Quantum Optics, IPT5340

Time: RnF8F9 (12:10-13:00, Thursday and 16:30-18:00, Friday), at Room 201, Delta Hall

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(Dated: Spring, 2023)

- References:
  1. **Text Book**: Pierre Meystre, *"Quantum Optics,"* Springer (2021).
  2. P. W. Milonni, *"An Introduction to Quantum Optics and Quantum Fluctuations,"* Oxford (2019).
  3. G. S. Agarwal, *"Quantum Optics,"* Cambridge University (2013).
  4. U. Leonhardt, *"Essential Quantum Optics,"* Cambridge (2010).
  5. G. Grynberg, A. Aspect, and C. Fabre, *"Introduction to Quantum Optics,"* Cambridge (2010).
  6. D. F. Walls and G. J. Milburn, *"Quantum Optics,"* 2nd Ed. Springer (2008).
  7. M. Fox, *"Quantum Optics, an introduction,"* Oxford (2006).
  8. C. C. Gerry and P. L. Knight, *"Introductory Quantum Optics,"* Cambridge (2005).
  9. Y. Yamamoto and A. Imamoglu, *"Mesoscopic Quantum Optics,"* Wiley (1999).
  10. M. O. Scully, and M. S Zubairy, *"Quantum Optics,"* Cambridge (1997).
- Teaching Method:
  in-class lectures with discussions and assignments.
- **Expected Outputs:**
  - Quantum properties of Electromagnetic Fields;
  - Non-classical light and its generation, measurement, and applications;
  - Interaction between photon-atoms;
  - Test of Quantum Mechanics by Optics;
  - Applications in Quantum Metrology, Quantum Communication, and Quantum Computing.
- **Syllabus:**
  - **Introduction to Quantum Optics**
  - Quantum Theory
  - **Quantum Field theory of Light:**
    1. Number states and Coherent States,
    2. Squeezed States and Phase Space,
  - **Simple Optical Instruments:**
    1. Beam Splitter,
    2. Detection.
  - **Photon-atom interaction:**
    1. Rabi oscillation,
    2. Jaynes-Cummings Hamiltonian,
    3. Dicke model,
    4. Cavity-Quantum Electro-Dynamics (Cavity-QED),
    5. Electromagnetically Induced Transparency (EIT),
    6. Optical Parametric Oscillator (OPO),
    7. Dissipative Systems.
  - **Applications of Quantum Optics:**
    1. Entanglement,
    2. Horizons,
    3. Gravitational Wave Detectors,
    4. Test of Quantum Mechanics,
    5. Quantum Information Processing.

- **Evaluation:**
  - Homework, 40%;
  - Midterm, 30%;
  - Final Exam, 30%;
- **Class suspended (to be confirmed):**
  ~~2/21~~, ~~2/24~~: RK to NAOJ
- **Online Materials:**
  - https://eeclass.nthu.edu.tw
  - Slack Channel: https://quantumoptics-zgq1695.slack.com/archives/C032Y1UABEW
  - RKLee's web site: http://mx.nthu.edu.tw/ rklee/index.html
- **Office hours:**
  - 1:00-3:30 PM, Wednesday and Friday, at R911, Delta Hall
  - Or by appointment.
- **TA:**
  Mr. Hauser (Zi-Hau Shi), PhD Student, IPT/NTHU
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- **Questions:**
  1. What is the nature of light?
     - As a wave, do you known how to measure/estimate phase, interference?
     - As a particle, do you know how to characterize the pureness of a single photon?
     - As a quantum state, how to distinguish the quantum and classical nature of light?
     - For bipartite, how to know the identity, correlation, entanglement between them?
  2. 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?
  3. Applications of Quantum Optics.
     - Quantum Information Processing.
     - Interferometry: Gravitational Wave Detectors.

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Syllabus:

Date	Topic	To Know	To Think
Feb. 16th	Introduction	Scope	☐ Your and My Expectations. ☐ What is the nature of light? ☐ Anything else ?
Feb. 17th (Fridayt)	Simple Harmonic Oscillator (SHO)	☐ classical trajectory ☐ analogue to EM waves	☐ Bohmian mechanics ☐ Inverted SHO ☐
~~2/22-2/24~~,			
preview	Quantum Mechanics	☐ Schrödinger picture ☐ Heisenberg picture ☐ Interaction picture	☐ Uncertainty Relation ☐ Probability Interpretation ☐ Measurement problem ☐ Non-locality ☐ Macrorealism ☐
week 2	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 3	Coherent states, $\|\alpha\rangle$	☐ photon statistics ☐ bunching ☐ Correlation function	☐ Minimum Uncertainty States ☐ Classical-Quantum boundary ☐
~~3/15-3/17~~,			
week 4	Squeezed states	☐ $\|\xi\rangle$ ☐ OPO	☐ Continuous Variables ☐
week 5	Two-mode Squeezed states	☐ EPR pair ☐ Cat states ☐ non-Gaussian states	☐ Quantum Discord ☐ Entanglement ☐ Steering ☐ Bell's inequality ☐
week 6	Optical devices	☐ Beam splitter ☐ Mach-Zehnder interferometer	☐ linear optics ☐
week 6	Interferometry	☐ Young's Interferometry, $g^{(1)}$ ☐ HBT-Interferometry, $g^{(2)}$	☐ Quantum Phase Estimation ☐ Quantum Fisher Information ☐
April 14th	Midterm		
week 8	Quantum Phase Space	☐ Wigner function	☐ Quasi-probability ☐ Quantum State Tomography ☐

Syllabus:

Date	Topic	To Know	To Think
week 9-10	Photon-Atom Interactions	☐ Einstein's AB coefficients ☐ Classical model ☐ Semi-Classical	☐ Rabi-frequency ☐ Wavefunction Revival ☐
weeks 10-11	Full Quantum model	☐ Jaynes-Cummings ☐ Dicke model ☐ Cavity-QED	☐ Vacuum Rabi oscillation ☐ Collective interaction ☐ Circuit-QED ☐
week 11-12	Open systems	☐ Weisskopf-Wigner approximation ☐ Born-Markovian approximation ☐ Master equation ☐ Lindblad equation	☐ dissipation-fluctuation theorem ☐ non-Markovian ☐
week 13-14	Selected Applications of QO	☐ Quantum Sensor ☐ Test of Quantum Mechanics ☐ Quantum Communication ☐ Quantum Computing ☐	☐ Gravitational Wave Detectors ☐ Quantum Zeno effect ☐ Quantum Key Distribution ☐ Quantum Photonic Circuit ☐
June 14th	Fina Examl		
Related Courses	☐ Quantum Mechanics ☐ Atomic Physics ☐ Nonlinear Optics ☐ Quantum Information ☐ Quantum Computing ☐ Quantum Communication ☐ Quantum Simulation ☐	☐ AMO-Physics ☐ QIS ☐ IBM Qiskit ☐ Quantum Machine Learning ☐	
Open Questions	☐ Quantum in Macroscopic ☐ Extended QM ☐ Quantum Gravity ☐		
May 29-30	KIW	KAGRA International Workshop	NTHU
June 19-22	EACN	Entanglement-Assisted Communication Network	IAMS/AS
June 26-30	ICSSUR	International Conference on Squeezed States and Uncertainty Relations	IAMS/AS
Late August	AMO Summer School		