Atoms and photons

Chapter 1

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Introduction

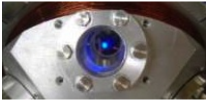
The fundamental importance of the atom-field interaction problem

- Provides all information we have on the universe except gravitational waves, which requires (quantum) optics
- Provides the most precise theory so far: QED (ex: theory/experiment comparisons for α or h/m, search for variation of constants (α, $m_e/m_p \ldots$)
- Provides the best tests of fundamental quantum physics (ex: Bell inequalities, non-locality. . .)

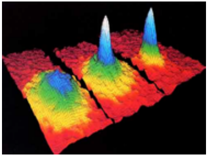
Introduction

The practical importance of the atom-field interaction problem

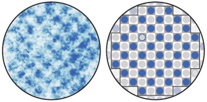
- Lasers
- Atomic clocks
- Cold atoms and BEC
- Quantum simulation
- Entanglement used as a resource (quantum spectroscopy, quantum information. . .)



Sr clock



BEC



AF state with cold fermions

Outline of this course

Chapter 1: Interaction of atoms with a classical field

1. The harmonically bound electron: a surprisingly successful model
2. The Einstein coefficients

Outline of this course

Chapter 2: Quantized atom and classical field

1. Interaction Hamiltonian
2. Free atom and resonant field
3. Relaxing atom and resonant field
4. Optical Bloch equations
5. Applications of the optical Bloch equations

Outline of this course

Chapter 3: Field quantization

1. Field eigenmodes
2. Quantization
3. Field quantum states
4. Field relaxation

Outline of this course

Chapter 4: quantized matter and quantized field

1. Interaction Hamiltonian
2. Spontaneous emission
3. Photodetection
4. The dressed atom
5. Applications of quantum optics (CQED = Cavity Quantum ElectroDynamics, squeezing for precision measurements, quantum simulation...)

Bibliography

- lecture notes by J.-M. Raimond (or C. Fabre in French) and slides handouts.
- C. Cohen-Tannoudji, J. Dupont-Roc and G. Grynberg, *An introduction to quantum electrodynamics* and *Photons and atoms*, Wiley, 1992 (or Fr.)
- C. Cohen-Tannoudji and D. Guéry-Odelin *Advances in atomic physics: an overview*, World Scientific 2012 (or the French version, Hermann 2016)
- W. Schleich, *Quantum optics in phase space*, Wiley 2000
- Vogel, Welsch and Wallentowitz, *Quantum optics an introduction*, Wiley 2001
- P. Meystre and Sargent *Elements of quantum optics*, Springer 1999
- Barnett and Radmore *Methods in theoretical quantum optics*, OUP, 1997
- Scully and Zubairy *Quantum optics*, 1997
- Loudon *Quantum theory of light*, OUP 1983
- S. Haroche and J.-M. Raimond *Exploring the quantum*, OUP 2006

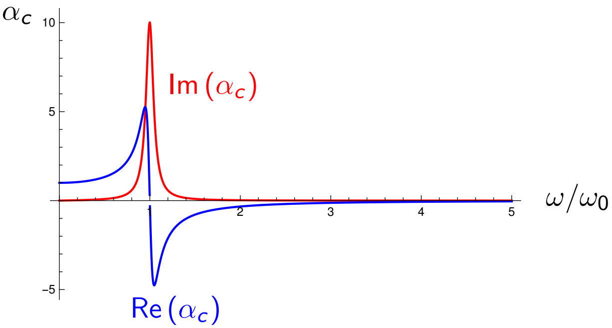
Online lecture notes

- `www-lpl.univ-paris13.fr/bec`, following the menu items Group members / Hélène Perrin
- C. Fabre M2 lecture notes (in French)

A classical model: the harmonically bound electron

Polarizability

$$\alpha_c = \frac{q^2}{m\epsilon_0}\frac{1}{\omega_0^2 - \omega^2 - i\gamma\omega}$$



A classical model: the harmonically bound electron

Diffusion

Cross Section

$$\sigma_c = \frac{1}{6\pi}\left(\frac{\omega}{c}\right)^4 |\alpha_c|^2 = \frac{8\pi}{3} r_e^2 \frac{\omega^4}{(\omega_0^2 - \omega^2)^2 + \gamma^2\omega^2}$$