18.14: Current and Resistance (Summary)

Key Terms

ampere (amp)	SI unit for current; $1 A=1 C/s$
circuit	complete path that an electrical current travels along
conventional current	current that flows through a circuit from the positive terminal of a battery through the circuit to the negative terminal of the battery
critical temperature	temperature at which a material reaches superconductivity
current density	flow of charge through a cross-sectional area divided by the area
diode	nonohmic circuit device that allows current flow in only one direction
drift velocity	velocity of a charge as it moves nearly randomly through a conductor, experiencing multiple collisions, averaged over a length of a conductor, whose magnitude is the length of conductor traveled divided by the time it takes for the charges to travel the length
electrical conductivity	measure of a material's ability to conduct or transmit electricity
electrical current	rate at which charge flows, $I=\frac{dQ}{dt}$
electrical power	time rate of change of energy in an electric circuit
Josephson junction	junction of two pieces of superconducting material separated by a thin layer of insulating material, which can carry a supercurrent
Meissner effect	phenomenon that occurs in a superconducting material where all magnetic fields are expelled
nonohmic	type of a material for which Ohm's law is not valid
ohm	(Ω) unit of electrical resistance, $1 \Omega=1 V/A$
ohmic	type of a material for which Ohm's law is valid, that is, the voltage drop across the device is equal to the current times the resistance
Ohm's law	empirical relation stating that the current I is proportional to the potential difference V; it is often written as $V=IR$, where R is the resistance
resistance	electric property that impedes current; for ohmic materials, it is the ratio of voltage to current, $R=V/I$
resistivity	intrinsic property of a material, independent of its shape or size, directly proportional to the resistance, denoted by ρ
schematic	graphical representation of a circuit using standardized symbols for components and solid lines for the wire connecting the components
SQUID	(Superconducting Quantum Interference Device) device that is a very sensitive magnetometer, used to measure extremely subtle magnetic fields
superconductivity	phenomenon that occurs in some materials where the resistance goes to exactly zero and all magnetic fields are expelled, which occurs dramatically at some low critical temperature (T_C)

Key Equations

Average electrical current	$I_{ave} = \frac{\Delta Q}{\Delta t}$
Definition of an ampere	$1A = 1C/s$
Electrical current	$I = \frac{dQ}{dt}$
Drift velocity	$v_d = \frac{I}{nqA}$
Current density	$I = \iint_{area} \vec{J} \cdot d\vec{A}$
Resistivity	$\rho = \frac{E}{J}$
Common expression of Ohm's law	$V = IR$
Resistivity as a function of temperature	$\rho = \rho_0[1 + \alpha(T - T_0)]$
Definition of resistance	$R \equiv \frac{V}{I}$
Resistance of a cylinder of material	$R = \rho\frac{L}{A}$
Temperature dependence of resistance	$R = R_0(1 + \alpha\Delta T)$
Electric power	$P = IV$
Power dissipated by a resistor	$P = I^2R = \frac{V^2}{R}$

Summary

9.2 Electrical Current

- The average electrical current I_{ave} is the rate at which charge flows, given by $I_{ave} = \frac{\Delta Q}{\Delta t}$, where ΔQ is the amount of charge passing through an area in time Δt.
- The instantaneous electrical current, or simply the current I, is the rate at which charge flows. Taking the limit as the change in time approaches zero, we have $I = \frac{dQ}{dt}$, where $\frac{dQ}{dt}$ is the time derivative of the charge.
- The direction of conventional current is taken as the direction in which positive charge moves. In a simple direct-current (DC) circuit, this will be from the positive terminal of the battery to the negative terminal.
- The SI unit for current is the ampere, or simply the amp (A), where $1A = 1C/s$.
- Current consists of the flow of free charges, such as electrons, protons, and ions.

9.3 Model of Conduction in Metals

- The current through a conductor depends mainly on the motion of free electrons.
- When an electrical field is applied to a conductor, the free electrons in a conductor do not move through a conductor at a constant speed and direction; instead, the motion is almost random due to collisions with atoms and other free electrons.
- Even though the electrons move in a nearly random fashion, when an electrical field is applied to the conductor, the overall velocity of the electrons can be defined in terms of a drift velocity.
- The current density is a vector quantity defined as the current through an infinitesimal area divided by the area.
- The current can be found from the current density, $I = \iint_{area} \vec{J} \cdot d\vec{A}$.
- An incandescent light bulb is a filament of wire enclosed in a glass bulb that is partially evacuated. Current runs through the filament, where the electrical energy is converted to light and heat.

9.4 Resistivity and Resistance

- Resistance has units of ohms (Ω), related to volts and amperes by $1\Omega = 1V/A$.
- The resistance **R** of a cylinder of length **L** and cross-sectional area A is $R = \frac{\rho L}{A}$, where ρ is the resistivity of the material.
- Values of ρ in Table 9.1 show that materials fall into three groups—conductors, semiconductors, and insulators.
- Temperature affects resistivity; for relatively small temperature changes ΔT, resistivity is $\rho = \rho_0(1 + \alpha\Delta T)$, where ρ_0 is the original resistivity and α is the temperature coefficient of resistivity.
- The resistance **R** of an object also varies with temperature: $R = R_0(1 + \alpha\Delta T)$, where R_0 is the original resistance, and **R** is the resistance after the temperature change.

9.5 Ohm's Law

- Ohm's law is an empirical relationship for current, voltage, and resistance for some common types of circuit elements, including resistors. It does not apply to other devices, such as diodes.
- One statement of Ohm's law gives the relationship among current I, voltage V, and resistance R in a simple circuit as $V = IR$.
- Another statement of Ohm's law, on a microscopic level, is $J = \sigma E$.

9.6 Electrical Energy and Power

- Electric power is the rate at which electric energy is supplied to a circuit or consumed by a load.
- Power dissipated by a resistor depends on the square of the current through the resistor and is equal to $P = I^2R = \frac{V^2}{R}$.
- The SI unit for electric power is the watt and the SI unit for electric energy is the joule. Another common unit for electric energy, used by power companies, is the kilowatt-hour (kW ·· h).
- The total energy used over a time interval can be found by $E = \int Pdt$.

9.7 Superconductors

- Superconductivity is a phenomenon that occurs in some materials when cooled to very low critical temperatures, resulting in a resistance of exactly zero and the expulsion of all magnetic fields.
- Materials that are normally good conductors (such as copper, gold, and silver) do not experience superconductivity.
- Superconductivity was first observed in mercury by Heike Kamerlingh Onnes in 1911. In 1986, Dr. Ching Wu Chu of Houston University fabricated a brittle, ceramic compound with a critical temperature close to the temperature of liquid nitrogen.
- Superconductivity can be used in the manufacture of superconducting magnets for use in MRIs and high-speed, levitated trains.
