Quantum Optics, IPT5340

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

Ray-Kuang Lee[1]

[1] *Room 911, Delta Hall, National Tsing Hua University, Hsinchu, Taiwan.*
*Tel: +886-3-5742439; E-mail: rklee@ee.nthu.edu.tw**

(Dated: Spring, 2021)

Syllabus:

Date	Topic	To Know	To Think
weeks 9-10 (5/18, 5/21, 5/25, 5/28)	Full Quantum model	☐ Jaynes-Cummings ☐ Dicke model ☐ Cavity-QED	☐ Vacuum Rabi oscillation ☐ Collective interaction ☐ Circuit-QED ☐
week 11-12 (6/1, 6/4, 6/8, 6/11)	Open systems	☐ Weisskopf-Wigner approximation ☐ Born-Markovian approximation ☐ Master equation ☐ Lindblad equation	☐ dissipation-fluctuation theorem ☐ non-Markovian ☐
week 13-14 (6/15, 6/18)	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 ☐

- **Take-home Messages:**
  1. Dissipation-Fluctuation theorem
  2. Input-output formulation of optical cavity
  3. Cavity-QED
  4. Mollow's triplet in the fluorescence spectrum
  5. Master equation
  6. Born-Markovian approximation

- **Assignment**
  Deadline: 4:00PM, Tuesday, June 15th

- (1) Below the threshold, the Hamiltonian for an Optical Parametric Oscillator (OPO) is

$$\hat{H}_S = \hbar\omega_0 \hat{a}^\dagger \hat{a} + \frac{i\hbar}{2}(\epsilon \hat{a}^{\dagger 2} - \epsilon^* \hat{a}^2). \tag{1}$$

Show that the Fourier components for the output field is

$$\hat{a}_O(\omega) = \frac{1}{([\frac{\gamma}{2} - i(\omega-\omega_0)]^2 - |\epsilon|^2}\{[(\frac{\gamma}{2})^2 + (\omega-\omega_0)^2 + |\epsilon|^2]\hat{a}_I(\omega) + \epsilon\gamma\hat{a}_I^\dagger(-\omega)\}, \tag{2}$$

If we define the output quadrature phase operator:

$$\begin{aligned} \hat{X}_1^O(\omega) &= \hat{a}_O(\omega) + \hat{a}_O^\dagger(-\omega), \\ \hat{X}_2^O(-\omega) &= -i[\hat{a}_O(\omega) - \hat{a}_O^\dagger(-\omega)]. \end{aligned}$$

show that the two output spectra are

$$S_1^O(\omega) \propto 1 + \langle \hat{X}_1^O(\omega), \hat{X}_1^O(\omega')\rangle = 1 + \frac{2\gamma|\epsilon|}{(\frac{\gamma}{2} - |\epsilon|)^2 + (\omega-\omega_0)^2}\,\delta(\omega+\omega'), \tag{3}$$

$$S_2^O(\omega) \propto 1 + \langle \hat{X}_2^O(\omega), \hat{X}_2^O(\omega')\rangle = 1 - \frac{2\gamma|\epsilon|}{(\frac{\gamma}{2} + |\epsilon|)^2 + (\omega-\omega_0)^2}\,\delta(\omega+\omega'), \tag{4}$$

where the correlation function is defined as

$$\langle U, V\rangle \equiv \langle UV\rangle - \langle U\rangle\langle V\rangle.$$

Then, a *squeezing* occurs in the X_2 quadrature, for $S_2^O(\omega) < 1$.

*Electronic address: `rklee@ee.nthu.edu.tw`