

Contents

| | |
|--|----------------|
| <i>Introduction</i> | <i>page ix</i> |
| 1 Localized and itinerant electrons in solids | 1 |
| 1.1 Itinerant electrons, band theory | 1 |
| 1.2 Hubbard model and Mott insulators | 5 |
| 1.3 Magnetism of Mott insulators | 11 |
| 1.4 Interplay of electronic motion and magnetism in Mott insulators | 14 |
| 1.5 Doped Mott insulators | 19 |
| S.1 <i>Summary of Chapter 1</i> | 22 |
| 2 Isolated transition metal ions | 25 |
| 2.1 Elements of atomic physics | 25 |
| 2.2 Hund's rules | 28 |
| 2.3 Spin–orbit interaction | 31 |
| S.2 <i>Summary of Chapter 2</i> | 35 |
| 3 Transition metal ions in crystals | 37 |
| 3.1 Crystal field splitting | 37 |
| 3.2 Jahn–Teller effect for isolated transition metal ions | 57 |
| 3.3 High-spin vs low-spin states | 65 |
| 3.4 Role of spin–orbit coupling | 71 |
| 3.5 Some general principles of the formation of typical crystal structures of transition metal compounds | 78 |
| S.3 <i>Summary of Chapter 3</i> | 91 |
| 4 Mott–Hubbard vs charge-transfer insulators | 94 |
| 4.1 Charge-transfer insulators | 94 |
| 4.2 Exchange interaction in charge-transfer insulators | 103 |
| 4.3 Systems with small or negative charge-transfer gap | 105 |
| 4.4 Zhang–Rice singlets | 108 |
| S.4 <i>Summary of Chapter 4</i> | 118 |

| | | |
|----------|--|-----|
| vi | <i>Contents</i> | |
| 5 | Exchange interaction and magnetic structures | 120 |
| 5.1 | Superexchange in insulators and Goodenough–Kanamori–Anderson rules | 120 |
| 5.2 | Double exchange | 136 |
| 5.3 | Role of spin–orbit interaction: magnetic anisotropy, magnetostriction, and weak ferromagnetism | 142 |
| 5.4 | Systems with unquenched orbital moments | 156 |
| 5.5 | Singlet magnetism | 159 |
| 5.6 | Magnetic ordering in some typical situations | 163 |
| 5.7 | Frustrated magnets | 173 |
| 5.8 | Different magnetic textures | 191 |
| 5.9 | Spin-state transitions | 194 |
| S.5 | <i>Summary of Chapter 5</i> | 198 |
| 6 | Cooperative Jahn–Teller effect and orbital ordering | 204 |
| 6.1 | Cooperative Jahn–Teller effect and orbital ordering in e_g systems | 205 |
| 6.2 | Reduction of dimensionality due to orbital ordering | 221 |
| 6.3 | Orbitals and frustration | 225 |
| 6.4 | Orbital excitations | 227 |
| 6.5 | Orbital effects for t_{2g} -electrons | 228 |
| 6.6 | Quantum effects in orbitals | 231 |
| S.6 | <i>Summary of Chapter 6</i> | 234 |
| 7 | Charge ordering in transition metal compounds | 238 |
| 7.1 | Charge ordering in half-doped systems | 240 |
| 7.2 | Charge ordering away from half-filling | 244 |
| 7.3 | Charge ordering vs charge density waves | 253 |
| 7.4 | Charge ordering in frustrated systems: Fe_3O_4 and similar | 255 |
| 7.5 | Spontaneous charge disproportionation | 259 |
| S.7 | <i>Summary of Chapter 7</i> | 265 |
| 8 | Ferroelectrics, magnetoelectrics, and multiferroics | 269 |
| 8.1 | Different types of ferroelectrics | 269 |
| 8.2 | Magnetoelectric effect | 282 |
| 8.3 | Multiferroics: materials with a unique combination of magnetic and electric properties | 288 |
| 8.4 | “Multiferroic-like” effects in other situations | 303 |
| S.8 | <i>Summary of Chapter 8</i> | 307 |
| 9 | Doping of correlated systems; correlated metals | 310 |
| 9.1 | Nondegenerate Hubbard model at arbitrary band filling | 311 |
| 9.2 | Representative doped transition metal oxides | 319 |
| 9.3 | Doped Mott insulators: ordinary metals? | 331 |

| <i>Contents</i> | vii |
|--|------------|
| 9.4 Magnetic properties of doped strongly correlated systems | 338 |
| 9.5 Other specific phenomena in doped strongly correlated systems | 341 |
| 9.6 Superconductivity in strongly correlated systems | 350 |
| 9.7 Phase separation and inhomogeneous states | 357 |
| 9.8 Films, surfaces, and interfaces | 363 |
| S.9 <i>Summary of Chapter 9</i> | 371 |
| 10 Metal–insulator transitions | 378 |
| 10.1 Different types of metal–insulator transitions | 378 |
| 10.2 Examples of metal–insulator transitions in systems with correlated electrons | 384 |
| 10.3 Theoretical description of Mott transitions | 404 |
| 10.4 Insulator–metal transitions for different electronic configurations | 408 |
| 10.5 Insulator–metal transitions in Mott–Hubbard and charge-transfer insulators | 415 |
| 10.6 Formation of molecular clusters and “partial” Mott transitions | 420 |
| 10.7 Mott transition: a normal phase transition? | 426 |
| S.10 <i>Summary of Chapter 10</i> | 428 |
| 11 Kondo effect, mixed valence, and heavy fermions | 433 |
| 11.1 Basic features of <i>f</i> -electron systems | 433 |
| 11.2 Localized magnetic moments in metals | 436 |
| 11.3 Kondo effect | 438 |
| 11.4 Heavy fermions and mixed valence | 442 |
| S.11 <i>Summary of Chapter 11</i> | 448 |
| Appendix A Some historical notes | 452 |
| A.1 Mott insulators and Mott transitions | 452 |
| A.2 Jahn–Teller effect | 456 |
| A.3 Peierls transition | 456 |
| Appendix B A layman’s guide to second quantization | 459 |
| Appendix C Phase transitions and free energy expansion: Landau theory in a nutshell | 462 |
| C.1 General theory | 462 |
| C.2 Dealing with the Landau free energy functional | 464 |
| C.3 Some examples | 466 |
| <i>References</i> | 469 |
| <i>Index</i> | 481 |