A Set of Lectures on *Precision Atomic Physics*

Learning objective:
Through this set of lectures, I will try to give an in-depth view on the topics that are of current interests in the field of atomic physics. The style will be **informal** and each of the lectures will be **self-contained**. We will emphasize more on developing an intuition for the physical phenomena that will be discussed.

During this set of lectures, we will have the pleasure of discussing the following topics together:

- Gain geometric intuition on the addition of angular momenta using representation theory. Wigner symbols and build a geometric intuition for situations when more than two or three angular momenta are coupled.
- Interpret various spectroscopic line-shapes with various broadening mechanisms. Understand the role of multi-photon processes in atomic spectroscopy. Various higher-order multipole transitions (quadruple and octuple). Learn how to beat the natural-linewidth-limit in spectroscopy.
- Calculate various dynamic (scalar, vector, tensor) polarizabilities and hyperpolarizability from first principle; analyse and appreciate the exquisite piece of art that an atomic clock is by discussing the long list of systematics involved in operating an atomic clock.

Prerequisites: Non-relativistic Quantum Mechanics and Classical electrodynamics.

References: As suggested reading, various book-chapters and papers will be suggested at the end of each lecture.

Target Audience: Graduate Students, Part III students, and anyone with interest in Atomic Physics.

Schedule:

Lecture	Date and Time
Lec. 1: Coupling Several Angular Momenta	Oct. 17th, Thurs. 4:00-5:30 PM at Ryle Seminar Room (Rutherford)
Lec. 2: An Experimentalist's view on Wigner-Eckart Theorem and Representation Theory	Oct. 24th, Thurs. 4:00-5:30 PM at Small LT
Lec. 3: Spectroscopy Done Right!	Oct. 31st, Thurs. 4:00-5:30 PM at Small LT
Lec. 4: Dipole, Quadruple & Octuple Transitions	Nov. 7th, Thurs. 4:00-5:30 PM at Small LT
Lec. 5: Scalar, Vector, and Tensor Polarizability of Atoms/Ions	Nov. 14th, Thurs. 4:00-5:30 PM at Small LT
Lec. 6: The Art and Craft of an Atomic Clock	Nov. 21st, Thurs. 4:00-5:30 PM at Small LT

Lecture Plan:

Module 1: Geometry of Angular Momentum Coupling

Lecture – 1: Addition of two, three, four, … angular momenta

Review: Angular momentum algebra & Representation theory

Main Topic: Coupling several angular momenta and how one can 'see' them in a unified way from the perspective of representation theory. Special attention will be given to the geometric intuition rather than the long formulas since now-a-days one can just calculate each of the coupling coefficients (3j, 6j, and 9j symbols) with a single command in Mathematica.

Lecture – 2: Wigner, his symbols, and his theorem with Eckart: A geometric perspective

Review: Representation theory

Main Topic: Calculation of Wigner symbols. The 'magic' associated with Wigner-Eckart theorem will be unraveled with practical examples.

Module 2: Spectroscopy

Lecture – 3: Spectroscopy Done Right!

Review: Wigner-Weisskopf theory; Atom-light interaction.

Main Topic: Spectroscopic tools to probe the atomic lines, how to interpret the line-shape observed in an experiment. Various homogeneous and inhomogeneous broadening mechanisms in spectroscopy. Techniques to overcome the natural-linewidth-barrier using spectroscopy.

Lecture – 4: Non-linear atom-light interaction: An in-depth view

Review: Hyperfine Interaction

Main Topic: Non-linear interaction of an atom with light, multi-photon excitation (mainly, two- and three-photon excitations). Higher order multipole transitions (E1, E2, E3 & M1, M2). Selection rules of the above-mentioned transitions. Hyperfine mixing and clock transitions. Spectroscopy on an optical clock transition.

Module 3: Applications

Lecture – 5: Dynamic polarizability and hyperpolarizability: A computational point of view

Review: Perturbation theory and Stark shift.

Main Topic: Calculation of the typical dynamic polarizabilities (i.e., the scalar, vector, and tensor light-shifts) using second-order perturbation theory. Hyperpolarizability and its relevance in precision measurement. Mathematica and MATLAB codes will be used (and distributed) for parts of this lecture.

Lecture – 6: The Art and Craft of an Atomic Clock

Review: An atomic clock and its operation.

Main Topic: Almost all the topics covered will be put together here, and we will see how they play crucial roles in the operation of an optical clock. The long list of systematics that one needs to understand and have exquisite control over, to operate a neutral-atom optical clock, with a systematic uncertainty of order 10^{-19} (and what that means). Moreover, some major challenges that need to be addressed in the field will be mentioned.