Quantum Optics, IPT5340

Time: T7T8F7F8 (15:30-17:20, Tuesday, and 16:00-17:20, Friday), at Room 208, Delta Hall

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Syllabus:

Date	Topic	To Know	To Think
week 1 (3/2, 3/9)	Quantum SHO	☐ Fock states, $\|n\rangle$ ☐ creation operator, $\hat{a}^\dagger$	☐ single-photon detection ☐ Wave-Particle Duality ☐ photon-number resolving ☐
		☐ Vacuum state ☐ Quantum Fluctuations	☐ Shot Noise Limit ☐ Casimir Force ☐
week 2 (3/12, 3/16, ~~3/19~~)	Quantum Mechanics	☐ Schrödinger picture ☐ Heisenberg picture ☐ Interaction picture	☐ Uncertainty Relation ☐ Probability Interpretation ☐ Measurement problem ☐ Non-locality ☐ Macrorealism ☐

- What is the *essence* of quantum mechanics (QM)?
  1. The Axiom of QM.
  2. Superposition.
  3. Purity of a quantum state.
  4. Entanglement.
  5. Measurement.
- Test of Quantum Mechanics by Optics.
  - Are we satisfied with the axioms of quantum mechanics (QM)?
  - Why QM can not be seen in daily life?
  - Do we need to extend and/or modify QM?
  - What is the link between QM and Gravity?

- **Take-home Messages:**
  1. *"Those who are not shocked when they first come across quantum theory cannot possibly have understood it."* Niels Bohr, in a 1952 conversation with Heisenberg and Pauli in Copenhagen
  2. Vacuum state $|0\rangle$
  3. *"You can't blame most physicists for following this '***shut up and calculate***' ethos because it has led to tremendous developments in nuclear physics, atomic physics, solid state physics and particle physics.* Jean Bricmont, quoted in Zeeya Merali, "What is Really Real?", Nature (2015).
  4. Thinking about foundations pays off in the long run. David Mermin once summarized a popular attitude towards quantum theory as *"Shut up and calculate!"*. We suggest an alternative slogan: *"Shut up and contemplate!"* Lucien Hardy and Robert Spekkens, "Why Physics Needs Quantum Foundations" (2010)
  5. Pure and Mixed states
  6. Density Operator

- **From Scratch !!**
- Expectation value: For the quantum mechanical description, if we know that the system is in state $|\psi\rangle$, then an operator $\hat{O}$ has the expectation value,

$$\langle \hat{O} \rangle_{\rm qm} = \langle \psi | \hat{O} | \psi \rangle.$$

- Density Matrix: But, typically, we do not know that we are in state $|\psi\rangle$, then an *ensemble average* must be performed,

$$\langle \langle \hat{O} \rangle_{\rm qm} \rangle_{\rm ensemble} = \sum_n P_n \langle \psi_n | \hat{O} | \psi_n \rangle,$$

  where the P_n is the probability of being in the state $|\psi_n\rangle$ and we introduce a density operator,

$$\hat{\rho} = \sum_n P_n |\psi_n\rangle\langle\psi_n|.$$

  The expectation value of any operator $\hat{O}$ is given by,

$$\langle \hat{O} \rangle_{\rm qm} = {\rm Tr}[\hat{\rho}\,\hat{O}],$$

  where Tr stands for trace.
- Schrödinger equation:
- Heisenberg equation:

- Uncertainty Relation:
- Interaction Picture:

- Positive-semi-definite of Density Matrix:
- Von Neumann entropy of quantum states:
- Purity of quantum states:
- Schmidt decomposition:

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