

# Contents

<b>1. A Historical Introduction</b> .....	1
<b>2. Consequences of Fermi Statistics</b> .....	13
2.1 Quantum Statistics of Fermions .....	13
2.2 Free Energy of the Fermi Gas .....	16
<b>3. Paramagnetism</b> .....	25
<b>4. Energy Bands in the Crystal</b> .....	31
<b>5. Experimental Basis of Ferromagnetism</b> .....	37
5.1 Nickel Alloys .....	42
5.2 Iron Alloys .....	43
5.3 Palladium Alloys .....	44
5.4 Iron–Nickel Alloys .....	44
5.5 Effects of Strong Magnetic Fields .....	44
5.6 Effects of High Pressure .....	46
5.7 Effects of Finite Temperature .....	47
5.8 Susceptibility above $T_c$ .....	47
5.8.1 Susceptibility of “Classical Spins” .....	48
5.9 Critical Exponents .....	50
5.10 Neutron Diffraction .....	51
5.11 Further Experimental Methods .....	52
<b>6. Weiss Molecular Field Model</b> .....	53
6.1 Rhodes–Wohlfarth Plot .....	59
<b>7. Heisenberg Model</b> .....	63
7.1 Magnon Operators .....	63
7.2 Heisenberg Hamiltonian in Magnon Variables .....	66
7.3 Magnon Dispersion Relation .....	67
7.3.1 Specific Heat of Magnons .....	69
7.3.2 Ordering Temperature .....	70
7.4 Approximations for the Heisenberg Model .....	71
7.4.1 Ising Model .....	71

7.4.2	XY Model . . . . .	72
7.4.3	Mean Field Solutions of the Heisenberg Model . . . . .	73
<b>8.</b>	<b>Itinerant Electrons at 0 K . . . . .</b>	<b>75</b>
8.1	Pauli Susceptibility of the Itinerant Electrons . . . . .	80
8.2	Susceptibility of the Interacting Itinerant Electrons . . . . .	80
8.3	Non-linear Effects . . . . .	83
8.4	Effects of High Fields at 0 K . . . . .	83
8.4.1	Non-magnetic Limit . . . . .	84
8.4.2	Strong Ferromagnets . . . . .	85
8.4.3	Weak Ferromagnets . . . . .	85
8.4.4	bcc Iron and hcp Cobalt . . . . .	85
8.4.5	Extremely High Fields . . . . .	87
8.4.6	Metamagnetism . . . . .	87
8.5	Susceptibility of Paramagnetic Alloys . . . . .	89
<b>9.</b>	<b>Band Gap Theory of Strong Ferromagnetism . . . . .</b>	<b>93</b>
9.1	Magnetism of Alloys . . . . .	97
<b>10.</b>	<b>Magnetism and the Crystal Structure –</b>	
	<b>Covalent Magnetism . . . . .</b>	<b>101</b>
10.1	Crystal Structure of Mn, Fe, Co, and Ni . . . . .	103
10.2	Covalent Magnetism . . . . .	105
10.3	Covalent Polarization . . . . .	111
<b>11.</b>	<b>Magnetic Impurities in an Electron Gas . . . . .</b>	<b>117</b>
11.1	Impurity Potential in the Jellium . . . . .	117
11.2	Strong Perturbations in the Jellium . . . . .	119
11.3	Layer and Line Defects . . . . .	119
11.4	Magnetic Impurities and Oscillations of the Magnetization . . . . .	120
<b>12.</b>	<b>Itinerant Electrons at <math>T &gt; 0</math>: A Historical Survey . . . . .</b>	<b>123</b>
12.1	Excitations at Low Temperatures . . . . .	127
12.1.1	Strongly Ferromagnetic Systems . . . . .	127
12.1.2	Weakly Ferromagnetic Systems . . . . .	129
12.2	Stoner Theory for a Rectangular Band . . . . .	130
12.3	Weak Excitations with $\zeta \ll 1$ . . . . .	132
<b>13.</b>	<b>Hubbard Model . . . . .</b>	<b>135</b>
13.1	Beyond Hartree–Fock . . . . .	137
<b>14.</b>	<b>Landau Theory for the Stoner Model . . . . .</b>	<b>139</b>
14.1	General Considerations . . . . .	139
14.2	Application to the Stoner Model . . . . .	141
<b>15.</b>	<b>Coupling Between Itinerant and Localized Moments . . . . .</b>	<b>147</b>

**16. Origin of the Molecular Field** . . . . . 151

    16.1 Heitler–London Theory for the Exchange Field . . . . . 151

        16.1.1 Magnetism of a Spin Cluster . . . . . 156

        16.1.2 Spinwaves for Localized Electrons . . . . . 158

**17. Exchange and Correlation in Metals** . . . . . 161

    17.1 Free Electron Gas . . . . . 161

    17.2 Tightly Bound Electrons . . . . . 163

**18. Spin Fluctuations** . . . . . 169

    18.1 Fluctuations of a Thermodynamical Variable . . . . . 170

    18.2 Fluctuations of the Magnetic Moment . . . . . 171

    18.3 Specific Heat of the Spin Fluctuations . . . . . 177

    18.4 Magneto–Volume Coupling . . . . . 177

    18.5 Applications of the Spin Fluctuation Model . . . . . 179

    18.6 Comparing the Spin-Fluctuation and the Stoner-Model . . . . . 182

**19. Single Particle Excitations Versus Spin Waves** . . . . . 185

**20. Landau–Ginzburg Model for Spin Fluctuations** . . . . . 191

**21. Conclusion and Lookout** . . . . . 199

**A. Appendices** . . . . . 203

    A. Convexity Property of the Free Energy . . . . . 203

    B. Derivation of the Coefficient  $a$  in (3.17) . . . . . 203

    C. Quenching of the Orbital Momentum . . . . . 206

    D. Properties of “Classical” Spins . . . . . 208

    E. Derivation of the Constant  $c$  in (8.24) . . . . . 210

    F. Ornstein–Zernicke Extension . . . . . 211

    G. Bogoliubov–Peierls–Feynman Inequality . . . . . 213

    H. The Factor 2 in Equation (7.27) . . . . . 214

    I. Hund’s Rules . . . . . 216

    J. Polynomial Coefficients in (18.12) . . . . . 218

    K. Conversion Between Magnetic Units . . . . . 219

**References** . . . . . 221

**Index** . . . . . 227