9.S: Condensed Matter Physics (Summary)

Key Terms

acceptor impurity	atom substituted for another in a semiconductor that results in a free electron
amplifier	electrical device that amplifies an electric signal
base current	current drawn from the base *n*-type material in a transistor
BCS theory	theory of superconductivity based on electron-lattice-electron interactions
body-centered cubic (BCC)	crystal structure in which an ion is surrounded by eight nearest neighbors located at the corners of a unit cell
breakdown voltage	in a diode, the reverse bias voltage needed to cause an avalanche of current
collector current	current drawn from the collector *p*-type material
conduction band	above the valence band, the next available band in the energy structure of a crystal
Cooper pair	coupled electron pair in a superconductor
covalent bond	bond formed by the sharing of one or more electrons between atoms
critical magnetic field	maximum field required to produce superconductivity
critical temperature	maximum temperature to produce superconductivity
density of states	number of allowed quantum states per unit energy
depletion layer	region near the *p*-*n* junction that produces an electric field
dissociation energy	amount of energy needed to break apart a molecule into atoms; also, total energy per ion pair to separate the crystal into isolated ions
donor impurity	atom substituted for another in a semiconductor that results in a free electron hole
doping	alteration of a semiconductor by the substitution of one type of atom with another
drift velocity	average velocity of a randomly moving particle
electric dipole transition	transition between energy levels brought by the absorption or emission of radiation
electron affinity	energy associated with an accepted (bound) electron
electron number density	number of electrons per unit volume
energy band	nearly continuous band of electronic energy levels in a solid
energy gap	gap between energy bands in a solid
equilibrium separation distance	distance between atoms in a molecule
exchange symmetry	how a total wave function changes under the exchange of two electrons
face-centered cubic (FCC)	crystal structure in which an ion is surrounded by six nearest neighbors located at the faces at the faces of a unit cell
Fermi energy	largest energy filled by electrons in a metal at $T = 0K$
Fermi factor	number that expresses the probability that a state of given energy will be filled
Fermi temperature	effective temperature of electrons with energies equal to the Fermi energy

forward bias configuration	diode configuration that results in high current
free electron model	model of a metal that views electrons as a gas
hole	unoccupied states in an energy band
hybridization	change in the energy structure of an atom in which energetically favorable mixed states participate in bonding
impurity atom	acceptor or donor impurity atom
impurity band	new energy band create by semiconductor doping
ionic bond	bond formed by the Coulomb attraction of a positive and negative ions
junction transistor	electrical valve based on a *p*-*n*-*p* junction
lattice	regular array or arrangement of atoms into a crystal structure
Madelung constant	constant that depends on the geometry of a crystal used to determine the total potential energy of an ion in a crystal
majority carrier	free electrons (or holes) contributed by impurity atoms
minority carrier	free electrons (or holes) produced by thermal excitations across the energy gap
***n*-type semiconductor**	doped semiconductor that conducts electrons
***p*-*n* junction**	junction formed by joining *p*- and *n*-type semiconductors
***p*-type semiconductor**	doped semiconductor that conducts holes
polyatomic molecule	molecule formed of more than one atom
repulsion constant	experimental parameter associated with a repulsive force between ions brought so close together that the exclusion principle is important
reverse bias configuration	diode configuration that results in low current
rotational energy level	energy level associated with the rotational energy of a molecule
selection rule	rule that limits the possible transitions from one quantum state to another
semiconductor	solid with a relatively small energy gap between the lowest completely filled band and the next available unfilled band
simple cubic	basic crystal structure in which each ion is located at the nodes of a three-dimensional grid
type I superconductor	superconducting element, such as aluminum or mercury
type II superconductor	superconducting compound or alloy, such as a transition metal or an actinide series element
valence band	highest energy band that is filled in the energy structure of a crystal
van der Waals bond	bond formed by the attraction of two electrically polarized molecules
vibrational energy level	energy level associated with the vibrational energy of a molecule

Key Equations

Electrostatic energy for equilibrium separation distance between atoms	$U_{coul} = -\frac{ke^2}{r_0}$
Energy change associated with ionic bonding	$U_{form} = E_{transfer} + U_{coul} + U_{ex}$
Critical magnetic field of a superconductor	$B_c(T) = B_c(0)[1 - (\frac{T}{T_c})^2]$
Rotational energy of a diatomic molecule	$E_r = l(l+1)\frac{\hbar^2}{2I}$

Characteristic rotational energy of a molecule	$E_{0r} = \frac{\hbar^2}{2I}$
Potential energy associated with the exclusion principle	$U_{ex} = \frac{A}{r^n}$
Dissociation energy of a solid	$U_{diss} = \alpha\frac{ke^2}{r_0}(1 - \frac{1}{n})\backslash($
oment of inertia of a diatomic molecule with reduced mass μ	$I = \mu r_0^2$
Electron energy in a metal	$E = \frac{\pi^2\hbar^2}{2mL^2}(n_1^2 + n_2^2 + n_3^2)$
Electron density of states of a metal	$g(E) = \frac{\pi V}{2}(\frac{8m_e}{h^2})^{3/2}E^{1/2}$
Fermi energy	$E_F = \frac{h^2}{8m_e}(\frac{3N}{\pi V})^{2/3}$
Fermi temperature	$T_F = \frac{E_F}{k_B}$
Hall effect	$V_H = uBw$
Current versus bias voltage across *p-n* junction	$I_{net} = I_0(e^{eV_b/k_BT} - 1)$
Current gain	$I_c = \beta I_B$
Selection rule for rotational energy transitions	$\Delta l = \pm 1$
Selection rule for vibrational energy transitions	$\Delta n = \pm 1$

Summary

9.1 Types of Molecular Bonds

- Molecules form by two main types of bonds: the ionic bond and the covalent bond. An ionic bond transfers an electron from one atom to another, and a covalent bond shares the electrons.
- The energy change associated with ionic bonding depends on three main processes: the ionization of an electron from one atom, the acceptance of the electron by the second atom, and the Coulomb attraction of the resulting ions.
- Covalent bonds involve space-symmetric wave functions.
- Atoms use a linear combination of wave functions in bonding with other molecules (hybridization).

9.2 Molecular Spectra

- Molecules possess vibrational and rotational energy.
- Energy differences between adjacent vibrational energy levels are larger than those between rotational energy levels.
- Separation between peaks in an absorption spectrum is inversely related to the moment of inertia.
- Transitions between vibrational and rotational energy levels follow selection rules.

9.3 Bonding in Crystalline Solids

- Packing structures of common ionic salts include FCC and BCC.
- The density of a crystal is inversely related to the equilibrium constant.
- The dissociation energy of a salt is large when the equilibrium separation distance is small.
- The densities and equilibrium radii for common salts (FCC) are nearly the same.

9.4 Free Electron Model of Metals

- Metals conduct electricity, and electricity is composed of large numbers of randomly colliding and approximately free electrons.
- The allowed energy states of an electron are quantized. This quantization appears in the form of very large electron energies, even at $T = 0K$.

- The allowed energies of free electrons in a metal depend on electron mass and on the electron number density of the metal.
- The density of states of an electron in a metal increases with energy, because there are more ways for an electron to fill a high-energy state than a low-energy state.
- Pauli's exclusion principle states that only two electrons (spin up and spin down) can occupy the same energy level. Therefore, in filling these energy levels (lowest to highest at $T = 0K$), the last and largest energy level to be occupied is called the Fermi energy.

9.5 Band Theory of Solids

- The energy levels of an electron in a crystal can be determined by solving Schrödinger's equation for a periodic potential and by studying changes to the electron energy structure as atoms are pushed together from a distance.
- The energy structure of a crystal is characterized by continuous energy bands and energy gaps.
- The ability of a solid to conduct electricity relies on the energy structure of the solid.

9.6 Semiconductors and Doping

- The energy structure of a semiconductor can be altered by substituting one type of atom with another (doping).
- Semiconductor *n*-type doping creates and fills new energy levels just below the conduction band.
- Semiconductor *p*-type doping creates new energy levels just above the valence band.
- The Hall effect can be used to determine charge, drift velocity, and charge carrier number density of a semiconductor.

9.7 Semiconductor Devices

- A diode is produced by an *n*-*p* junction. A diode allows current to move in just one direction. In forward biased configuration of a diode, the current increases exponentially with the voltage.
- A transistor is produced by an *n*-*p*-*n* junction. A transistor is an electric valve that controls the current in a circuit.
- A transistor is a critical component in audio amplifiers, computers, and many other devices.

9.8 Superconductivity

- A superconductor is characterized by two features: the conduction of electrons with zero electrical resistance and the repelling of magnetic field lines.
- A minimum temperature is required for superconductivity to occur.
- A strong magnetic field destroys superconductivity.
- Superconductivity can be explain in terms of Cooper pairs.
