Contents

I Quantum Mechanics **11**

1 Quantum Mechanics History **13**
1.1 Light: wave particle duality . . . 15
1.2 The Black Body . . . 15
1.3 The photoelectric effect . . . 19
1.4 The race for a representation of the atom . . . 20
1.4.1 Spectroscopy . . . 22
1.4.2 The Bohr's Model . . . 24
1.4.3 The frst great debate: Bohr vs Einstein . . . 25
1.4.4 The Sommerfeld's model . . . 25
1.5 The Stern and Gerlach Experiment . . . 26
1.6 Particles can be waves . . . 27
1.7 Schrödinger & Heisenberg . . . 28
1.7.1 Schrödinger . . . 28
1.7.2 Heisenberg . . . 30
1.7.3 The second great debate: Schrödinger vs Heisenberg . 32
1.8 Dirac . . . 32

2 Quantum mechanics tools for computing **35**
2.1 Postulates . . . 36
2.2 Representation of a state in the Bloch sphere . . . 38
2.3 Superposition . . . 38
2.4 Entanglement . . . 39
2.5 Quantum Dirac notation . . . 40

II Quantum Computing **41**

3 Discrete Quantum Computing **43**
3.1 Quantum circuits . . . 44
3.1.1 Single qubit gates . . . 44
3.1.2 Two qubit gates . . . 46
3.1.3 Three qubit gates . . . 47

3.2 Bell states 47

4 Continuous Variable Quantum Computing 49
4.1 Preliminaries 50
4.2 Quantum gates 52
4.2.1 The squeezing gate 52
4.2.2 The displacement gate 52
4.3 Measurment 52
4.3.1 Homodyne detection 52
4.3.2 Heterodyne detection 53
4.3.3 Photon counting number 53
4.4 Gaussian Boson Sampling 53
4.5 Comparison to discrete quantum computing 54

5 Quantum Technologies 55
5.1 Superconducting qubits: the transmon 56
5.1.1 The quantum harmonic oscillator 56
5.1.2 Proof 57
5.1.3 Superconducting circuits: the transmon 59
5.2 Photonics 61
5.2.1 Encoding the qubits 62
5.2.2 Common gates 62
5.2.3 Measurment 63
5.2.4 State preparation 63
5.3 Rydberg atoms 63
5.3.1 Atom cooling 63
5.3.2 Resonant absorbtion 63
5.3.3 Zeeman slower 63
5.4 Technologies comparison 64

6 Pure Quantum Algorithms 67
6.1 Deutsch Josza 68
6.2 Grover 69
6.2.1 Hadamard transform: 69
6.2.2 Oracle 70
6.2.3 Diffusion transform 70
6.2.4 The circuit 71
6.3 Fourier Transform 71
6.3.1 Classical Fourier Transform 71
6.3.2 Quantum Fourier Transform 72

III Quantum Machine Learning 75

7 Variational Quantum Algorithms 77
7.1 Information Encoding . . . 78
7.1.1 QRAM . . . 78
7.1.2 Basis encoding . . . 79
7.1.3 Amplitude encoding . . . 79
7.1.4 Angle encoding . . . 80
7.2 Supervised Learning with Neural Networks . . . 80
7.2.1 Supervised Learning . . . 80
7.2.2 Neural Networks . . . 81
7.3 Variational Quantum Classifiers . . . 82
7.4 Quantum Approximate Optimisation Algorithm . . . 83
7.5 The Optimization Algorithm . . . 83
7.5.1 Nelder Mead . . . 83
7.5.2 Adam . . . 85
7.5.3 Results . . . 85

8 Hyper Parameter Optimisation 89
8.1 Grid Search . . . 90
8.2 Random Search . . . 91
8.3 Bayesian Optimization . . . 91
8.3.1 Gaussian Process . . . 91
8.3.2 Acquisition function . . . 92
8.3.3 Bayesian optimization iterations . . . 92
8.4 Optimization of a simple 1D function . . . 93
8.5 Optimization of the depth of a Variational Classifier . . . 93
8.5.1 Results . . . 94

9 Quantum Reinforcement Learning 95
9.1 Classical Reinforcement Learning . . . 97
9.1.1 The reward . . . 97
9.1.2 The value function . . . 98
9.1.3 Exploration vs. Exploitation . . . 98
9.2 Fitted Q learning . . . 99
9.3 Reinforcement Learning with variational circuits . . . 100
9.4 Examples . . . 100
9.4.1 Mountain Car . . . 101
9.4.2 Lunar Lander . . . 101

IV Quantum Cryptography 103

10 Quantum Cryptography 105
10.1 The Einstein Podolsky Rosen experiment . . . 106

10.2 The Bell's inequalities 107
10.3 Quantum Cheque protocole 109