QUANTUM TECHNOLOGIES

[Enrique Rico, Jorge Casanova]

I. Ultra-cold atoms in optical lattices, Superconducting quantum technologies

Quick Review on Optical lattices potentials. 1D optical lattice: a standing wave. Square and cubic lattices. **Reminder on band theory.** Bloch's theorem and Bloch's waves. Band structure. Wannier functions. Very deep lattices: disconnected harmonic wells. Tight-binding limit. Square and cubic lattices. **Dynamics of a Bose-Einstein condensate in an optical lattice.** Adiabatic loading. Time of flight. Band mapping. **Superfluid-Mott insulator transition.**

Single-electron effects. Plasma oscillation. Quantum LC oscillator: harmonic oscillator. Driven LC oscillator. Coherent states. Coupled LC resonators. Bogoliubov transformation. Modes of transmission lines resonators. Semi-infinite transmission lines, dissipation and input/output theory. **Superconducting qubits.** Quick review of the Josephson effect. The Cooper pair box. Inductively shunted qubits. The 0-pi qubit. **Noise and decoherence.** Rate equation analysis: two-level systems. Noise induced decoherence in qubit circuits. Density matrix description of decoherence. **Circuit QED.**

Bibliography

R. Grimm *et al.*, *Optical dipole traps for neutral atoms,* Adv. At. Mol. Opt. Phys. **42**, 95 (2000).
G. Grynberg and C. Robilliard, *Cold atoms in dissipative optical lattices,* Phys. Rep. **355**, 335 (2001).
I. Bloch *et al.*, *Many-body physics with ultracold gases,* Rev. Mod. Phys. **80**, 885 (2008).
I. Bloch *et al.*, *Quantum simulations with ultracold quantum gases,* Nat. Phys. **8**, 267 (2012).

Makhlin *et al.*, *Quantum-state engineering with Josephson-junction devices*, Rev. Mod. Phys. **73**, 357 (2001).
Blais *et al.*, *Cavity quantum electrodynamics for superconducting electrical circuits: An architecture for quantum computation*, Phys. Rev. A **69**, 062320 (2004).
Clerk *et al.*, *Introduction to quantum noise, measurement and amplification*, Rev. Mod. Phys (2008).
M. Devoret, *Quantum Fluctuations in Electrical Circuits*, Les Houches, Session LXIII 1995, Elsevier 1997.
S. Girvin, *Circuit QED: Superconducting Qubits Coupled to Microwave Photons*.

II. NV centers, Trapped ions

Quantum control. Two-level systems quantum control. The rotating wave approximation. Electron spin resonances. Coherent electron-nucleus couplings. The nitrogen vacancy center in diamond. Quantum sensing and polarization. Dynamical decoupling techniques.

Quantum information processing.
Trapped ion systems. Laser-driven and microwave-driven setups. Controlled entanglement generation in trapped ions for quantum computing.

Bibliography

Malcom H. Levitt, *Spin dynamics: Basics of Nuclear Magnetic Resonance* (Wiley, 2008).
Nitrogen-Vacancy Centers in Diamond: Nanoscale Sensors for Physics and Biology (2014).
Programmable quantum simulations of spin systems with trapped ions (2021).

Assessment by **continuous evaluation** (homework, class activities).