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Quantum Theory of radiation interactions
Fall 2012 ~ Paola Cappellaro
Why QM?

Why study quantum theory of matter/radiation interactions?

1. Effect of QM in nature

1. Application of QM in (almost) everyday life

Your favorite QM application
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- Colors, photosynthesis, bird compass ...

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- DVD (laser), GPS (atomic clock), MRI

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  - NMR (superconductivity + spins, simple to complex description)
Striking Characteristics of QM

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  - Energy levels, *quanta* of light
  - Discrete systems
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These characteristics are revealed in the interaction between matter and radiation.
Electrons are emitted 1 by 1 from the source in the electron microscope. They pass through a device called the "electron biprism", which consists of two parallel plates and a fine filament at the center. Electrons are then detected 1 by 1 as particles at the detector. The electrons were accelerated to about 40% of the speed of the light. So they pass through a 1m-long electron microscope in $10^{-8}$s. There is no more than one electron in the microscope at one time, since only 10 electrons are emitted per second. The experiment lasts 20 minutes (video 1 min!)
Molecule interferometry
M. Arndt, K. Hornberger, A. Zeilinger

(a) The buckyball carbon-70 (and C-60) (1999)
(b) the pancake-shaped biomolecule tetraphenylporphyrin (TPP) C_{44}H_{30}N_4; (2003)
(c) the fluorinated fullerene C_{60}F_{48}. (2004)

TPP is the first-ever biomolecule to show its wave nature.
C_{60}F_{48} has an atomic mass of 1632 units and currently holds the world record for the most massive and complex molecule to show interference.
Schroedinger’s virus

Quantum superposition of living organisms. Illustration of the protocol to create quantum superposition states applied to living organisms, such as viruses, trapped in a high-finesse optical cavity by optical tweezers.

Cat State decoherence

Reconstruction of non-classical cavity field states with snapshots of their decoherence

Quantum e.m. field in a cavity

- Preparation of electromagnetic radiation in Schrödinger cat states
- Atoms crossing the cavity extract information about the field: reconstruction of state
- Cavity damping induces decoherence that quickly washes out interferences
Rydberg atoms are prepared in the circular state $|g\rangle$ in box B. The atoms cross the cavity C sandwiched between the Ramsey cavities $R_1$ and $R_2$ fed by the classical microwave source $S'$, before being detected in D. The source S prepares a coherent field in C in the cat state.

Measure atoms

$n = \# \text{ of photons in cavity}$
Schrödinger cat

- Wigner Function representation
- Cat = 12 photons (macroscopic?)
- Oscillation indicate entanglement (quantumness)
50 ms in the life of a Schrödinger cat

http://www.nature.com/nature/journal/v455/n7212/suppinfo/nature07288.html
50 ms in the life of a Schrödinger cat

Goals of Course

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- entanglement,
- open quantum system dynamics,
- matter interaction with quantized e.m. field,...
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- Stop worrying about the qualifying exam!
Textbooks

- **Lecture notes**
  - usually posted before the lecture

- **Recommended books**
  - J.J. Sakurai *Modern Quantum Mechanics*
  - M. Le Bellac *Quantum Physics*
  - Chen, S.H.; Kotlarchyk, M., *Interactions of Photons and Neutrons with Matter*
  - Ballentine, Griffiths, Liboff, Haroche & Raimond, Scully & Zubairy
The problem sets are an essential part of the course: they are meant for you to learn, not for me to judge you.
Grading

Homeworks will be graded on a 0-1 scale,

0 if no Pset, 1 for a serious effort.

The final grade will be

\[ G = \frac{1}{2} (ME + FE) \langle Pset \rangle + \delta \]

Mid-Term: October 29th