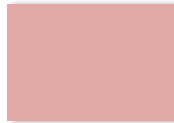


Contents



is not part of exam

Introduction	5
1 Electrons in the periodic crystal - band structure	8
1.1 Symmetries of crystals	8
1.1.1 Space groups of crystals	8
1.1.2 Reciprocal lattice	10
1.2 Bloch's theorem and Bloch functions	11
1.3 Nearly free electron approximation	12
1.4 Tight-binding approximation	14
1.4.1 Linear combination of atomic orbitals - LCAO	16
1.4.2 Band structure of s-orbitals	17
1.4.3 Band structure of p-orbitals	17
1.4.4 Wannier functions	19
1.4.5 Tight binding model in second quantization formulation	21
1.5 Symmetry properties of the band structure	21
1.6 Band-filling and materials properties	24
1.6.1 Electron count and band filling	24
1.6.2 Metals, semiconductors and insulators	25
1.7 Semi-classical description	27
1.7.1 Equations of motion	27
1.7.2 Bloch oscillations	28
1.7.3 Current densities	29
1.8 Appendix: Approximative band structure calculations	30
1.8.1 Pseudo-potential	30
1.8.2 Augmented plane wave	33
2 Semiconductors	35
2.1 The band structure in group IV	36
2.1.1 Crystal and band structure	36
2.2 Elementary excitations	38
2.2.1 Electron-hole excitations	39
2.2.2 Excitons	40
2.2.3 Optical properties	43
2.3 Doping semiconductors	44
2.3.1 Impurity state	44
2.3.2 Carrier concentration	46
2.4 Semiconductor devices	46
2.4.1 pn-contacts	46
2.4.2 Diodes	48
2.4.3 MOSFET	49

3	Metals	51
3.1	The Jellium model	51
3.1.1	Theory of metals - Sommerfeld and Pauli	52
3.1.2	Stability of metals - a Hartree-Fock approach	54
3.2	Charge excitations	57
3.2.1	Dielectric response and Lindhard function	58
3.2.2	Electron-hole excitation	60
3.2.3	Collective excitation - Plasmon	60
3.2.4	Screening	63
3.3	Phonons	66
3.3.1	Vibration of a isotropic continuous medium	66
3.3.2	Phonons in metals	68
3.3.3	Peierls instability in one dimension	69
3.3.4	Dynamics of phonons and the dielectric function	74
4	Itinerant electrons in a magnetic field	76
4.1	The de Haas-van Alphen effect	76
4.1.1	Landau levels	76
4.1.2	Oscillatory behavior of the magnetization	78
4.1.3	Onsager equation	79
4.2	Quantum Hall Effect	80
4.2.1	Hall effect of the two-dimensional electron gas	82
4.2.2	Integer Quantum Hall Effect	83
4.2.3	Fractional Quantum Hall Effect	89
5	Landau's Theory of Fermi Liquids	93
5.1	Lifetime of quasiparticles	93
5.2	Phenomenological Theory of Fermi Liquids	96
5.2.1	Specific heat	98
5.2.2	Compressibility	100
5.2.3	Spin susceptibility	101
5.2.4	Galilei invariance	102
5.2.5	Stability of the Fermi liquid	103
5.3	Microscopic considerations	105
5.3.1	Landau parameters	106
5.3.2	Distribution function	108
5.3.3	Fermi liquid in one dimension?	109
6	Transport properties of metals	111
6.1	Electrical conductivity	111
6.2	Transport equations and relaxation time	113
6.2.1	The Boltzmann equation	113
6.2.2	The Drude form	115
6.2.3	The relaxation time	118
6.3	Impurity scattering	119
6.3.1	Potential scattering	119
6.3.2	Kondo effect	121
6.4	Electron-phonon interaction	122
6.5	Electron-electron scattering	125
6.6	Matthiessen's rule and the Ioffe-Regel limit	127
6.7	General transport coefficients	128
6.7.1	Generalized Boltzmann equation	128
6.7.2	Thermoelectric effect	130

6.8	Anderson localization	133
6.8.1	Landauer Formula for a single impurity	133
6.8.2	Scattering at two impurities	135
6.8.3	Anderson localization	136
7	Magnetism in metals	138
7.1	Stoner instability	139
7.1.1	Stoner model within the mean field approximation	139
7.1.2	Stoner criterion	140
7.1.3	Spin susceptibility for $T > T_C$	143
7.2	General spin susceptibility and magnetic instabilities	144
7.2.1	General dynamic spin susceptibility	144
7.2.2	Instability with finite wave vector \mathbf{Q}	147
7.2.3	Influence of the band structure	148
7.3	Stoner excitations	150
8	Magnetism of localized moments	153
8.1	Mott transition	154
8.1.1	Hubbard model	154
8.1.2	Insulating state	155
8.1.3	The metallic state	156
8.1.4	Fermi liquid properties of the metallic state	158
8.2	The Mott insulator as a quantum spin system	160
8.2.1	The effective Hamiltonian	160
8.2.2	Mean field approximation of the anti-ferromagnet	161
8.3	Collective modes – spin wave excitations	163