Antonin Coutant
antonin.coutant@aei.mpg.de

What the hell is Quantum Mechanics ?

The global aim of this course is to familiarize the students with some fundamental concepts of quantum mechanics (Heisenberg uncertainty, wave-particle duality, superposition principle, non-commuting variable). We will try to be as less technical as possible, and focus instead on the physical issues. All mathematical tools will be introduced after physically motivating their relevance. Depending on time and ease of the students, when describing various models (Harmonic oscillator, two level systems, Bohr atom), we will discuss physical effects as an opportunity to introduce the main approximation schemes (Stationary perturbation theory, Variational principle, Time-dependent perturbation theory).

Plan

1. Historical introduction
   (a) Failure of classical physics
   We present briefly some historical experiments, the Planck law of radiation, the Frank and Hertz experiment, the Atom's spectra, to show the inadequacy of classical concepts.
   (b) First quantum principles
   We introduce a couple of fundamental quantum notions, that was historically proposed to explain the preceding experiments: quantization of light and de-Broglie relations.
2. Schrödinger Equation
   (a) Free particle
   Starting from de-Broglie relations, we build the Schrödinger equation of a free particle. We solve it and discuss fundamental notions, such as superposition principle, group velocity, spread of the wave packet, Fourier transform and Heisenberg uncertainty relations.
   (b) Tunnel effect
   We present the Scrödinger equation in an external potential. A toy model for the tunnel effect is studied as a first physical consequence.
   (c) Harmonic oscillator
   We discuss the model of a one-dimensional Harmonic Oscillator, and derive its spectrum algebraically. This opens the gate to the modern formalism of quantum mechanics. We also (briefly) present how this can be applied to the Electromagnetic field.
3. Quantum mechanics à la Dirac
   (a) Postulates of Quantum Mechanics
   We introduce the basic notions of the modern formalism. Hilbert space, operators, bra, ket and the Born rule.

(b) Two level systems

We exploit two dimensional Hilbert space to model the NH_3 molecule.

(c) The spin

We introduce the electronic spin and discuss some physical consequences.

(d) Angular momentum, and an introduction to spectroscopy

We present the quantum notion of angular momentum. Without presenting a full resolution, we discuss the hydrogen atom and the structure of its spectrum.

4. Modern Quantum Physics

(a) The tight binding model: road to superconductivity

We present a simple model of electronic gaps, and discuss its relevance in modern condensed matter physics.

(b) Entanglement and the gate to quantum logic

We discuss the notion of entangled states. We discuss its realization in fundamental experiment (e.g., Haroche's experiments) and its consequences for quantum computing.

(c) Measurement theory

We carefully discuss a Young interference experiment, and the effect of the measurement apparatus. This leads to the modern theory of decoherence, and its numerous implications.

References

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[2] J. J. Sakurai "Modern Quantum Mechanics", Addison Wesley (1993) *(English)*

[3] K. Gottfried and T. Yan "Quantum Mechanics: Fundamentals", Springer, 2nd ed. (2003) *(English)*

[4] U. Leonhardt "Essential quantum optics: from quantum measurements to Black Holes" Cambridge University Press (2010) *(English)*