Chapter 27 Current and Resistance

The preceding chapters have dealt with charges at rest.

We now go on to study effects associated with charges in motion, that is, electric currents.

How to detect the electricity? Example, animal electricity.



The Development of Voltage Sources

- 1. Where are steady current or voltage sources?
- 2. How to measure current or voltage?



Same trend in the development of millimeter/sub-millimeter waves sources.

27.1 Current

If in time Δt a net charge ΔQ flows through the surface, the average electric field is defined as

$$I_{av} = \frac{\Delta Q}{\Delta t}$$
 $I = \frac{dQ}{dt}$ (instantaneous)

An electrical current is the rate of flow of charge through a surface.

The SI unit of current is the Ampere (A).

1 A =1 C/s

The direction of *I* is taken by convention to be that the flow of positive charge.

27.1 Current (II)

A current will flow continuously only through a *closed* loop, called *an electrical circuit*.

One advantage of the conventional direction of current is that *current flows from high potential to low potential*.

A potential difference between two points on a wire implies the existence of an *electric field* along the wire. (no longer static)

How do the charged particles (i.e. electrons) flow within a conducting wire?



 $\begin{array}{c} -\Theta -\Theta -\Theta \\ \Theta -\Theta -\Theta \end{array}$

(b)





27.1 Current (III)

The path of a conduction electron in a current-carry wire is quite erratic, as shown in the right figure.

The motion of an electron resembles that of a steel ball rolling down a nail-studded incline.

There is an analogy between a wind and an electric current.

Wind: molecules speed 300m/s, wind speed 10m/s.

Current: electron thermal speed 10^6 m/s, drift speed 10^{-4} m/s.



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27.2 Current Density

The current density is defined as the current per unit area:

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

The SI unit of current density is A/m².

Whereas the current is a scalar, current density is defined to be a vector in the definition of the drift velocity. We have

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

For negative charge carriers J is opposite to Vd.

Example 27.1

A copper wire carries a current of 10 A. It has a cross-section area of 0.05 cm². Estimate the drift velocity of the electron.

Solution:

number density
$$n = \frac{N_A}{V_A} = \frac{\rho N_A}{M} = 8.5 \times 10^{28} \text{ atoms/m}^3$$

drift velocity
$$v_d = \frac{I}{neA} = 1.5 \times 10^{-4} \text{ m/s}$$

This is the extremely small drift speed at which the electron gas as a whole moves along a wire.

27.3 Resistance

The resistance of the conductor between these pointsis defined as

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

The SI unit of resistance is the ohm (Ω). 1 Ω =1 V/A

The electric field within a wire accelerates the electrons. However their velocities do not increase indefinitely because they *collide* with the array of positive ions that form the crystal lattice.

This steady drift is analogous to the terminal velocity of a body falling through a viscous fluid.

27.3 Resistance (II)

Assume the drift velocity is proportional to the electric field in the wire. Since the current density is proportional to the drift velocity . Thus the relation between the current density and 表 27.1 電阻率 (20 ℃時)

electric field is written as

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

Where ρ and σ are resistivity and conductivity, respectively

物質名稱	電阻率 (Ω・m)	溫度係數 (℃ ⁻¹)
雲母	2×10^{-15}	-50×10^{-3}
玻璃	$10^{12} - 10^{13}$	-70×10^{-3}
硬質橡膠	10 ¹³	
矽	2200	-0.7
鍺	0.45	-0.05
碳(石墨)	3.5×10^{-5}	-0.5×10^{-3}
鎳克羅	1.2×10^{-6}	0.4×10^{-3}
錳銅合金	44×10^{-8}	5×10^{-7}
鋼	40×10^{-8}	8×10^{-4}
鉑	11×10^{-8}	3.9×10^{-3}
鋁	2.8×10^{-8}	3.9×10^{-3}
銅	1.7×10^{-8}	3.9×10^{-3}
銀	1.5×10^{-8}	3.8×10^{-3}

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27.3 Resistance (III)

Temperature Dependence of Resistivity

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

Where α is the temperature coefficient of resistivity.



27.4 Ohm's Law

Macroscopic view: Ohm's law says that the potential difference across a device is directly proportional to the current through it.

$$V = IR$$

Microscopic view: Correlated the current density and the electric field. $\mathbf{I} - \mathbf{F} \neq \mathbf{c}$

$$\mathbf{J} - \mathbf{L}/p$$

The I-V relationship for an ohmic device is a straight line, but is not a straight line for an nonohmic device.

Is there a component with negative resistivity? Yes, diode.

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27.5 Power

How much energy dissipates on a resistor per unit time? Power.

$$P = dU / dt = (dq / dt)V$$
$$= IV = I^{2}R = \frac{V^{2}}{R}$$

The **SI** unit of power is the watt (W). The thermal loss in a resistor is often called Joule heating.

Exercises and Problems

Ch.27: Ex. 9, 12, 18, 39 Prob. 3, 4, 5