Dynamics of Quantum Coherence and Fisher Information of a Three-Level Atom in Photonic Crystals

Ghafar Ahmadi

Institute for Advanced Studies in Basic Sciences

Supervisors: Dr. Shahpoor Saeidian
Dr. Ghasem Naeimi

g.ahmadi418@gmail.com

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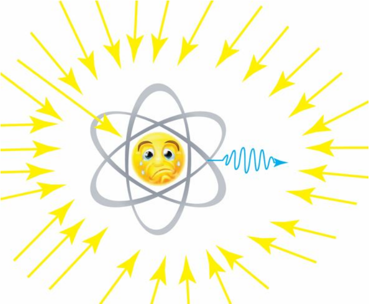
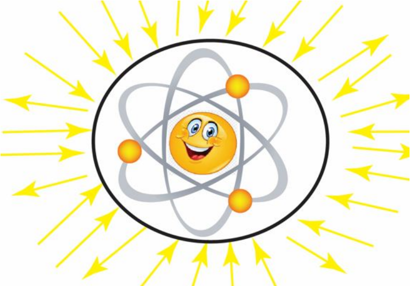
- Qunatum Entanglement.
- Quantum Superposition.



Atom in the free space



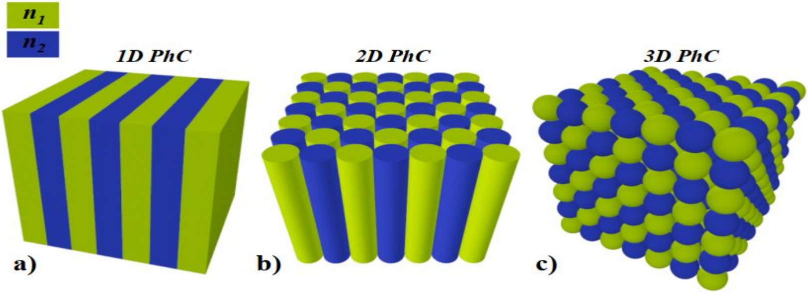
Atom in a photonic crystals

Outline

1. Photonic Crystals
2. Model System and Methods
3. Dynamics of Quantum Coherence
4. Dynmaics of Quantum Fisher Information

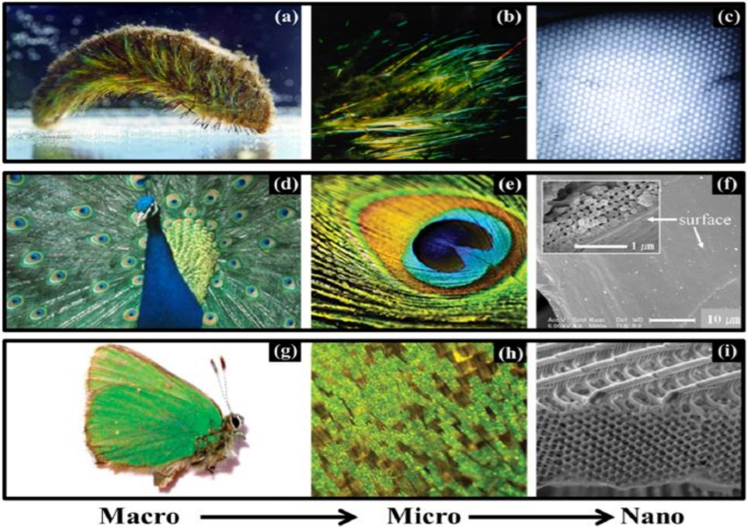
What are Photonic Crystals ?

Natural or engineered **periodic dielectric** structures



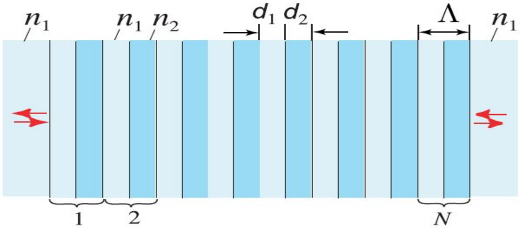
M.A. Butt, S.N. Khonina, Optics & Laser Technology 142 (2021) 107265.

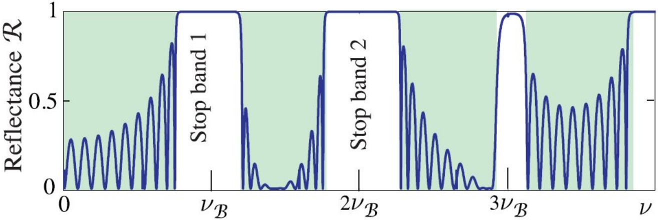
Photonic Crystals in Nature



Lu, Tao, et al." Nanotechnology 27.12 (2016): 122001.

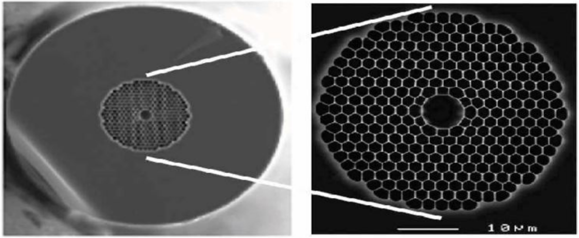
Photonic Band Gap (PBG)



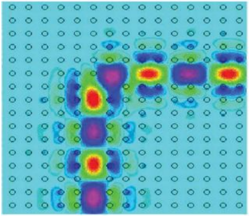


Saleh, Bahaa EA, Fundamentals of photonics. john Wiley & sons, 2019.

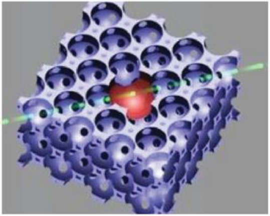
PBG Matrial Applicaltions



(a) PBG Fiber



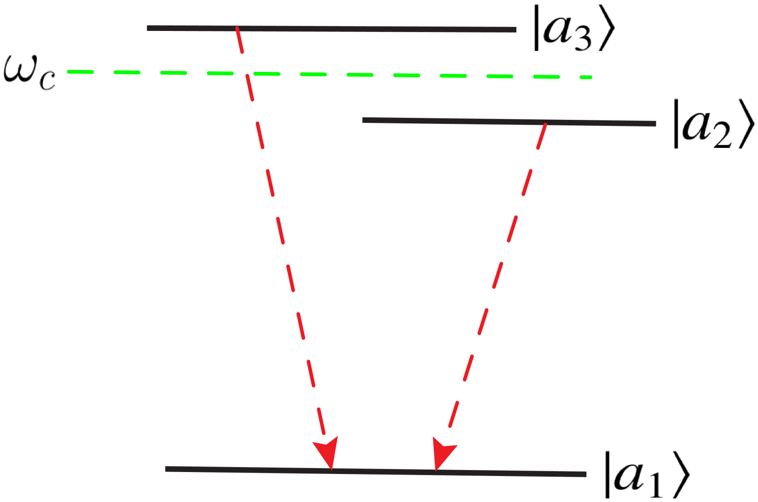
(b) PBG Waveguide



(c) Localization of Light

http://ab-initio.mit.edu/photons/tutorial/L2-defect

Model System: A V-Type Three Level Atom



Previous Works

PHYSICAL REVIEW A, VOLUME 61, 043809

Spontaneous-emission enhancement and population oscillation in photonic crystals via quantum interference

Yaping Yang[1,2] and Shi-yao Zhu[2,3]
[1]*Department of Physics, Tongji University, Shanghai 200092, China*
[2]*Department of Physics, Hongkong Baptist University, Hong Kong*
[3]*Department of Physics, Texas A&M University, College Station, Texas 77863*
(Received 10 March 1999; published 16 March 2000)

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Journal of the Optical Society of America B

OPTICAL PHYSICS

Effects of engineering initial states and quantum interference near the edge of a photonic bandgap on the entanglement

Haozhen Li, Shuangyuan Xie,* Jingping Xu, and Yaping Yang

Quantum enhancement of qutrit dynamics through driving field and photonic band-gap crystal

Negar Nikdel Yousefi,[1] Ali Mortezapour,[1,*] Ghasem Naeimi,[2,†] Farzam Nosrati,[3,4] Aref Pariz,[5] and Rosario Lo Franco[3,‡]
[1]*Department of Physics, University of Guilan, P. O. Box 41335–1914, Rasht, Iran*
[2]*Department of Physics, Qazvin Branch, Islamic Azad University, Qazvin, Iran*
[3]*Dipartimento di Ingegneria, Università di Palermo, Viale delle Scienze, 90128 Palermo, Italy*
[4]*INRS-EMT, 1650 Boulevard Lionel-Boulet, Varennes, Québec J3X 1S2, Canada*
[5]*Department of Biology, University of Ottawa, ON, Canada*
(Dated: January 27, 2022)

The Hamiltonian

The **Hamiltonian** of the system is composed of the following terms.

$$H = H_0 + H_{Int}$$

$$H_0 = \hbar\omega_3 |a_3\rangle\langle a_3| + \hbar\omega_2 |a_2\rangle\langle a_2| + \hbar\omega_1 |a_1\rangle\langle a_1| + \sum_{\lambda=1}^{2} \sum_{k} \hbar\omega_k a^{\dagger}_{k\lambda} \hat{a}_{\lambda k}$$

$$H_{Int} = i\hbar \sum_{k\lambda} [g^{13}_{k\lambda}(a^{\dagger}_{k\lambda}\sigma_{13} - \sigma_{31}a_{k\lambda}) + g^{21}_{k\lambda}(a^{\dagger}_{k\lambda}\sigma_{12} - \sigma_{21}a_{k\lambda})]$$

$$\sigma_{ij} = |a_i\rangle\langle a_j|$$

Some Definations

1. Coupling constant.

$$g_{k\lambda}^{ij} = \frac{\omega_{ij} d_{ij}}{\hbar} \left(\frac{\hbar}{2\epsilon_0 \omega_k V} \right)^{\frac{1}{2}} \hat{e}_{k\lambda}.\hat{d}_{ij}$$

2. The initial state of the systems is prepared by a pulse laser beam as superposition of the exited states.

$$|\psi(0)\rangle = \cos(\theta/2)\,|a_3, 0\rangle + e^{i\phi} \sin(\theta/2)\,|a_2, 0\rangle$$

3. The parameter θ controls the superpositions.

Some Definations

1. The state of the system in time t

$$|\psi(t)\rangle = A_3(t)e^{-i\omega_3 t}|a_3,0\rangle + A_2(t)e^{-i\omega_2 t}|a_2,0\rangle + \sum_{k\lambda} B_{k\lambda}(t)e^{-i\omega_k t}|a_1,1_{k\lambda}\rangle$$

2. With substituting the Hamiltonian and the states in the Schrodinger equation

$$i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle = \hat{H}|\psi(t)\rangle$$

Reduced Density Matrix

$$\rho_a(t) = Tr_f\{\rho_{af}(t)\} = \begin{pmatrix} \rho_{33} & \rho_{32} & 0 \\ \rho_{23} & \rho_{22} & 0 \\ 0 & 0 & \rho_{11} \end{pmatrix}$$

where

$$\rho_{33} = |A_3(t)|^2$$

$$\rho_{22} = |A_2(t)|^2$$

$$\rho_{32} = \rho_{23}^* = A_3(t)A_2(t)^*$$

Quatnum Coherence

1. Quantum coherence represents the coherent superposition of distinct physical states.

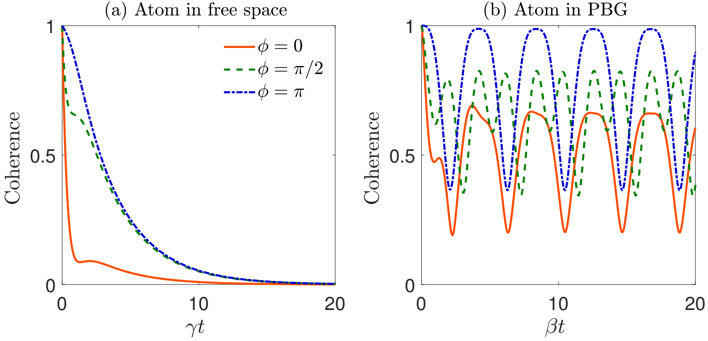
2. It is a resource for quantum information processing.

3. Its a fundamental distinction between quantum and classical states.

Streltsov, A., Adesso, G., & Plenio, M. B. Colloquium: Quantum coherence as a resource. Reviews of Modern Physics, (2017).

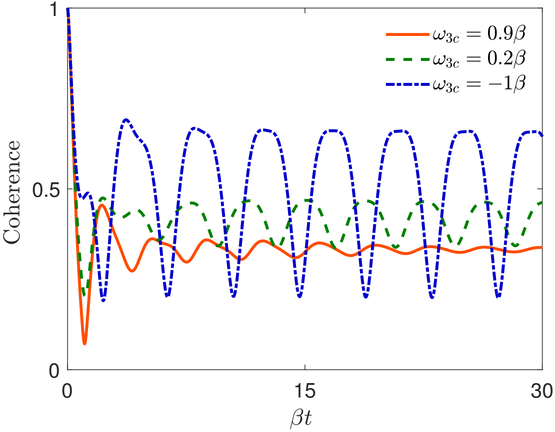
Results: Dynamics of Quantum Coherence

Dynamics of quatnum coherence in free space and in PBG materials with $\theta = \pi/2$ and $\omega_{3c} = -1\beta$



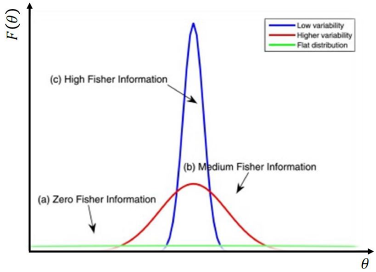
Results: Dynamics of Quantum Coherence

Dynamics of quatnum coherence for different values of detuning ω_{3c} with $\theta = \pi/2$



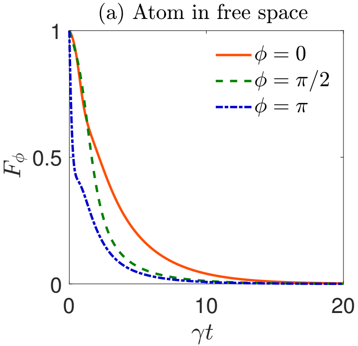
1. In estimation theory, the **Cramer–Rao bound** expresses a lower bound on the variance of unbiased estimators.

2. $$\Delta\theta_{es} \geq \frac{1}{\sqrt{F(\theta)}} \,, \qquad F(\theta) = E([\frac{\partial}{\partial\theta} \ln f(x,\theta)]^2)$$



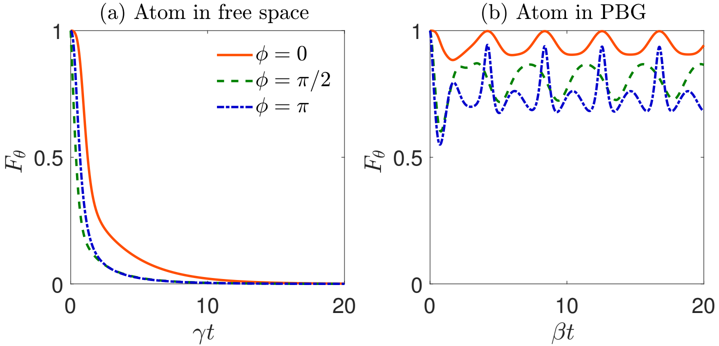
https://awni.github.io/intro-fisher-information.

Dynamics of quantum Fisher information for the parameter ϕ in free space and PBG materials with $\omega_{3c} = -1\beta$ and $\theta = \pi/2$

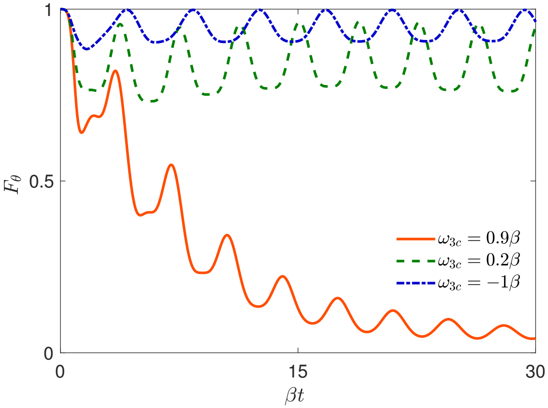


Results: Dynamics of F_θ (Single Parameter)

Dynamics of F_θ in free space and PBG materials with $\omega_{3c} = -1\beta$ and $\theta = \pi/2$



Dynamics of F_θ for various value of detuning ω_{3c} with $\theta = \pi/2$



Special Thanks

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Gava Zang, Zanjan, Iran

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PHYSICS WITHOUT FRONTIERS

Thank you for your attention!

Any Questions?