Physics 1214 — Chapter 19: Current, Resistance, and Direct-Current Circuits — 01/30

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1 Current

current: (also called *electric current*) is an motion of charge from one region of a conductor to another.

Current

When a net charge ΔQ passes through a cross section of conductor during time Δt, the current is

$$I = \frac{\Delta Q}{\Delta t}.$$

Unit: 1 coulomb/second = 1 C/s = 1 ampere = 1 A.

The current at any instant is the same at all cross sections.

ITC: ***the currents will be described as though they consisted entirely of positive charge flow, even in cases in which we know the actual current is due to electrons (negatively charged).***

- in metals, the moving charges are always electrons and thus negative
- in ionic solutions, both positive and negative ions are moving
- "conventional current" describes a flow of positive charge that is equivalent to the actual flow of charge of either sign

2 Resistance and Ohm's Law

Resistance

When the potential difference V between the ends of a conductor is proportional to the current I in the conductor, the ratio V/I is called the resistance of the conductor:

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

Unit: The SI unit of resistance is the ***ohm***, equal to 1 volt per ampere. The ohm is abbreviated with Ω.

$$\boxed{1\Omega = 1\text{V/A}}$$

Ohm's law

The potential difference V between the ends of a conductor is proportional to the current I through the conductor; the proportionality factor is the resistance R.

Ohm's law is an idealized model.

Resistivity

The resistance R is proportional to the length L and inversely proportional to the cross-sectional area A, with a proportionality factor ρ called the resistivity of the material. That is,

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

where ρ, in general different for different materials, characterizes the conduction properties of a material. Unit: The SI unit of resistivity is 1 ohm $\cdot$ meter = 1 $\Omega \cdot$ m.

It's important to distinguish between *resistivity* and *resistance*. *Resistivity* is a property of a material, independent of the shape and size of the specimen, while *resistance* depends on the size and shape of the specimen or device, as well as on its resistivity.

The resistance of every conductor varies somewhat with temperature. Where R_0 is the resistance at a reference temperature T_0 and R_T is the resistance at temperature T, then the variation of R with temperature is described approximately by

$$\boxed{R_T = R_0 \left[1 + \alpha \left(T - T_0\right)\right]}$$

where α is the ***temperature coefficient of resistivity***.

thermistor: a small semiconductor crystal usde to make a sensitive electronic thermometer; its resistance is used as a thermometric property.
superconductivity: materials, which as the temperature decreases, the resistivity at first decreases smoothly, like a metal, but at a critical transition temperature T_c a phase transition occurs, and the resistivity suddenly drops to zero. Once a current has been established in a superconducting ring, it continues indefinitely without the presence of any driving field.
ohmic: a descriptive name given to a conductor that obeys Ohm's law and its current versus voltage graph is a straight line with a slope of $1/R$.
non-ohmic: a conductor that is not *ohmic*.

3 Electromotive Force and Circuits

complete circuit: a closed loop conductor with an energy source.
electromotive force (emf): the influence that moves charge from lower to higher potential despite the electric field forces in the opposite direction. Every *complete circuit* with a continuous current must include some device that provides *emf*. Symbol: $\mathcal{E}$. Unit: energy per unit charge.

For the ***ideal source*** of $\mathcal{E}$,

$$V_{ab} = \mathcal{E} = IR.$$

internal resistance: charge that moves through the material of any real source encounters resistance, denoted by r.
terminal voltage: V_{ab}
For real sources,

$$V_{ab} = \mathcal{E} - Ir$$

but the current, I is still $V_{ab} = IR$ so that

$$I = \frac{\mathcal{E}}{R + r}$$

Meters in circuits:

The symbol V in a circle represents an ideal voltmeter. It measures the potential difference between the two points in the circuit where it is connected, but *no current flows through the voltmeter.* The symbol A in a circle represents an ideal ammeter. It measures the current that flows through it, but *there is no potential difference between its terminals.* Thus the behavior of a circuit doesn't change when an ideal ammeter or voltmeter is connected to it.

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4 Energy and Power in Electric Circuits

The work ΔW represents electrical energy transferred *into* the circuit element.

$$\boxed{\Delta W = V_{ab}\Delta Q = V_{ab} I \Delta t}$$

Where power is the time rate of energy transfer, denoted by P, then

$$\boxed{P = \frac{\Delta W}{\Delta t} = V_{ab} I}$$

and the SI unit of power is 1 watt:

$$\boxed{(1\ \mathrm{J/C})(1\ \mathrm{C/s}) = 1\ \mathrm{J/s} = 1\ \mathrm{W}}$$

The power dissipated through a resistor:

$$\boxed{P = V_{ab} I - I^2 R = \frac{V_{ab}^2}{R}}.$$

Every resistor has a power rating: the maximum power that the device can dissipate without becoming overheated and damaged.

Power output of a source:

$$\boxed{P = V_{ab} I = \mathcal{E} I - I^2 r}$$

5 Resistors in Series and Parallel

equivalent resistance: the resistance of a single resistor that is equivalent to a combination of resistors that obey Ohm's law.

$$\boxed{V_{ab} = I R_{eq} \text{ or } R_{eq} = \frac{V_{ab}}{I}}.$$

Equivalent resistance for resistors in series

The equivalent resistance of any number of resistors in series equals the sum of their individual resistances:

$$R_{eq} = R_1 + R_2 + R_3 + ...$$

the equivalent resistance is always greater than any individual resistance.

Equivalent resistance for resistors in parallel

For any number of resistors in parallel, the reciprocal of the equivalent resistance equals the sum of the reciprocals of their individual resistances:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$$

The equivalent resistance is always less than any individual resistance.

6 Kirchhoff's Rules

junction: a point in a circuit where three or more conductors meet; aka *nodes* or *branch points.*
loop: any closed conducting path.

Kirchhoff's rules:

Kirchhoff's junction (or point) rule

The algebraic sum of the currents into any junction is zero; that is

$$\sum I = 0.$$

(Currents into a junction are positive; current out of a junction are negative. Based on conservation of electric charge.)

Kirchhoff's loop rule

The algebraic sum of the potential differences in any loop, including those associated with emf's and those of resistive elements, **must equal zero**; that is,

$$\sum_{around loop} V = 0.$$

(Based on conservation of energy.)

7 Electrical Measuring Instruments

8 Resistance-Capacitance Circuits

9 Physiological Effects of Currents

10 Power Distribution Systems