Theoretical Physics 2

Topics in Quantum Theory

Lent Term 2025

Nigel Cooper (Lectures) and Gaurav Chaudhary (Examples)

Lectures: Mon, Wed, Fri, 2-3pm starting 27 Jan *[break for week of 17 Feb]*

[27, 29, 31 Jan; 3, 5, 7 Feb; 10, 12, 14 Feb; 24, 26, 28 Feb; 3, 5, 7 Mar; 10 Mar]

Examples Classes: Tuesdays, 2-4pm, 4 Feb, 18 Feb, 4 Mar, 18 Mar

Examination: First week of Easter term

Notes, summaries, past papers + some solutions:

`https://www.tcm.phy.cam.ac.uk/~nrc25/tp2-new/index.html`

Panopto recordings on the Moodle page

`https://www.vle.cam.ac.uk/course/view.php?id=255504`

Synopsis

- **Quantum Dynamics:** Schrödinger, Heisenberg, interaction picture. The evolution operator and time ordering. Driven oscillator. Coherent states. A spin-1/2 in a field. Rabi oscillations. The adiabatic approximation. Landau-Zener transitions. Berry's phase.
- **Introduction to Path Integrals:** The propagator and the Green's function: free particle and harmonic oscillator. The method of stationary phase, the JWKB method and the semiclassical limit.
- **Scattering Theory:** Scattering in one dimension. Scattering amplitude and cross section. Optical theorem. Lippmann-Schwinger equation. Born series. Partial wave analysis. Bound states.
- **Identical Particles in Quantum Mechanics:** Second quantisation for bosons and fermions. Single-particle density matrix and density-density correlation function. Bose-Hubbard model. Bogoliubov transformation. Interference of condensates.
- **Density Matrices:** Density matrix and its properties. Applications in statistical mechanics. Density operator for subsystems and entanglement. Quantum damping.
- ***Lie Groups:*** *Symmetries are groups. Lie algebra of generators. Rotations as Lie group. Representations of SO(3), SU(2), Lorentz group SO(1,3) and SL(2,C).*
- ***Relativistic Quantum Physics:*** *Klein-Gordon equation. Antiparticles. Spinors and the Dirac equation. Relativistic covariance.*

[*Topics in Italics not for examination*]

Handout

Self-contained exposition of all necessary material.

Problems for the examples class are integrated within the Handout.

Lectures: largely handwritten, cover essential points + examples.

Recommendation: Put handout aside & take separate set of notes

Books

- JJ Sakurai, *Modern Quantum Mechanics*, 2nd edition, Addison-Wesley, 1994.
- F Schwabl, *Quantum Mechanics*, 4th edition, Springer 2007, and F Schwabl, *Advanced Quantum Mechanics*, 4th edition, Springer 2008.
- R Shankar *Principles of Quantum Mechanics*, 2nd edition, Springer 1994.
- G Baym, *Lectures on Quantum Mechanics*, W. A. Benjamin, 1969.
- M Stone & P Goldbart, *Mathematics for Physicists: A guided tour for graduate students* (CUP, 2009).

Lecture 1 – Quantum Dynamics

- Overview of Time Evolution
- Driven Oscillator & Coherent States

Summary of Lecture 1

- Schrödinger Picture $$i\hbar\frac{\mathrm{d}}{\mathrm{d}t}|\Psi(t)\rangle = H(t)|\Psi(t)\rangle$$

$$|\Psi(t)\rangle = U(t)|\Psi(0)\rangle \qquad U(t) = \mathscr{T}\mathrm{e}^{-\frac{\mathrm{i}}{\hbar}\int_0^t H(t')\mathrm{d}t'}$$

- Heisenberg Picture state, $|\Psi(0)\rangle$, time-independent

$$\mathcal{O}_{\mathrm{H}}(t) = U^{\dagger}(t)\mathcal{O}U(t) \qquad \frac{\mathrm{d}}{\mathrm{d}t}\mathcal{O}_{\mathrm{H}}(t) = \frac{\mathrm{i}}{\hbar}\left[H_{\mathrm{H}}(t), \mathcal{O}_{\mathrm{H}}(t)\right]$$

- Application to driven SHO

Next Lecture (2)

- Spin-1/2 in external field
- Adiabatic approximation