Current is related to current density by

$$i = \int \vec{J} \cdot d\vec{A},$$

Equation 26-4

26 Summary (2 of 6)

Drift Speed of the Charge Carriers

- Drift speed of the charge carriers in an applied electric field is related to current density by

$$\vec{J} = (ne)\vec{v}_d, \qquad \textbf{Equation 26-7}$$

Resistance of a Conductor

- Resistance R of a conductor is defined by

$$R = \frac{V}{i} \qquad \textbf{Equation 26-8}$$

26 Summary (3 of 6)

- Similarly the resistivity and conductivity of a material is defined by

$$\rho = \frac{1}{\sigma} = \frac{E}{J}$$

Equation 26-10&12

- Resistance of a conducting wire of length L and uniform cross section is

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

Equation 26-16

26 Summary (4 of 6)

Change of ρ with Temperature

- The resistivity of most material changes with temperature and is given as

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

Equation 26-17

Ohm's Law

- A given device (conductor, resistor, or any other electrical device) obeys Ohm's law if its resistance R (defined by **Eq. 26-8** as $\frac{V}{i}$) is independent of the applied potential difference V.

26 Summary (5 of 6)

Resistivity of a Metal

- By assuming that the conduction electrons in a metal are free to move like the molecules of a gas, it is possible to derive an expression for the resistivity of a metal:

$$\rho = \frac{m}{e^2 n\tau}. \qquad \textbf{Equation 26-22}$$

26 Summary (6 of 6)

Power

- The power P, or rate of energy transfer, in an electrical device across which a potential difference V is maintained is

$$P = iV$$

Equation 26-26

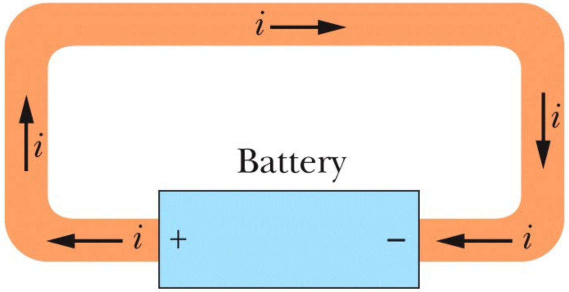
- If the device is a resistor, we can write

$$P = i^2 R = \frac{V^2}{R}$$

Equation 26-27&28

26-1 Electric Current (3 of 7)


(a)



(b)

As Fig. (a) reminds us, any isolated conducting loop—regardless of whether it has an excess charge — is all at the same potential. No electric field can exist within it or along its surface.

If we insert a battery in the loop, as in Fig. (b), the conducting loop is no longer at a single potential. Electric fields act inside the material making up the loop, exerting forces on internal charges, causing them to move and thus establishing a **current**. (The diagram assumes the motion of positive charges moving clockwise.)

26-1 Electric Current (4 of 7)

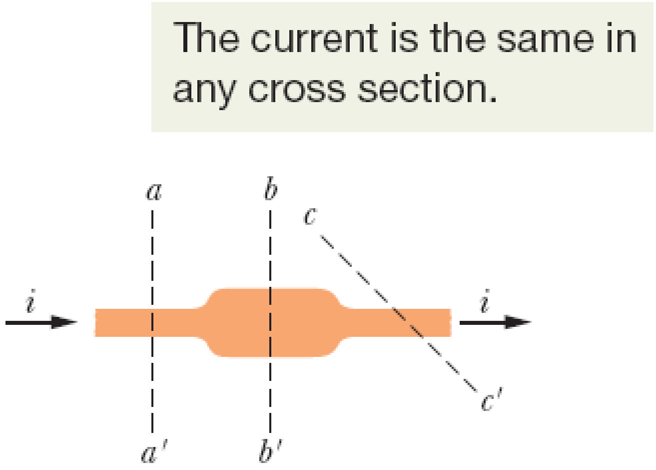


Figure c shows a section of a conductor, part of a conducting loop in which current has been established. If charge dq passes through a hypothetical plane $\left(\text{such as } aa'\right)$ in time dt, then the current i through that plane is defined as

$$i = \frac{dq}{dt} \quad \left(\text{definition of current}\right).$$

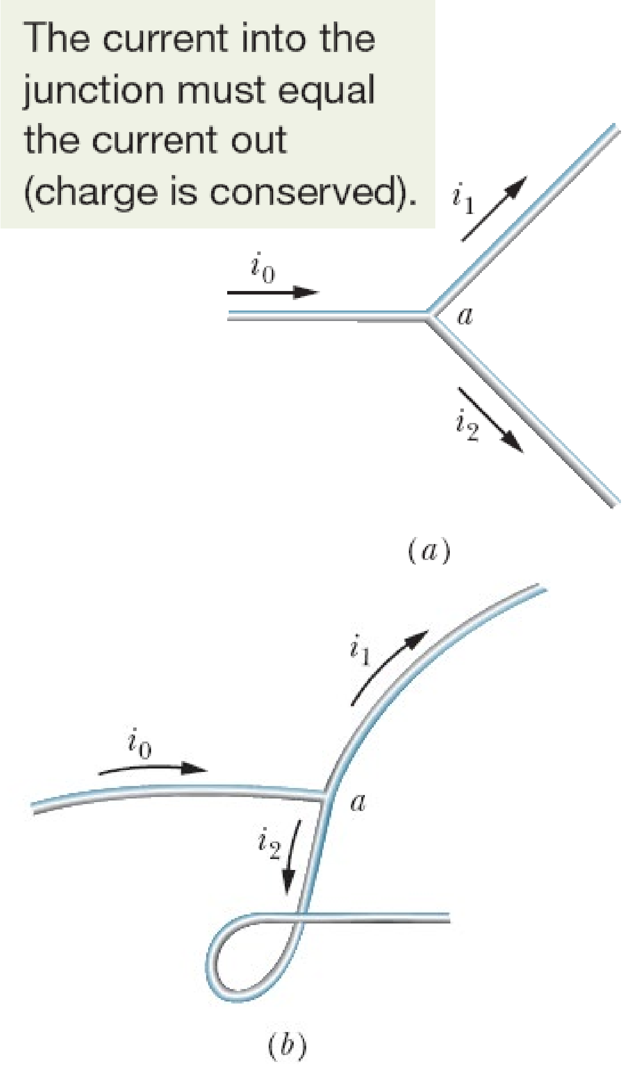
1 ampere = 1 A = 1 coulomb per second = 1 C/s.

26-1 Electric Current (6 of 7)

Figure (a) shows a conductor with current i_0 splitting at a junction into two branches. Because charge is conserved, the magnitudes of the currents in the branches must add to yield the magnitude of the current in the original conductor, so that

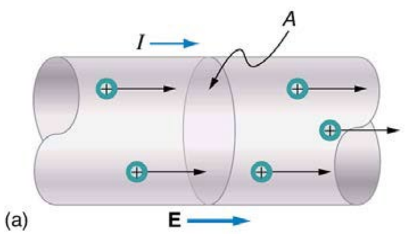
$$i_0 = i_1 + i_2.$$

Figure (b) suggests, bending or reorienting the wires in space does not change the validity of the above equation Current arrows show only a direction (or sense) of flow along a conductor, not a direction in space.

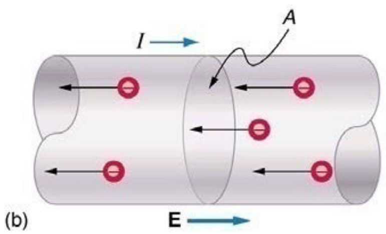


26-1 Electric Current (7 of 7)

A current arrow is drawn in the direction in which positive charge carriers would move, even if the actual charge carriers are negative and move in the opposite direction.



Imagination



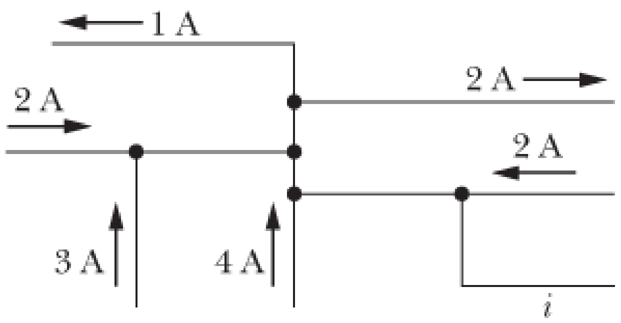
Real

26-1 Electric Current (7 of 7)

A current arrow is drawn in the direction in which positive charge carriers would move, even if the actual charge carriers are negative and move in the opposite direction.

Checkpoint 1

The figure here shows a portion of a circuit. What are the magnitude and direction of the current *i* in the lower right-hand wire?



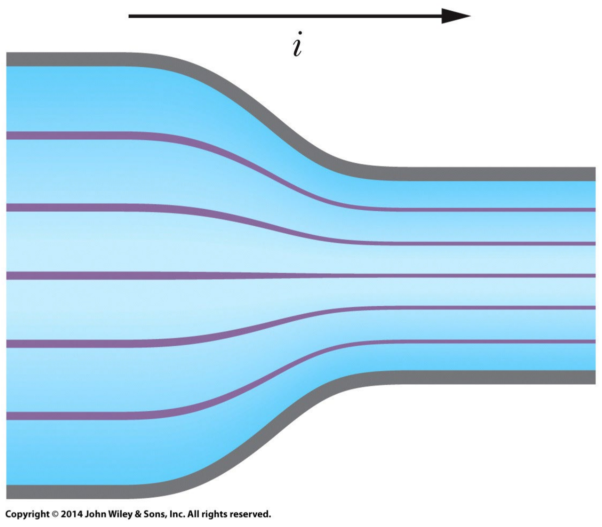
Answer: 8A with arrow pointing right

26-2 Current Density (4 of 7)

Current i (a scalar quantity) is related to **current density** $\vec{J}$ (a vector quantity) by

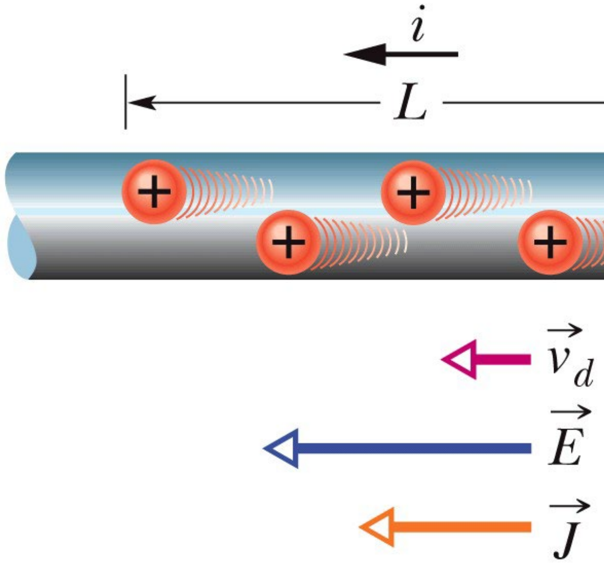
$$i = \int \vec{J} \cdot d\vec{A}.$$

where $d\vec{A}$ is a vector perpendicular to a surface element of area $d\vec{A}$ and the integral is taken over any surface cutting across the conductor. The current density $\vec{J}$ has the same direction as the velocity of the moving charges if they are positive charges and the opposite direction if the moving charges are negative.



Streamlines representing current density in the flow of charge through a constricted conductor.

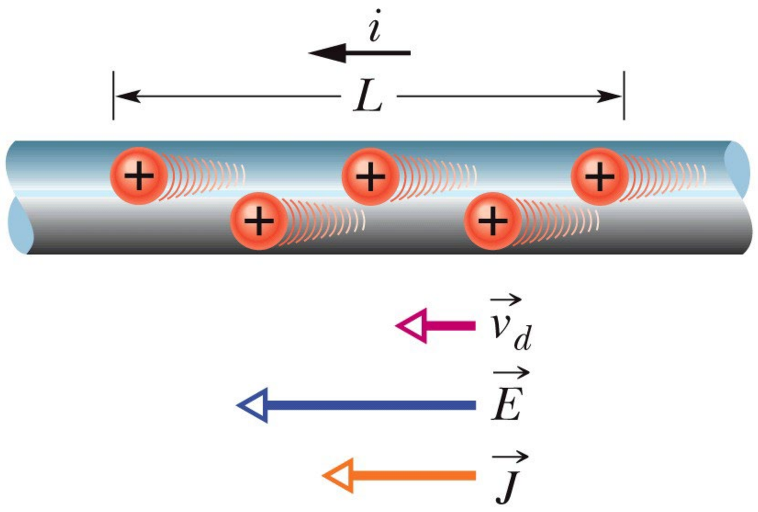
26-2 Current Density (6 of 7)



Current is said to be due to positive charges that are propelled by the electric field.

Conduction electrons are actually moving to the right but the conventional current i is said to move to the left.

26-2 Current Density (7 of 7)



Current is said to be due to positive charges that are propelled by the electric field. In the figure, positive charge carriers drift at speed v_d in the direction of the applied electric field $\vec{E}$ which here is applied to the left. By convention, the direction of the current density $\vec{J}$ and the sense of the current arrow are drawn in that same direction, as is the drift speed v_d.

The drift velocity v_d is related to the current density (J) by

$$J = i/A \xrightarrow{i = \frac{q}{t} = \frac{nALe}{L/v_d} = nAev_d} \vec{J} = (ne)\vec{v}_d .$$

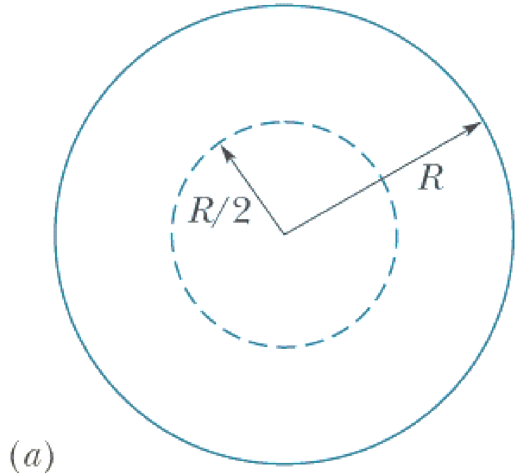
Here the product *ne*, whose SI unit is the coulomb per cubic meter $(\mathrm{C/m^3})$, is the **carrier charge density**.

26-2 Current Density (7 of 7)

The current density in a cylindrical wire of radius R = 2.0 mm is uniform across a cross section of the wire and is $J = ar^2$, in which $a = 4.0 \times 10^{11}$ A/m^4 and r is in meters. What is the current through the outer portion of the wire between radial distances $R/2$ and R?

$$i = \int \vec{J} \cdot d\vec{A}.$$

We want the current in the area between these two radii.



26-2 Current Density (7 of 7)

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$$i = \int \vec{J} \cdot d\vec{A}.$$

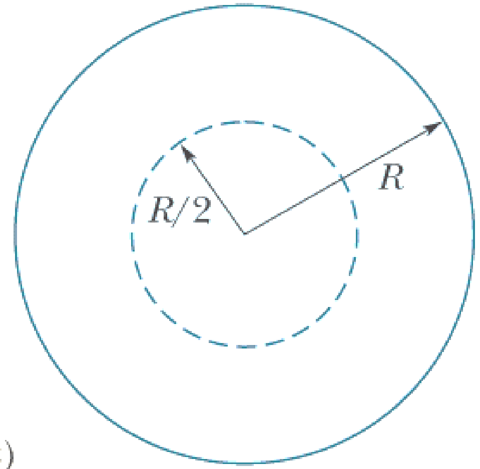
$$i = \int \vec{J} \cdot d\vec{A} = \int J \, dA$$

$$= \int_{R/2}^{R} ar^2 \, 2\pi r \, dr = 2\pi a \int_{R/2}^{R} r^3 \, dr$$

$$= 2\pi a \left[\frac{r^4}{4}\right]_{R/2}^{R} = \frac{\pi a}{2}\left[R^4 - \frac{R^4}{16}\right] = \frac{15}{32}\pi a R^4$$

= 9.5 A

We want the current in the area between these two radii.



(a)

26-3 Resistance (电阻) and Resistivity (电阻率) (4 of 8)

If we apply the same potential difference between the ends of geometrically similar rods of copper and of glass, very different currents result. The characteristic of the conductor that enters here is its **electrical resistance**. The resistance R of a conductor is defined as

$$R = \frac{V}{i} \quad (\text{definition of } R).$$

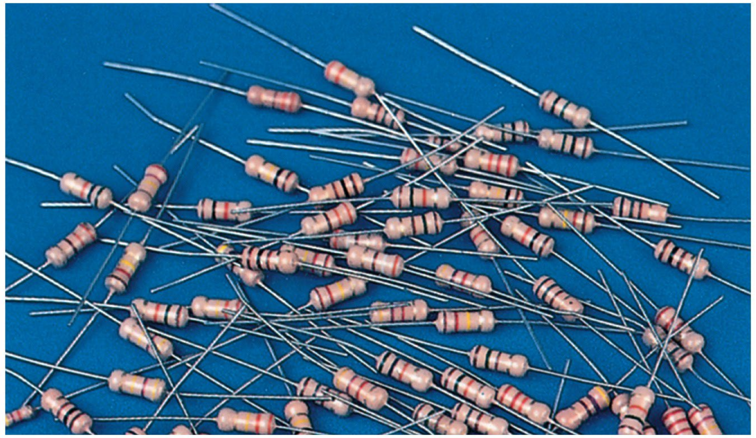
where V is the potential difference across the conductor and i is the current through the conductor. Instead of the resistance R of an object, we may deal with the **resistivity** ρ of the material:

$$\rho = \frac{E}{J} \quad (\text{definition of } \rho).$$

26-3 Resistance and Resistivity (5 of 8)

The reciprocal (倒数） of resistivity is **conductivity** σ of the material:

$$\sigma = \frac{1}{\rho} \quad (\text{definition of } \sigma).$$



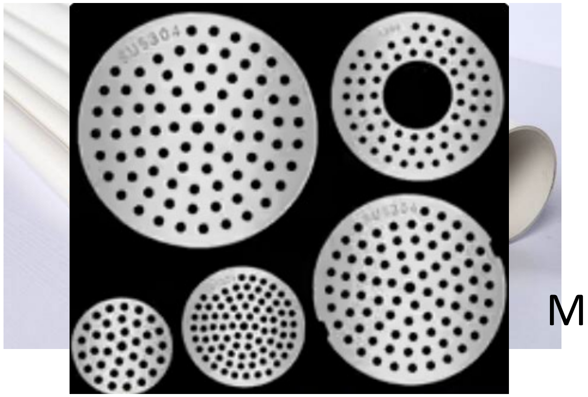
The Image Works

Assortment of Resistors

26-3 Resistance and Resistivity (5 of 8)

electrical resistance $$R = \frac{V}{i} \quad \text{(definition of } R\text{)}.$$

Resistance is a property of an object. Resistivity is a property of a material.



Thick wire → Pass quickly →small resistance

Long wire → Passs slowly →large resistance

More barriers in wire → Passs slowly →large resistance

26-3 Resistance and Resistivity (6 of 8)

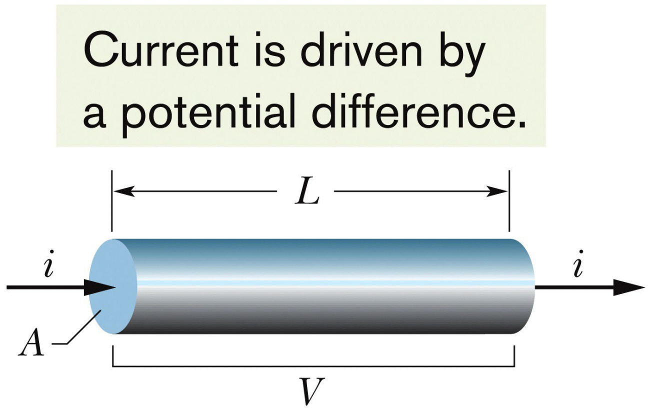
Thick wire (A) → small resistance

Long wire (L) → large resistance

More barriers in wire (ρ) → large resistance

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

ρ = resistivity
Unit: Ω m



Here A is the cross-sectional area.

26-3 Resistance and Resistivity (7 of 8)

The resistivity ρ for most materials changes with temperature. For many materials, including metals, the relation between ρ and temperature T is approximated by the equation

$$\rho - \rho_0 = \rho_0 \alpha (T - T_0). \quad \Rightarrow \quad \rho = \rho_0(1 + \alpha \Delta T)$$

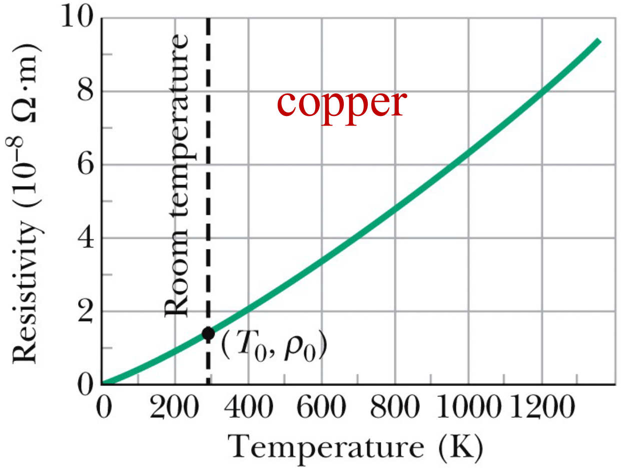
Here T_0 is a reference temperature ρ_0 is the resistivity at T_0, and α is the temperature coefficient of resistivity for the material.

26-3 Resistance and Resistivity (8 of 8)

Table 26-1 Resistivities of Some Materials at Room Temperature (20°C)

Material	Resistivity, ρ ($\Omega \cdot m$)	Temperature Coefficient of Resistivity, α (K^{-1})
	Typical Metals	
Silver	1.62×10^{-8}	4.1×10^{-3}
Copper	1.69×10^{-8}	$\boxed{4.3 \times 10^{-3}}$
Gold	2.35×10^{-8}	4.0×10^{-3}
Aluminum	2.75×10^{-8}	4.4×10^{-3}
Manganin[a]	4.82×10^{-8}	0.002×10^{-3}
Tungsten	5.25×10^{-8}	4.5×10^{-3}
Iron	9.68×10^{-8}	6.5×10^{-3}
Platinum	10.6×10^{-8}	3.9×10^{-3}
	Typical Semiconductors	
Silicon, pure	2.5×10^{3}	-70×10^{-3}
Silicon, *n*-type[b]	8.7×10^{-4}	
Silicon, *p*-type[c]	2.8×10^{-3}	
	Typical Insulators	
Glass	10^{10}–10^{14}	
Fused quartz	$\sim 10^{16}$	

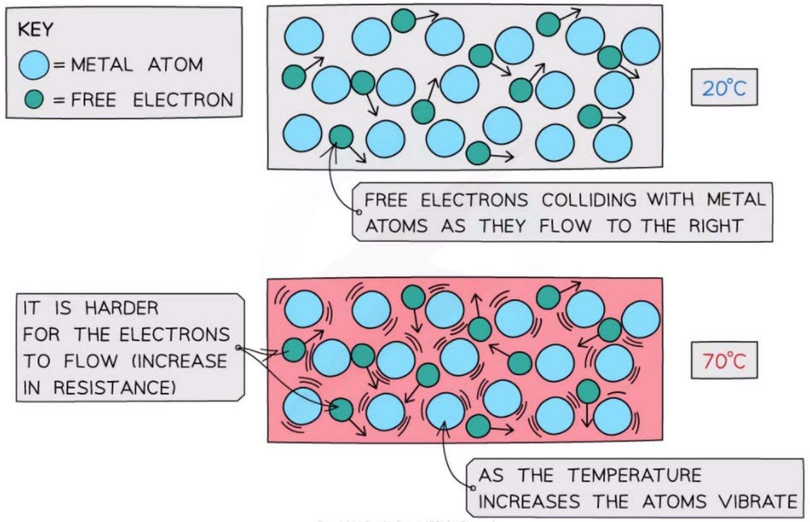
$$\rho = \rho_0(1 + \alpha \Delta T)$$



Metals

- α is positive
- Resistivity increases with temperature

Why α is positive for metal?



Higher temperature, the metal's constituent atoms vibrate with increasing amplitude, thus the electrons find it more difficult to pass through the atoms

26-3 Resistance and Resistivity (8 of 8)

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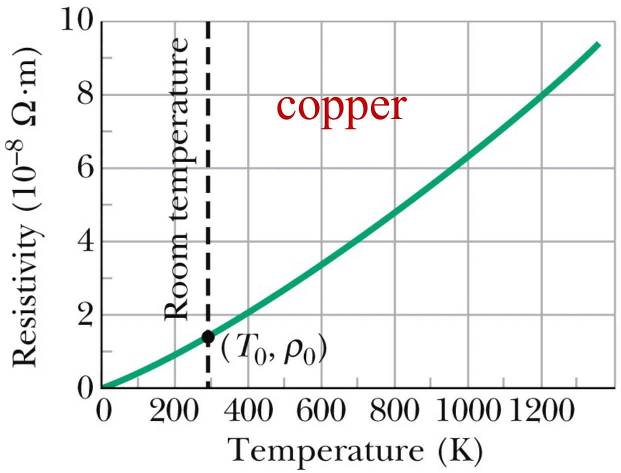
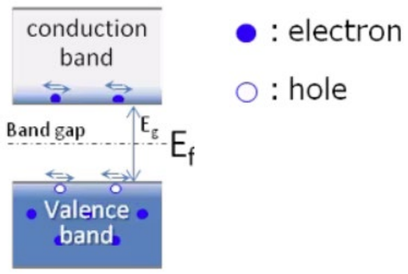
Fused quartz	$\sim 10^{16}$	

$$\rho = \rho_0 (1 + \alpha \Delta T)$$



Why α is negative for semiconductors ?



semiconductor

Semiconductors

- α is negative
- Resistivity decreases with temperature

thermal energy will assist electrons to jump the gap easily from VB to CB

26-3 Resistance and Resistivity (8 of 8)

Resistivity (ρ) =0 → superconductors

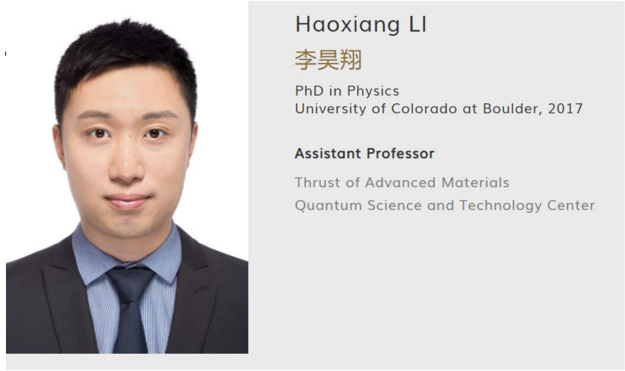
Why do people want RT superconductors? → new technological revolution

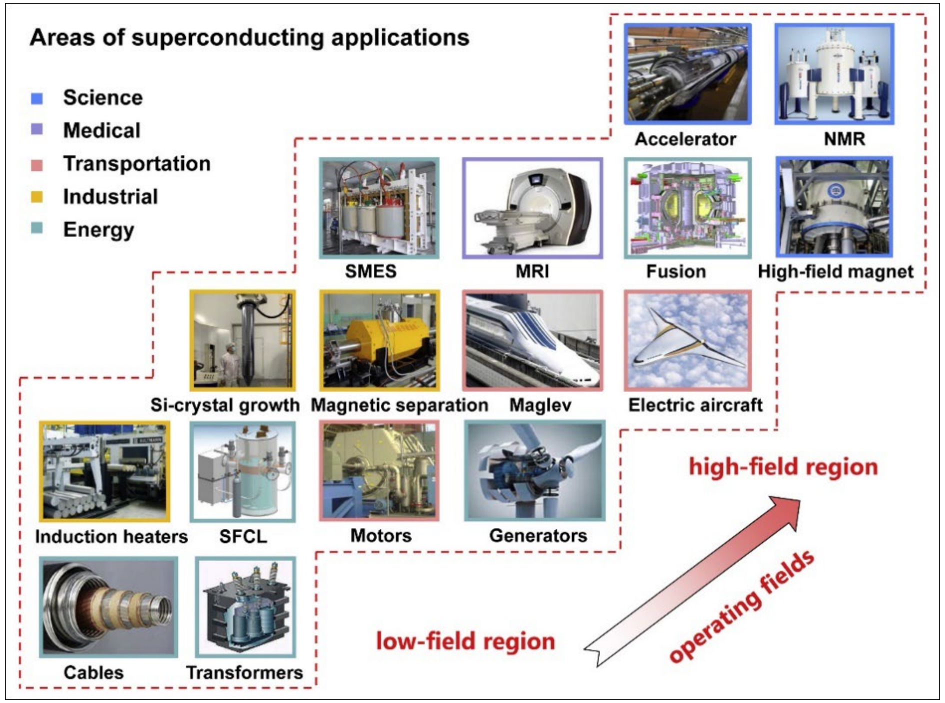
1. Zero energy loss electricity transmission

2. Supercomputer/mobile phone

3. Super-speed maglev trains

4. Powerful small electric motors





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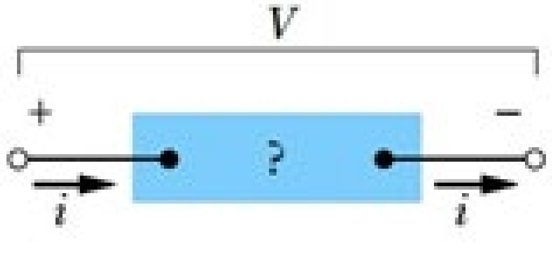
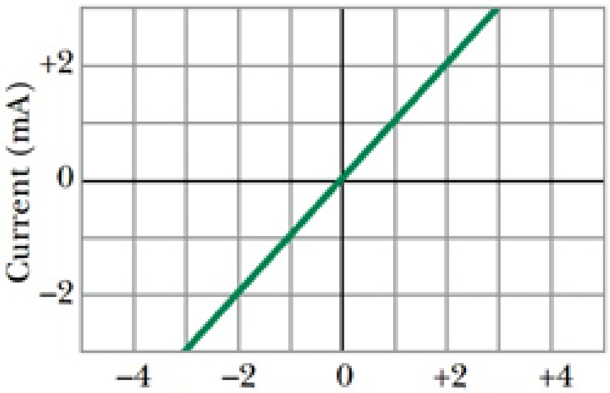
26-4 Ohm's Law (4 of 9)



(a)

A potential difference V is applied across the device being tested, and the resulting current i through the device is measured as V is varied

1000 Ω resistor

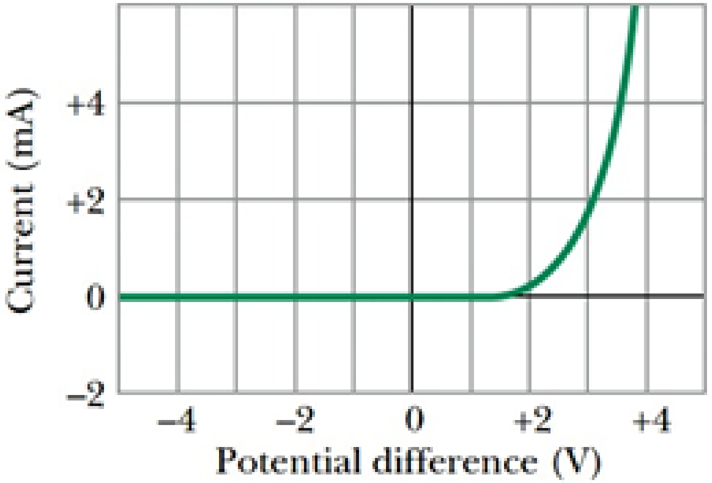


(b)

Figure (b) is a plot of i versus V for one device. This plot is a straight line passing through the origin, so the ratio $\frac{i}{V}$ (which is the slope of the straight line) is the same for all values of V. This means that the resistance $R = \frac{V}{i}$ of the device is independent of the magnitude and polarity of the applied potential difference V.

26-4 Ohm's Law (5 of 9)

Semiconducting *pn* junction diode



(*c*)

Figure (c) is a plot for another conducting device. Current can exist in this device only when the polarity of V is positive and the applied potential difference is more than about 1.5 V. When current does exist, the relation between i and V is not linear; it depends on the value of the applied potential difference V.

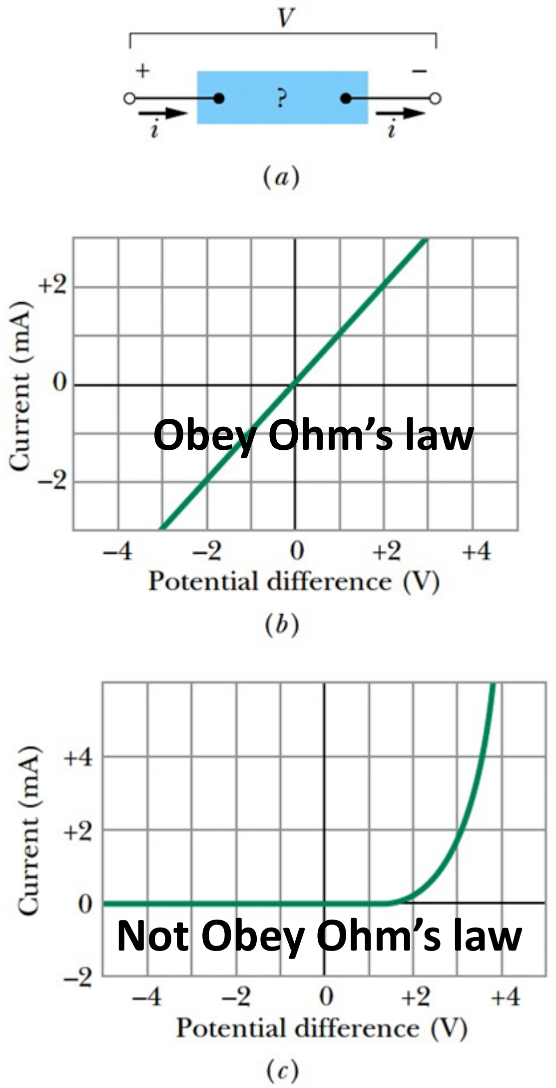
26-4 Ohm's Law (6 of 9)

Ohm's law is an assertion that the current through a device is always directly proportional to the potential difference applied to the device.

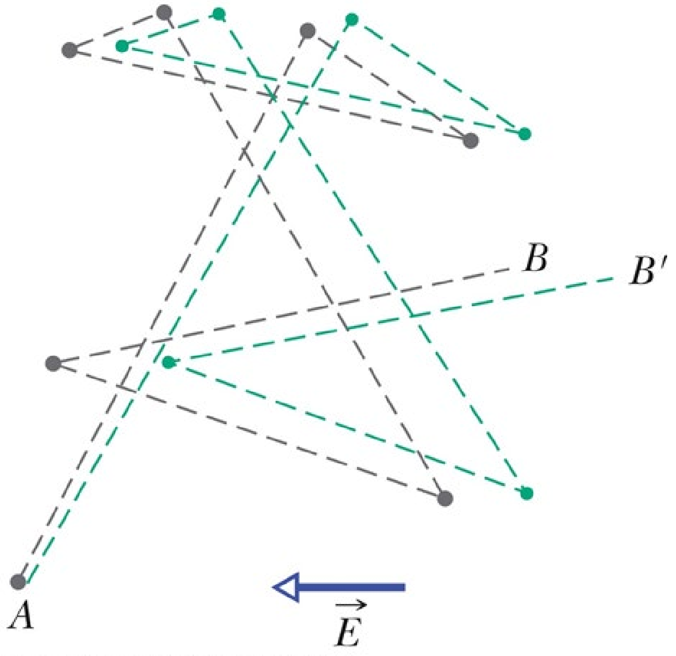
$$I \sim V \quad \text{or} \quad I = \frac{V}{R}$$

A conducting device obeys Ohm's law when the resistance of the device is independent of the magnitude and polarity of the applied potential difference.

A conducting material obeys Ohm's law when the resistivity of the material is independent of the magnitude and direction of the applied electric field.



26-4 Ohm's Law (8 of 9)



The gray lines show an electron moving from *A* to *B*, making six collisions en route. The green lines show what the electron's path might be in the presence of an applied electric field E

A Microscopic View

The assumption that the conduction electrons in a metal are free to move like the molecules in a gas leads to an expression for the resistivity of a metal:

$$\rho = \frac{m}{e^2 n\tau}.$$

n is the number of free electrons per unit volume; τ the mean time between the collisions of e

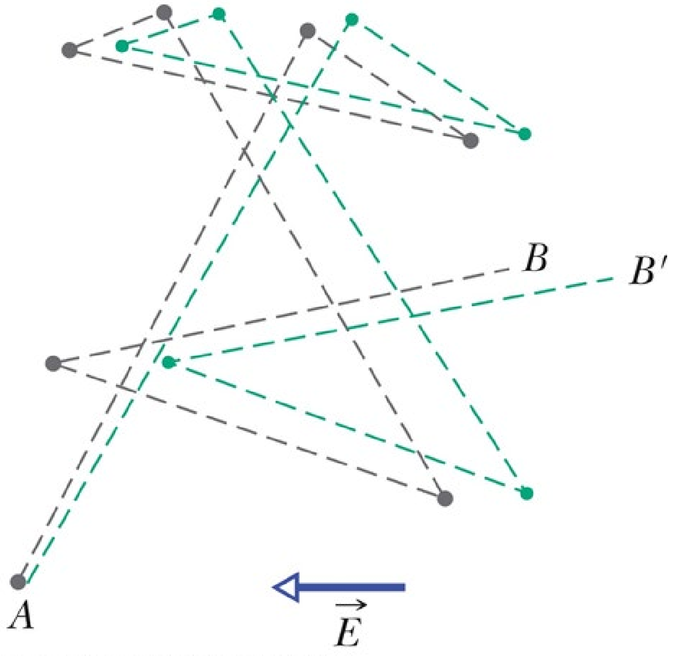
$$a = \frac{F}{m} = \frac{eE}{m}$$

drift speed $v_d = a\tau = \frac{eE\tau}{m}.$ $\quad v_d = \frac{J}{ne} = \frac{eE\tau}{m} \quad (\vec{J} = ne\vec{v}_d)$

$$\vec{E} = \rho\vec{J}$$

$$E = \left(\frac{m}{e^2 n\tau}\right) J \Rightarrow \rho = \frac{m}{e^2 n\tau}.$$

26-4 Ohm's Law (8 of 9)



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A Microscopic View

The assumption that the conduction electrons in a metal are free to move like the molecules in a gas leads to an expression for the resistivity of a metal:

$$\rho = \frac{m}{e^2 n\tau}.$$

n is the number of free electrons per unit volume; τ the mean time between the collisions of e

ρ (metal) is a constant, independent of the strength of the applied electric field E

Because:

n, the number of conduction electrons per volume, is independent of the field,
m and *e* are constants,
τ, the average time (or *mean free time*) between collisions, is independent of the strength of the applied electric field

26-5 Power, Semiconductors, Superconductors (3 of 7)

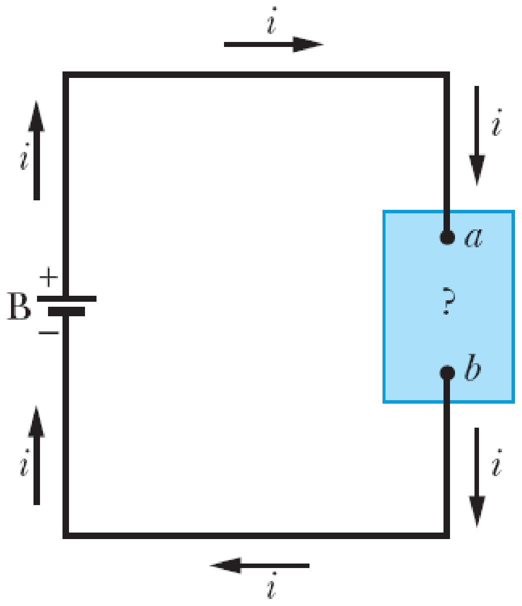


Figure 26-13 A battery B sets up a current i in a circuit containing an unspecified conducting device.

Figure shows a circuit consisting of a battery B that is connected by wires, which we assume have negligible resistance, to an unspecified conducting device. The device might be a resistor, a storage battery (a rechargeable battery), a motor, or some other electrical device. The battery maintains a potential difference of magnitude V across its own terminals and thus (because of the wires) across the terminals of the unspecified device, with a greater potential at terminal a of the device than at terminal b.

The power P, or rate of energy transfer, in an electrical device across which a potential difference V is maintained is

$$P = iV \quad \text{(rate of electrical energy transfer).}$$

26-5 Power, Semiconductors, Superconductors (4 of 7)

If the device is a resistor, the power can also be written as

$$P = i^2 R \quad (\text{resistive dissipation})$$

or,

$$P = \frac{V^2}{R} \quad (\text{resistive dissipation}).$$

We must be careful to distinguish these equations:
$P = iV$ applies to electrical energy transfers of all kinds;
$P = i^2R$ and $P = V^2/R$ apply only to the transfer of electric potential energy to thermal energy in a device with resistance.

26-5 Power, Semiconductors, Superconductors (5 of 7)

Semiconductors are materials that have few conduction electrons but can become conductors when they are doped with other atoms that contribute charge carriers.

E.g., Pure silicon has such a high resistivity that it is effectively an insulator and thus not of much direct use in microelectronic circuits. However, its resistivity can be greatly reduced in a controlled way by adding minute amounts of specific "impurity" atoms in a process called doping.

26-5 Power, Semiconductors, Superconductors (5 of 7)

Semiconductors

In a semiconductor, *n* (number of free electrons) is small (unlike conductor) but increases very rapidly with temperature as the increased thermal agitation makes more charge carriers available. This causes a decrease of resistivity with increasing temperature, as indicated by the negative temperature coefficient of resistivity for silicon.

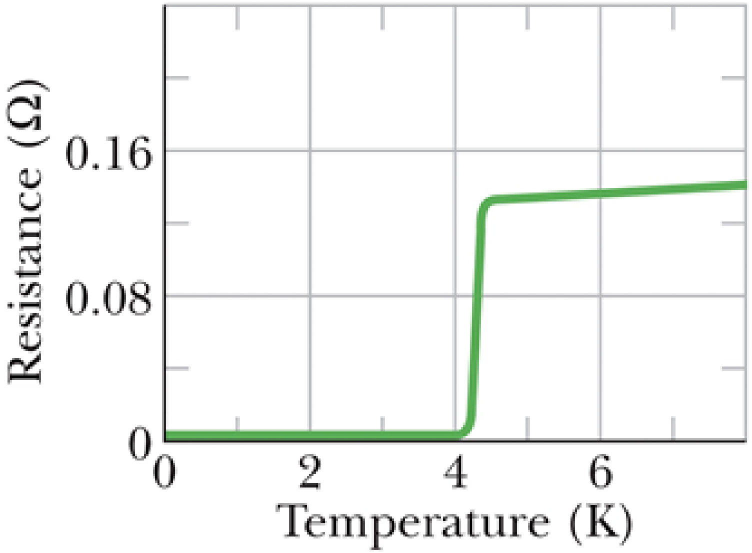
Table 26-2 Some Electrical Properties of Copper and Silicon

Property	Copper	Silicon
Type of material	Metal	Semiconductor
Charge carrier density, m^{-3}	8.49×10^{28}	1×10^{16}
Resistivity, $\Omega \cdot m$	1.69×10^{-8}	2.5×10^{3}
Temperature coefficient of resistivity, K^{-1}	$+4.3 \times 10^{-3}$	-70×10^{-3}

$$\rho = \rho_0(1 + \alpha\Delta T)$$

26-5 Power, Semiconductors, Superconductors (7 of 7)

Superconductors



The resistance of mercury drops to zero at a temperature of about 4 K.

In fact, the best of the normal conductors, such as silver and copper, cannot become superconducting at any temperature, and the new ceramic (陶瓷) superconductors are actually good insulators when they are not at low enough temperatures to be in a superconducting state.

A wire with a resistance of 6.0 Ω is drawn out through a die so that its new length is three times its original length. Find the resistance of the longer wire, assuming that the resistivity and density of the material are unchanged.

EXPRESS Since the mass and density of the material do not change, the volume remains the same. If L_0 is the original length, L is the new length, A_0 is the original cross-sectional area, and A is the new cross-sectional area, then $L_0A_0 = LA$ and

$$A = L_0A_0/L = L_0A_0/3L_0 = A_0/3.$$

ANALYZE The new resistance is

$$R = \frac{\rho L}{A} = \frac{\rho 3 L_0}{A_0 / 3} = 9\frac{\rho L_0}{A_0} = 9R_0,$$

where R_0 is the original resistance. Thus, $R = 9(6.0\ \Omega) = 54\ \Omega$.

What is the current in a wire of radius R = 3.40 mm if the magnitude of the current density is given by $J_b = J_0(1 - r/R)$, in which r is the radial distance and $J_0 = 5.50 \times 10^4$ A/m^2?

$$i = \int \vec{J} \cdot d\vec{A},$$

What is the current in a wire of radius R = 3.40 mm if the magnitude of the current density is given by $J_b = J_0(1 - r/R)$, in which r is the radial distance and $J_0 = 5.50 \times 10^4$ A/m^2?

$$i = \int_{\text{cylinder}} J_b \, dA = \int_0^R J_0 \left(1 - \frac{r}{R}\right) 2\pi r dr = \frac{1}{3}\pi R^2 J_0 = \frac{1}{3}\pi (3.40 \times 10^{-3}\,\text{m})^2 (5.50 \times 10^4\,\text{A/m}^2)$$

$$= 0.666\ \text{A}.$$

26 Summary (1 of 6)

Current

- The electric current i in a conductor is defined by

$$i = \frac{dq}{dt}.$$

Equation 26-1

Current Density

- Current is related to current density by

$$i = \int \vec{J} \cdot d\vec{A},$$

Equation 26-4

26 Summary (2 of 6)

Drift Speed of the Charge Carriers

- Drift speed of the charge carriers in an applied electric field is $R = \frac{V}{i}$ related to current density by

$$\vec{J} = (ne)\vec{v}_d,$$

Equation 26-7

Resistance of a Conductor

- Resistance R of a conductor is defined by

Equation 26-8

26 Summary (3 of 6)

- Similarly the resistivity and conductivity of a material is defined by

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

$$\rho = \frac{1}{\sigma} = \frac{E}{J}$$

Equation 26-10&12

- Resistance of a conducting wire of length L and uniform cross section is

Equation 26-16

26 Summary (4 of 6)

Change of ρ with Temperature

- The resistivity of most material changes with temperature and is given as

$$\rho - \rho_0 = \rho_0 \alpha (T - T_0).$$

Equation 26-17

Ohm's Law

- A given device (conductor, resistor, or any other electrical device) obeys Ohm's law if its resistance R (defined by **Eq. 26-8** as $\frac{V}{i}$) is independent of the applied potential difference V.

26 Summary (5 of 6)

Resistivity of a Metal

- By assuming that the conduction electrons in a metal are free to move like the molecules of a gas, it is possible to derive an expression for the resistivity of a metal:

$$\rho = \frac{m}{e^2 n\tau}.$$

Equation 26-22

26 Summary (6 of 6)

Power

- The power P, or rate of energy transfer, in an electrical device across which a potential difference V is maintained is

$$P = iV$$

$$P = i^2 R = \frac{V^2}{R}$$

Equation 26-26

- If the device is a resistor, we can write

Equation 26-27&28

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