Chapter 25: Current, resistance, and electromotive force

- What is electric current? And What is resistance?
- Ohm’s law
- Electromotive force
- Symbols in circuits
- Power in circuits

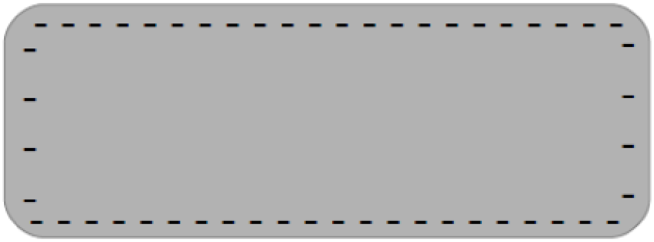
What is electric current?

In conductor:

If all charges are stationary ←→ no electric field

$$\Delta V = -\int_1^2 \vec{E} \cdot d\vec{l} = 0$$

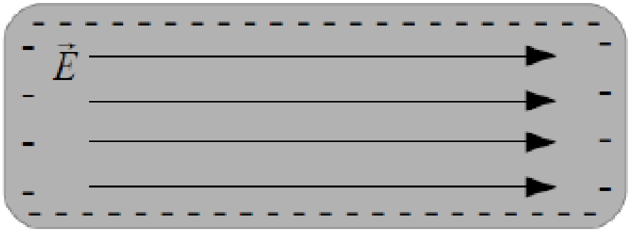
If all charges are stationary ←→ no potential difference



Conductor

$\vec{E} = 0$ $\Delta V = 0$

What is electric current?



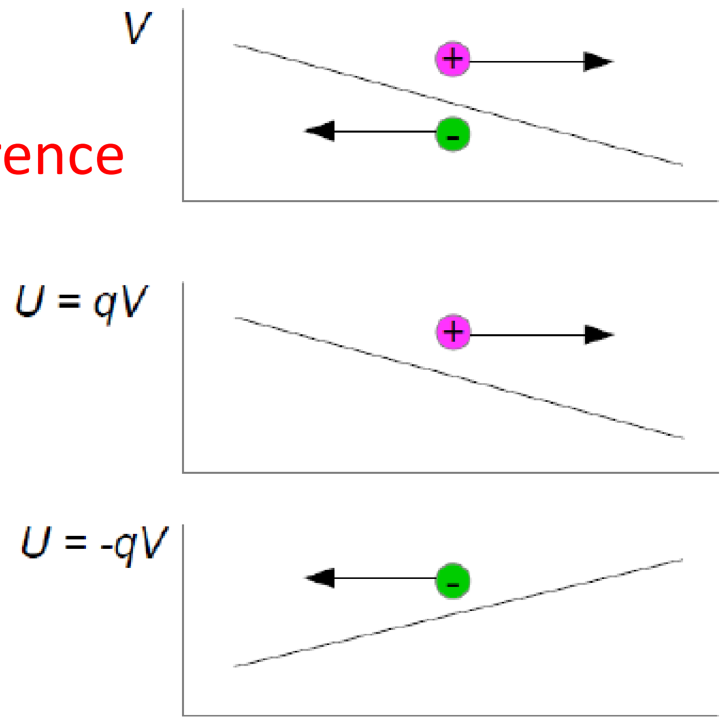
Conductor

In conductor:

If charges are moving ←→ electric field

$$\Delta V = -\int_1^2 \vec{E} \cdot d\vec{l} \neq 0$$

If charges are moving ←→ potential difference

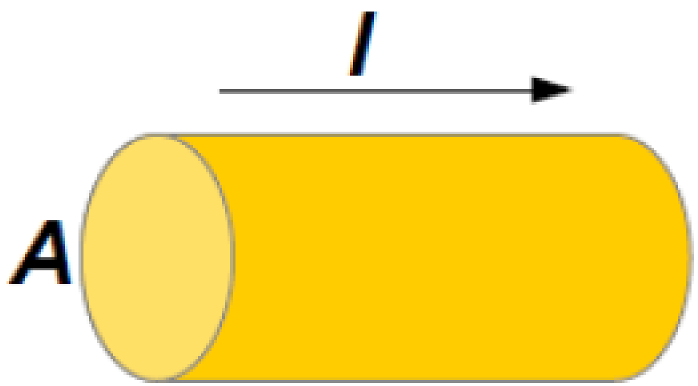


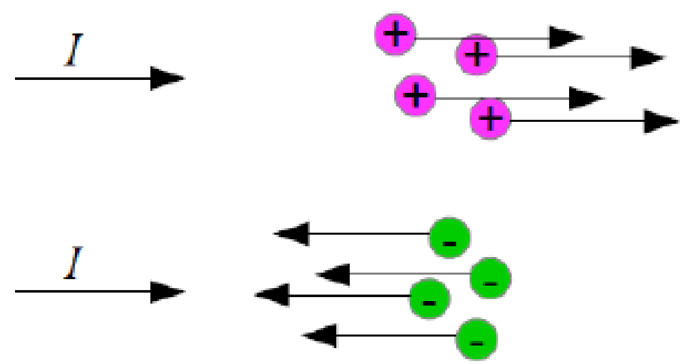
Electric field has the same direction with the current, despite the sign of the moving charges.

What is electric current?

Electric current is defined as how much Positive charge passing through a certain cross-section of materials.

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



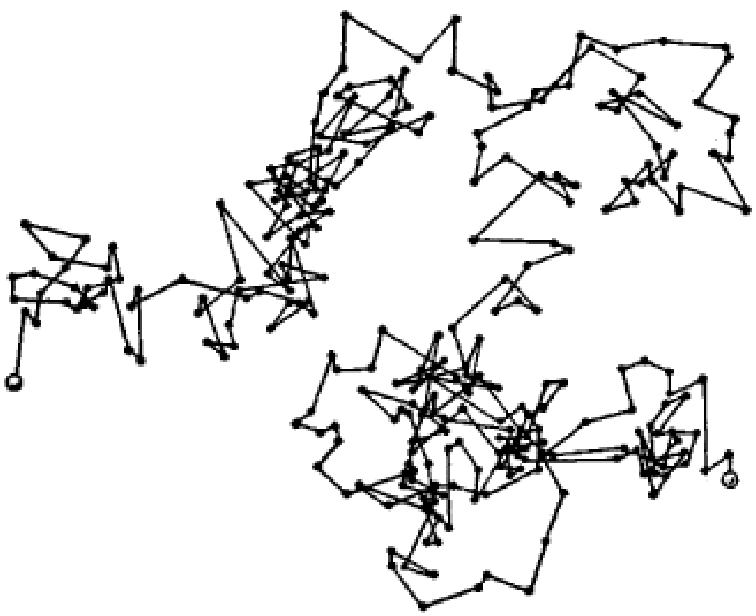


The unit of the current is Ampere:

$$1\ A = 1\frac{C}{s} = 1(coulomb\ per\ second)$$

What is resistance?

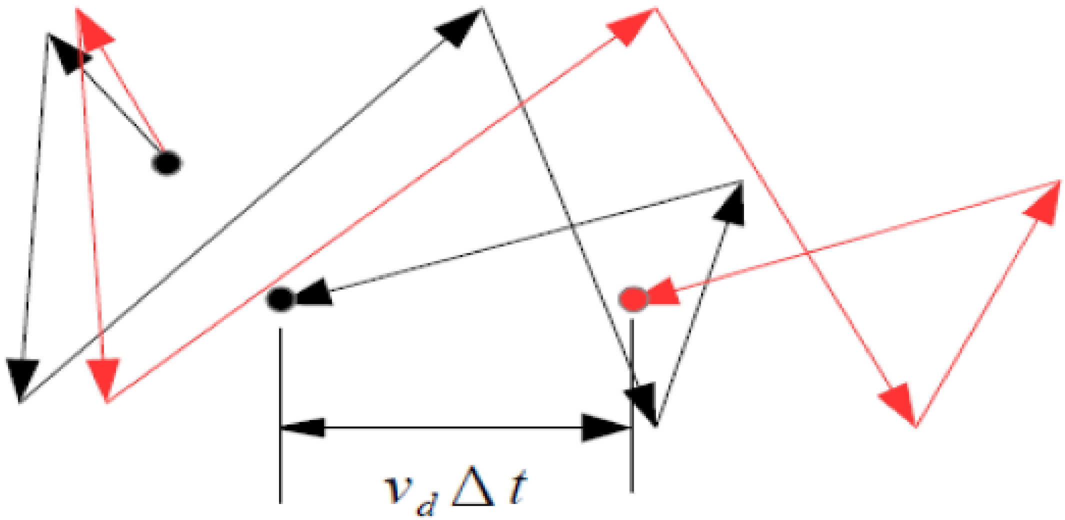
We say: charges could move freely in conductor. But how free?



Brownian Motion: random walk

What is resistance?

With electric field:



Black: electron motion without electric field

Red: electron motion with electric field

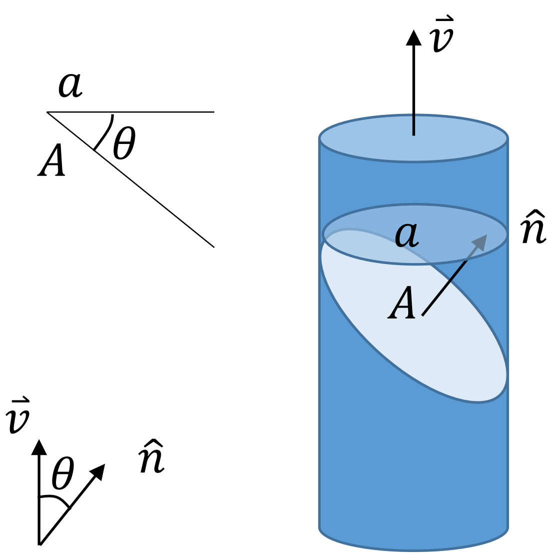
What is resistance?

- Just like Brownian motion for gas molecules, every turning point represents a collision with something, What are “something” here?
- Will the collision take out energy carried by the electrons?
- The transferred energy will go where?
- These collision events could be described as electric resistance: R
- The distance attained by the electrons with the presence of the electric field is: $\vec{v}_d \cdot \Delta t$
- $\vec{v}_d$ is called “drift velocity”, which is the velocity attained by the electrons with the presence of the electric field.

What is “flux”? And What is “electric flux”?

Flux: **How much “something” flows through a certain area.**

Electric flux: **How much electric field (lines) flow through a certain area.**



$$\frac{dV}{dt} = a \cdot |\vec{v}| = A \cdot cos\theta \cdot |\vec{v}| = \vec{v} \cdot A\hat{n} = \vec{v} \cdot \vec{A}$$

$$flux = \vec{v} \cdot \vec{A}$$

What is current?

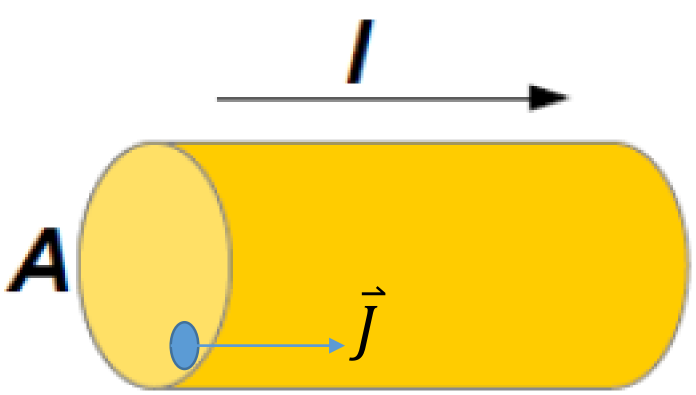
Volume flux: $$\frac{dV}{dt} = \vec{v} \cdot \vec{A}$$

$$I = \frac{dQ}{dt} = \frac{n|q|dV}{dt} = n|q||\vec{v}_d|A$$

Current: $$I = n|q||\vec{v}_d|A$$

What is current density?

$$\vec{J} = \frac{I}{A}\hat{J} = nq\vec{v}_d$$



Ohm's law

$$I \propto V \quad \Longrightarrow \quad \frac{V}{I} = R$$ (Resistance)

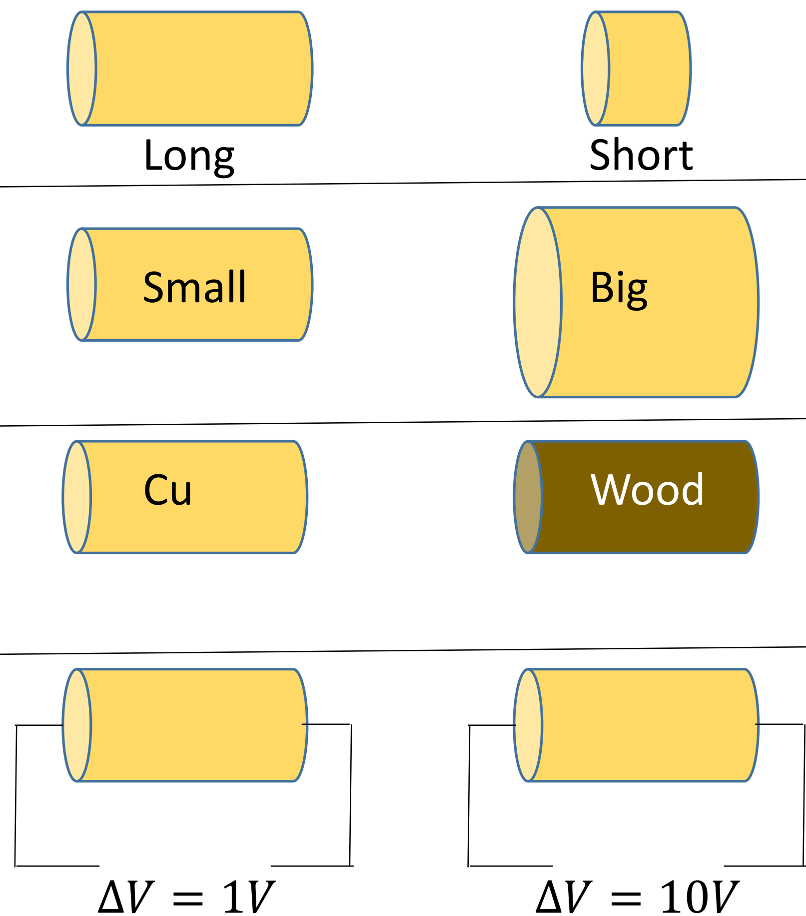
The unit of the resistance is Ohm, Ω:

$$1\Omega = 1\frac{V}{A}$$

The resistance represents how difficult the current flows

Ohm's law

Let's look at the current, *I*



$$I \propto \frac{1}{L}$$

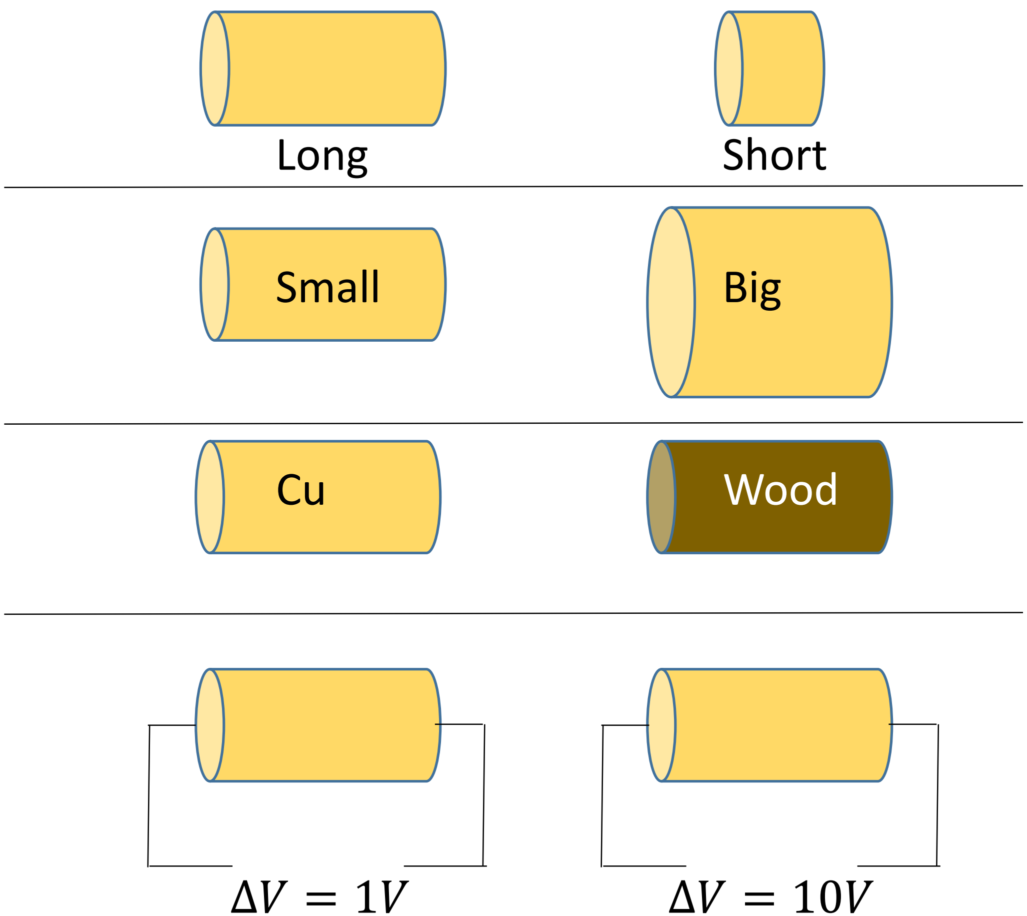
$$I \propto A$$

$$I \propto \frac{1}{\rho}$$

$$I \propto \Delta V$$

Ohm's law

Let's look at the current, *I*



$$I = \frac{1}{\rho}\frac{A}{L}\Delta V$$

$$\frac{V}{I} = R$$

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

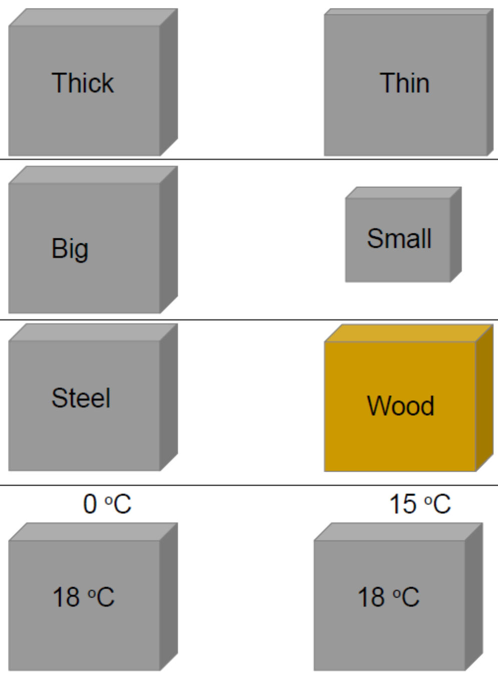
Resistivity

See table 25.1 (page 823)

The unit of resistivity is: **Ωm**

Recall in Ch17: Thermal conduction

Conduction (Which transfer more heat/sec?)



$$\frac{dQ}{dt} \propto \frac{1}{L}$$

$$\frac{dQ}{dt} \propto A$$

$$\frac{dQ}{dt} \propto k$$

$$\frac{dQ}{dt} \propto \Delta T$$

$$\frac{dQ}{dt} = k\,A\,\frac{\Delta T}{L}$$

Quiz

We learned that the resistance of a piece of material is a function of length, *L*, cross-section area, *A*, and material dependent resistivity, ρ.

Consider a copper wire with length *L*, cross-section area *A*, with a resistance *R*. Now, this copper wire is elongated to 2*L*, thus the cross-section reduced to A/2 (volume does not change). What is the resistance of the copper wire after the elongation?

(a) 4R
(b) 2R
(c) R
(d) R/2
(e) R/4

Example

1. What diameter must a copper wire have if its resistance is to be the same as that of an equal length of aluminum wire with diameter 3.26 mm?

2. An aluminum cube has sides of length 1.80 m. What is the resistance between two opposite faces of the cube?

Ohm's law: Another form

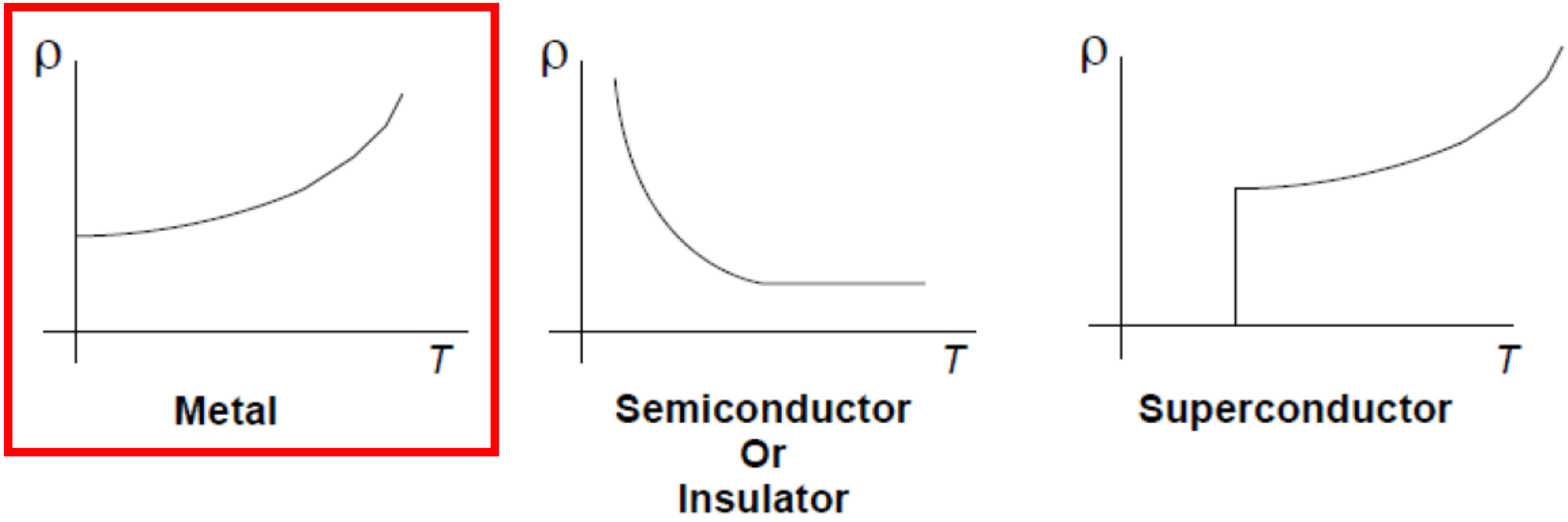
Ohm's law $\frac{V}{I} = R$

$$\frac{V}{I} = \frac{|\vec{E}|L}{|\vec{J}|A} = R = \rho\frac{L}{A}$$

Ohm's law in microscopic view $\frac{|\vec{E}|}{|\vec{J}|} = \rho$

Temperature dependence

Recall in Ch17, material properties could be changed by changing temperature.

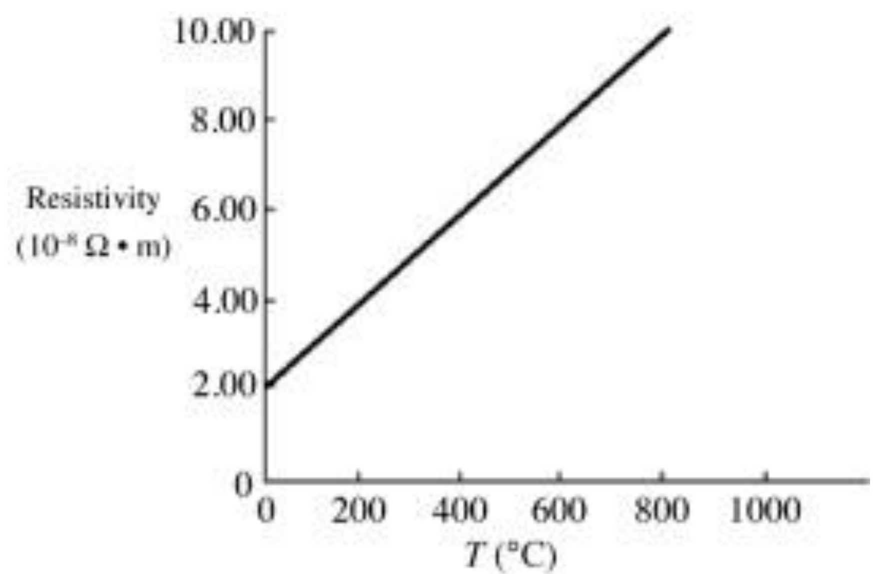


Let's use "linear approximation"

$$\frac{\Delta\rho}{\rho_0} = \alpha\Delta T \quad \Rightarrow \quad \frac{\Delta R}{R_0} = \alpha\Delta T$$

Example

- A piece of wire 44.0 cm long carries a current *I* when a voltage *V* is applied across its ends at a temperature of 0°C. If the resistivity of the material of which the wire is made varies with temperature as shown in the graph in the figure, what length of the same diameter wire is needed so that the same current flows when the same voltage is applied at temperature 400°C?

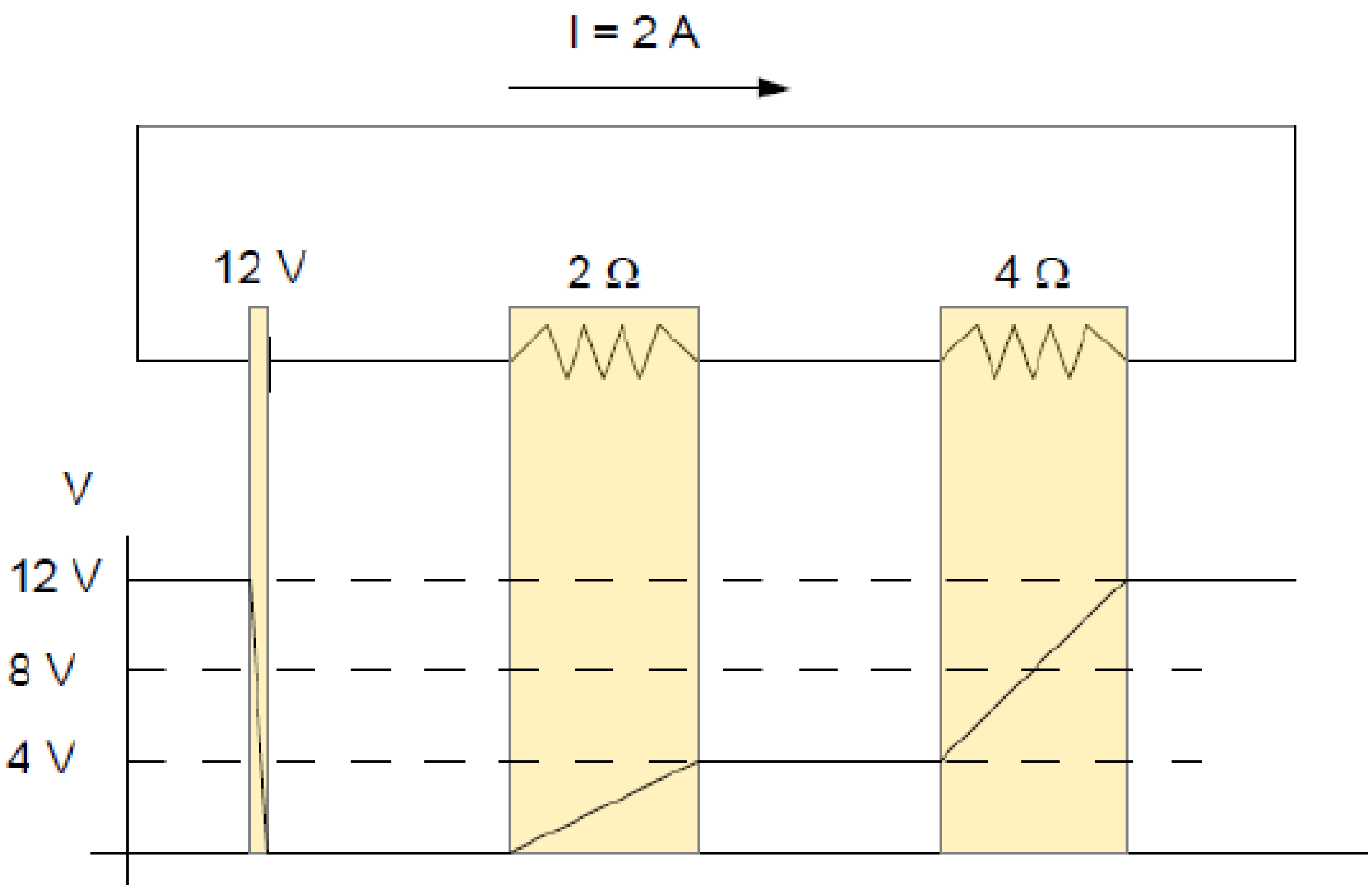


Electromotive force (emf, ε)

A circuit is a closed connections many electronic devices.

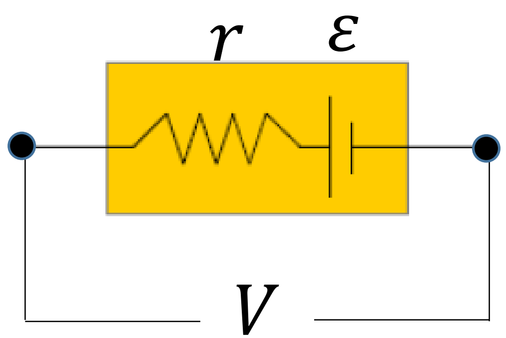
- Current is flowing from high electric potential toward low electric potential
- In a circuit, the current is usually kept flowing (steady state). There much be something in the circuit serves as “electric potential pump”. Such as **Batteries (Electrochemical reaction)**

Resistance ➔ Potential drop



Internal resistance in battery (source)

Almost all materials have resistance, include materials in battery.
➔ Battery has internal resistance (*r*):

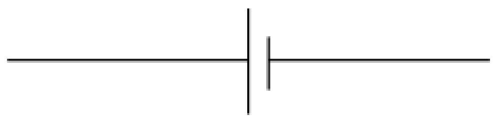


$$V = \varepsilon - I \cdot r$$

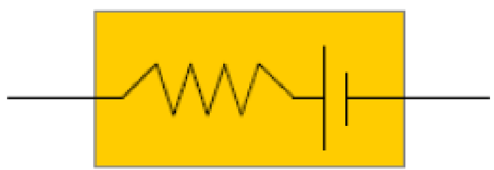
- Symbols in circuit

Ideal wire (negligible resistance)

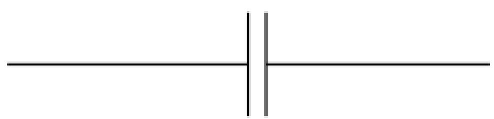
Resistor



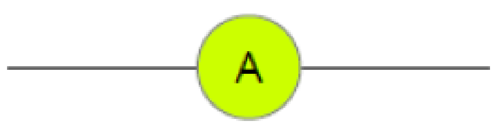
Ideal emf source (no internal resistance)



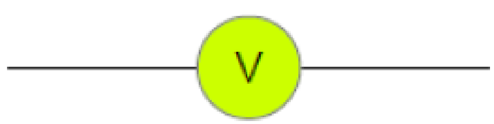
emf source (with internal resistance)



Capacitor



Ammeter (measure current through it)



Voltmeter (measure potential different at the two terminal)

Power in circuit

$$P = \frac{\Delta U}{\Delta t} = \frac{V\Delta q}{\Delta t} = VI$$

$$P = VI$$

use $V = IR$

$$P = VI = I^2R = \frac{V^2}{R}$$

Which to use? Depends on what you know.

Example

- Consider the circuit of Fig. E25.32 (page 845).

(a) What is the total rate at which electrical energy is dissipated in the 5.0 Ω and 9.0 Ω resistors?

(b) What is the power output of the 16.0 V battery?

(c) At what rate is electrical energy being converted to other form in the 8.0 V battery?

(d) Show that the power output of the 16.0 V battery equals the overall rate of dissipation of electrical energy in the rest of the circuit.