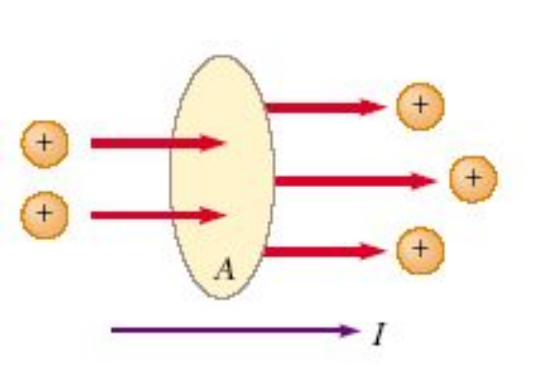
# Electric current and Resistance

## ELECTRIC CURRENT




Whenever there is a net flow of charge through some region, a **current** is said to exist.
Suppose that the charges are moving perpendicular to a surface of area *A*, The current is the rate at which charge flows through this surface.
If *Q is the amount of charge that passes through this area in a time interval t,* the average current *Iav is equal to the charge that passes through A per unit time:*

$$I_{av} = \frac{\Delta Q}{\Delta t}$$

If the rate at which charge flows varies in time, then the current varies in time; we define the **instantaneous current *I*** *as the differential limit of average current:*

$$I \equiv \frac{dQ}{dt}$$

The SI unit of current is the **ampere** (A):

$$1\ \mathrm{A} = \frac{1\ \mathrm{C}}{1\ \mathrm{s}}$$

# The direction of the current

It is conventional to assign to **the current the same direction as the flow of positive charge**.

***In electrical conductors***, such as copper or aluminum, the current is due to the motion of negatively charged electrons. Therefore, when we speak of current in an ordinary conductor, **the direction of the current is opposite the direction of flow of electrons.**

However, if we are considering ***a beam of positively*** charged protons in an accelerator, the current is in the direction of motion of the protons.

In some cases—such as those involving ***gases and electrolytes***, for instance—the current is the result of the flow of both positive and negative charges.

If the ends of the conducting wire are connected to a battery, all points on the loop are not at the same potential. The battery sets up a potential difference between the ends of the loop, creating an electric field within the wire. The electric field exerts forces on the conduction electrons in the wire, causing them to move around the loop and thus creating a current.

It is common to refer to a moving charge (positive or negative) as a mobile charge carrier. For example, ***the mobile charge carriers in a metal are electrons.***

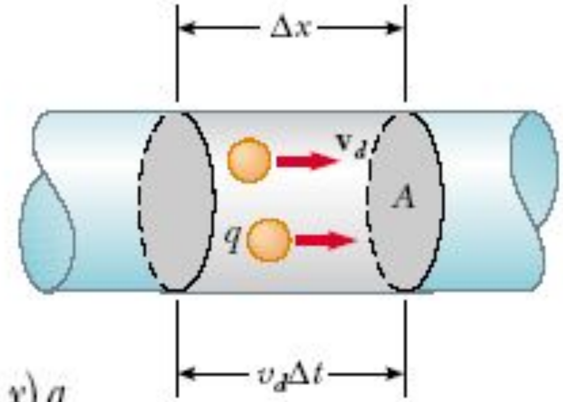
# Microscopic Model of Current

We can relate current to the motion of the charge carriers by describing a microscopic model of conduction in a metal. Consider the cu conductor of cross-sectional area *A*

The volume of a section of the conductor of length *Δx is Δx A*

the number of carriers in the gray section is *nA x.*

The charge *Q in this section is*




$$\Delta Q = \text{number of carriers in section} \times \text{charge per carrier} = (nA\,\Delta x)\,q$$

$$\Delta x = v_d\,\Delta t \qquad \Delta Q = (nAv_d\,\Delta t)\,q$$

**Average current in a conductor**

$$I_{\text{av}} = \frac{\Delta Q}{\Delta t} = nqv_dA$$

The speed of the charge carriers $v_d$ is an average speed called the **drift speed.**

# RESISTANCE AND OHM'S LAW

## Current density

Consider a conductor of cross-sectional area $A$ carrying a current $I$. The **current density** $J$ in the conductor is defined as the current per unit area. Because the current $I = nqv_dA$, the current density is

$$J \equiv \frac{I}{A} = nqv_d$$

where $J$ has SI units of $A/m^2$. This expression is valid only if the current density is uniform and only if the surface of cross-sectional area $A$ is perpendicular to the direction of the current. In general, the current density is a vector quantity:

$$\mathbf{J} = nq\mathbf{v}_d$$

**A current density J and an electric field E are established in a conductor whenever a potential difference is maintained across the conductor.** If the potential difference is constant, then the current also is constant. In some materials, the current density is proportional to the electric field:

$$\mathbf{J} = \sigma\mathbf{E}$$

where the constant of proportionality $\sigma$ is called the **conductivity**

# RESISTANCE AND OHM'S LAW

Ohm's law states that

for many materials (including most metals), the ratio of the current density to the electric field is a constant $\sigma$ that is independent of the electric field producing the current.

Materials that obey Ohm's law and hence demonstrate this simple relationship between
E and J are said to be ***ohmic.***
*Experimentally, it is found that not all materials* have this property, however, and materials that do not obey Ohm's law are said to be ***nonohmic****.*
*Ohm's law is not a fundamental law of nature but rather an empirical* relationship valid only for certain materials.

$$\Delta V = E\ell$$

$$J = \sigma E = \sigma \frac{\Delta V}{\ell}$$

$$\Delta V = \frac{\ell}{\sigma} J = \left(\frac{\ell}{\sigma A}\right) I$$

The quantity $\ell/\sigma A$ is called the **resistance** $R$ of the conductor. We can define the resistance as the ratio of the potential difference across a conductor to the current through the conductor:

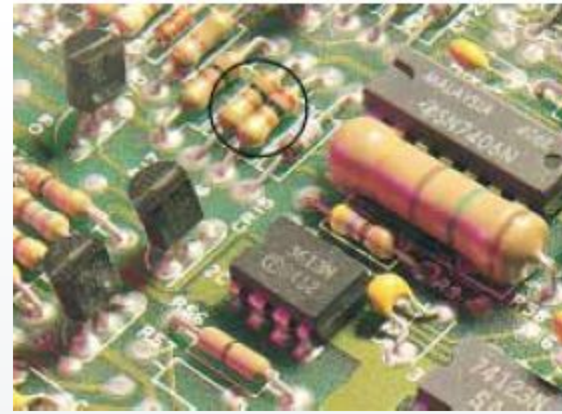
$$R \equiv \frac{\ell}{\sigma A} \equiv \frac{\Delta V}{I}$$

The inverse of conductivity is **resistivity**[3] $\rho$:

$$\rho \equiv \frac{1}{\sigma}$$

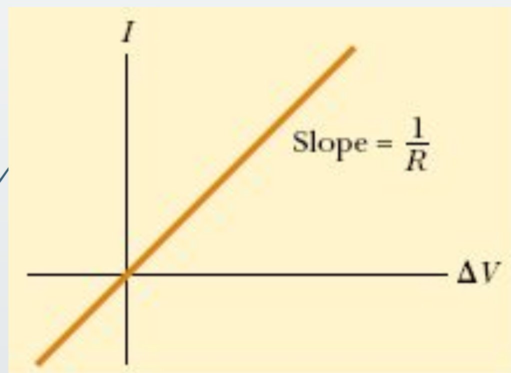
the resistance of a uniform block of material as

$$R = \rho \frac{\ell}{A} \qquad R \equiv \frac{\ell}{\sigma A} \equiv \frac{\Delta V}{I}$$

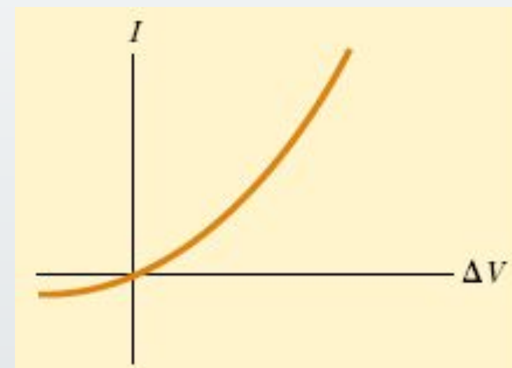


Most electric circuits use devices called **resistors** to control the current level

(a) Ohmic (Conductors)




(b) Non ohmic Semiconductors




(a) The current–potential difference curve for an ohmic material. The curve is linear, and the slope is equal to the inverse of the resistance of the conductor. (b) A nonlinear current–potential difference curve for a semiconducting diode. This device does not obey Ohm's law.

# RESISTANCE AND TEMPERATURE

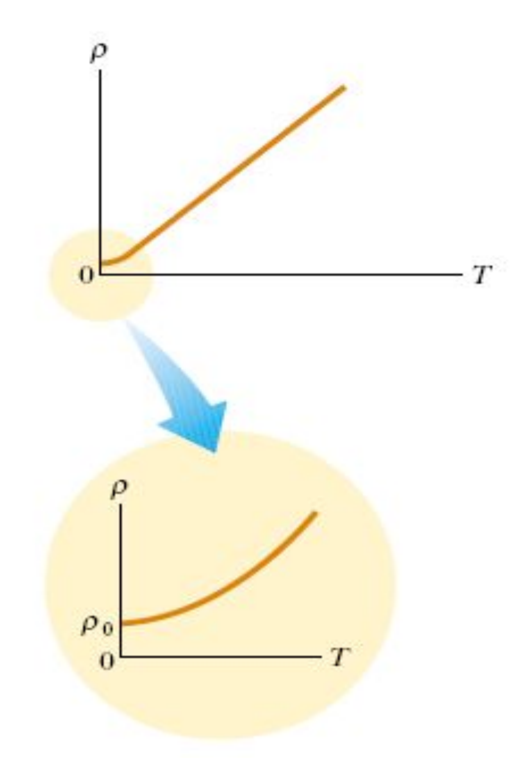
$$\rho = \rho_0[1 + \alpha(T - T_0)]$$

where $\rho$ is the resistivity at some temperature $T$ (in degrees Celsius), $\rho_0$ is the resistivity at some reference temperature $T_0$ (usually taken to be 20°C), and $\alpha$ is the **temperature coefficient of resistivity.**

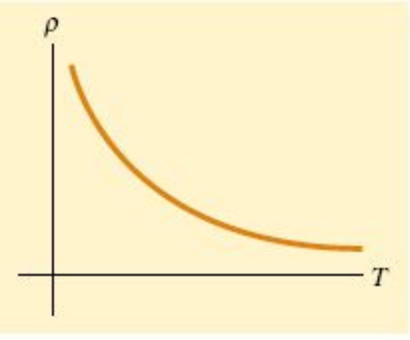
$$\alpha = \frac{1}{\rho_0}\frac{\Delta\rho}{\Delta T}$$

Because resistance is proportional to resistivity we can write the variation of resistance as

$$R = R_0[1 + \alpha(T - T_0)]$$



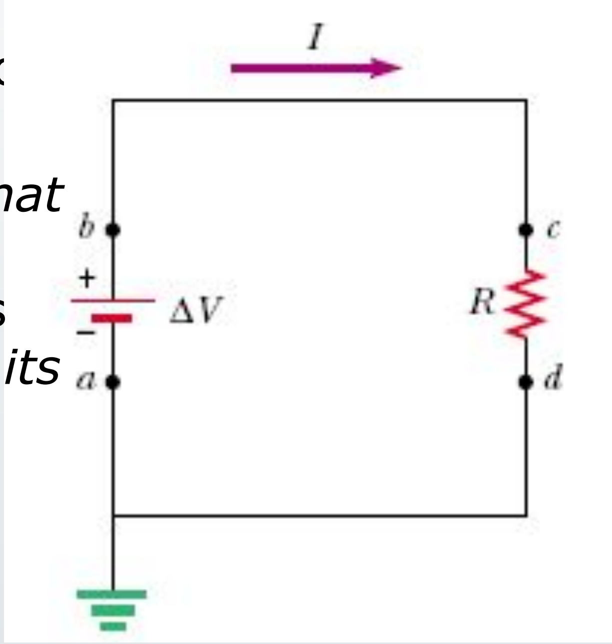

Resistivity versus temperature for a metal such as copper. The curve is linear over a wide range of temperatures, and increases with increasing temperature. As *T approaches absolute* zero (inset), the resistivity approaches a finite value 0 .




Resistivity versus temperature for a pure
semiconductor, such as silicon or germanium.

# ELECTRICAL ENERGY AND POWER

If a battery is used to establish an electric current in a conductor, the chemical energy
stored in the battery is continuously transformed into kinetic energy of the charge carriers.
The chemical energy stored in the battery is continuously transformed to internal energy associated with the temperature of
Consider a simple circuit consisting of a battery whc
connected to a resistor, as shown in Figure




Imagine following a positive quantity of charge *Q that is* moving clockwise around the circuit from point *a through the battery and resistor* back to point *a.* As the charge moves from *a to b through the battery, its electric potential energy U increases by an amount ΔV Δ Q (where Δ V is the potential difference between b and a), while the chemical potential energy in the battery decreases by the same* amount.

The rate at which the charge $\Delta Q$ loses potential energy in going through the resistor is

$$\frac{\Delta U}{\Delta t} = \frac{\Delta Q}{\Delta t}\Delta V = I\,\Delta V$$

The charge cannot build up at any point the current is the same everywhere in the circuit.

the rate at which the charge loses energy equals the power delivered to the resistor (which appears as internal energy),

$$\mathcal{P} = I\,\Delta V$$

In this case, the power is supplied to a resistor by a battery.
*ΔV = IR for a resistor, we can express* the power delivered to the resistor in the alternative forms

$$\mathcal{P} = I^2R = \frac{(\Delta V)^2}{R}$$

**When the internal resistance of the battery is neglected, the potential difference between points *a* and *b* in Figure 27.14 is equal to the emf $\mathcal{E}$ of the battery**—that is, $\Delta V = V_b - V_a = \mathcal{E}$. This being true, we can state that the current in the circuit is $I = \Delta V/R = \mathcal{E}/R$. Because $\Delta V = \mathcal{E}$, the power supplied by the emf source can be expressed as $\mathcal{P} = I\mathcal{E}$, which equals the power delivered to the resistor, $I^2R$.

# Current and Resistance

**Q.1:** Suppose that the material composing a fuse melts once the current density rises to $440 A/cm^2$. What diameter of cylinder wire should be used for the fuse to limit the current to 0.552A?

**Q.2:** How long does it take electrons to get from a car battery to the starting motor? Assume that the current is 115A and the electrons travel through copper wire with cross-sectional area $31.2 mm^2$ and length 85.5cm .($n = 8.49 \times 10^{28}\ m^{-3}$)

**Q.3:** A fluid with resistivity 9.4 $\Omega$ m seeps into the space between the plates of a 110pF parallel plate air capacitor. When the space is completely filled, what is the resistance between the plates?( $\varepsilon_\circ = 8.85$ pF/m)

**Q.4:** For a hypothetical electronic device, the potential difference V in volts, measured across the device, is related to the current "i" in mA by $V = 3.55i^2$. (a) find the resistance when current is 2.4mA. (b) At what value of the current is the resistance equal to 16 Ω ?

**Q.5:** A student's 9V , 7.5 W portable ratio was left on from 9:00p.m until 3:00 am .How much charge passed through the wires?

# Quiz 3



1. A cylindrical copper wire with a length of 10 meters and a diameter of 2 millimeters carries a current of 5 amps. Calculate the current density in the wire.
2. A material has a resistivity of $3.5\times10^{-6}$ ohm-meters. If a wire made of this material has a resistance of 25 ohms and a length of 10 meters, what is the cross-sectional area of the wire?
3. A circuit consists of three resistors connected in parallel: $R1=10$ ohms, $R2=20$ ohms, and $R3=30$ ohms. Calculate the total resistance of the circuit.
4. A copper wire with a resistance of 8 ohms is stretched to double its original length. Assuming its resistivity remains constant, calculate the new resistance of the wire.
5. A conductor has a cross-sectional area of $2\times10^{-6}$ square meters and a resistance of 50 ohms. If the length of the conductor is halved while keeping the cross-sectional area

1. If the waveforms in Figure 7–70 are applied to an active-HIGH S-R latch, draw the resulting $Q$ output waveform in relation to the inputs. Assume that $Q$ starts LOW.

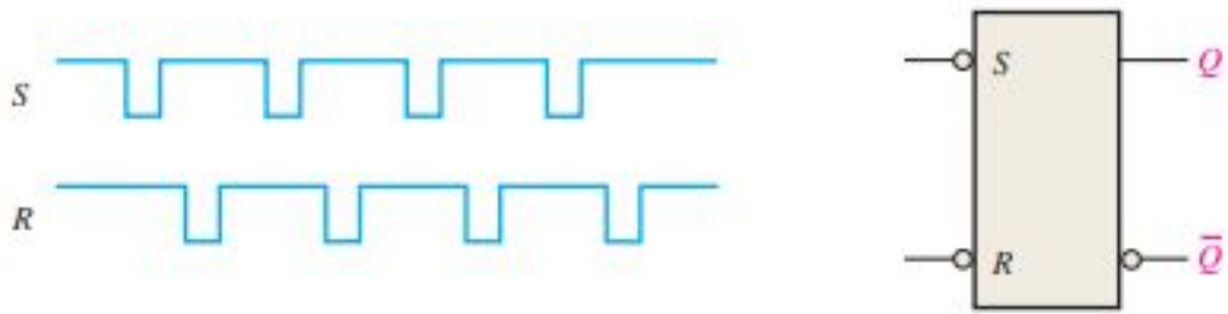
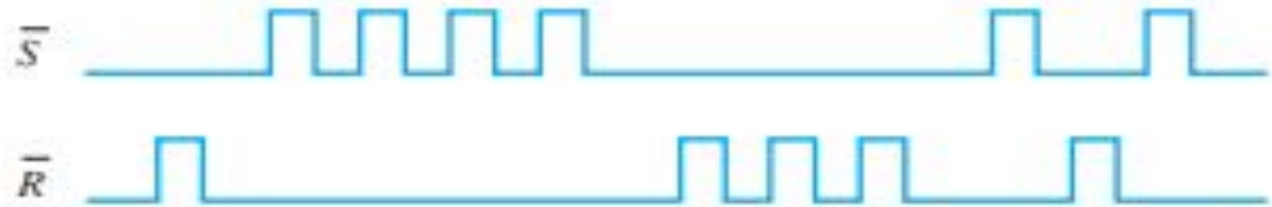



**FIGURE 7–70**

2. Solve Problem 1 for the input waveforms in Figure 7–71 applied to an active-LOW $\overline{S} - \overline{R}$ latch.




9. The $Q$ output of an edge-triggered D flip-flop is shown in relation to the clock signal in Figure 7–78. Determine the input waveform on the D input that is required to produce this output if the flip-flop is a positive edge-triggered type.