

Contents

Introduction	11
Publications	15
Chapter 1	
Making a degenerate Ytterbium gas	17
1.1 Fundamental properties of Ytterbium	18
1.1.1 Ground state collisional properties - SU(N) symmetry	20
1.1.2 Collisions in a $^1S_0 - ^3P_0$ mixture - the exchange interaction .	22
1.2 A quantum degenerate Yb gas	23
1.2.1 Resonant light laser sources	23
1.2.2 Trapping laser sources	26
1.2.3 Cooling procedure	27
1.2.4 Ground-state atoms - Manipulation and detection	31
1.2.5 Metastable 3P_0 atoms - Manipulation and detection	32
1.3 Optical lattices	34
1.3.1 Wannier functions and optical lattice properties	36
1.3.2 Experimental implementation and procedures	37
Chapter 2	
Quantum physics with real and synthetic magnetic fields	41
2.1 Edge currents and edge states in a Hall bar	42
2.1.1 Connections with topology	43
2.1.2 The role of Spin and Spin-orbit coupling	44
2.2 Hall physics on a lattice	46
2.2.1 Magnetic Brillouin zone	46
2.2.2 Tight binding model in presence of a magnetic field	48
2.2.3 Ladder systems	51
2.3 Realization of synthetic magnetic fields with ultracold atoms	54
2.3.1 Gauge fields on a lattice	55
2.3.2 The synthetic dimension approach	56
2.3.3 Synthetic dimension or synthetic Spin-Orbit coupling?	61

Chapter 3

Addressing the $^1S_0\rangle \rightarrow ^3P_0\rangle$ clock transition in ^{173}Yb	63
3.1 The hyperfine mixing mechanism	63
3.2 Magnetic properties of the transition	64
3.3 Spectroscopy of tightly-confined atoms in optical lattices	66
3.4 Coherent addressing of the transition	73
3.5 Fiber-link-enhanced spectroscopy	74

Chapter 4

Quantum simulation with ^{173}Yb atoms exploiting the orbital d.o.f.	79
4.1 Synthetic Spin-Orbit Coupling	80
4.1.1 Implementation of synthetic SOC in optical lattices	80
4.1.2 Spectroscopic signatures of SOC	82
4.1.3 Experimental observation of SOC	83
4.2 Hall physics with a synthetic two-leg ladder	85
4.2.1 Chiral currents	85
4.2.2 Experimental observation of the chiral currents	87
4.2.3 Tuning the synthetic flux	91
4.3 Tuning the interactions in a $^1S_0 - ^3P_0$ mixture	95
4.3.1 Orbital Feshbach resonance mechanism	96
4.3.2 Experimental realization of a strongly interacting ^{173}Yb gas .	98
4.4 Conclusions and Outlooks	100

Chapter 5

Synthetic dimensions with Raman	103
5.1 Nuclear spin states as synthetic dimension of a Hall ribbon	103
5.1.1 Raman couplings in the fundamental level of ^{173}Yb	104
5.1.2 Two- and three-leg ladders	107
5.2 Two-leg ladders	110
5.2.1 Chiral currents	110
5.2.2 Interactions-induced effects on the chiral currents	112
5.3 Three-leg ladders	116
5.3.1 Chiral currents	116
5.3.2 Skipping orbits	117
5.4 Conclusions and outlooks	118

Chapter 6

Clock transition spectroscopy on ^{174}Yb	121
6.1 Magnetic-field-induced spectroscopy	121
6.2 Clock transition spectroscopy	123
6.3 Interaction-peaks resolved spectroscopy	125
6.3.1 Measurement of the e-g scattering length	127
6.3.2 Measurement of the e-e scattering length	129
6.4 Spectroscopy of higher lattice bands	131
6.5 Coherent addressing of the transition	134
6.6 Detection of state-dependent inelastic collisions	136

6.6.1	Inelastic $e - g$ collisions	137
6.6.2	Inelastic $e - e$ collisions	138
6.7	Conclusions	141
Appendix A		
Number of atoms in fermionic wires		143
Appendix B		
Scattering length in the open channel of an orbital Feshbach resonance		145
Bibliography		147