4/22/2013

L15 Unraveling open Q systems

1. Motivation for single Q systems
2. QMCWF
3. Ex: Models for dephasing

Schrodinger 1952

"We never experiment with just one electron, or atom, or (small) molecule. In thought experiments, we sometimes assume that we do; this inevitably entails ridiculous consequences.... In the first place, it is fair to say that we are not experimenting with single particles, any more than we can raise ichthysauria in the zoo."

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QUANTUM JUMPING™

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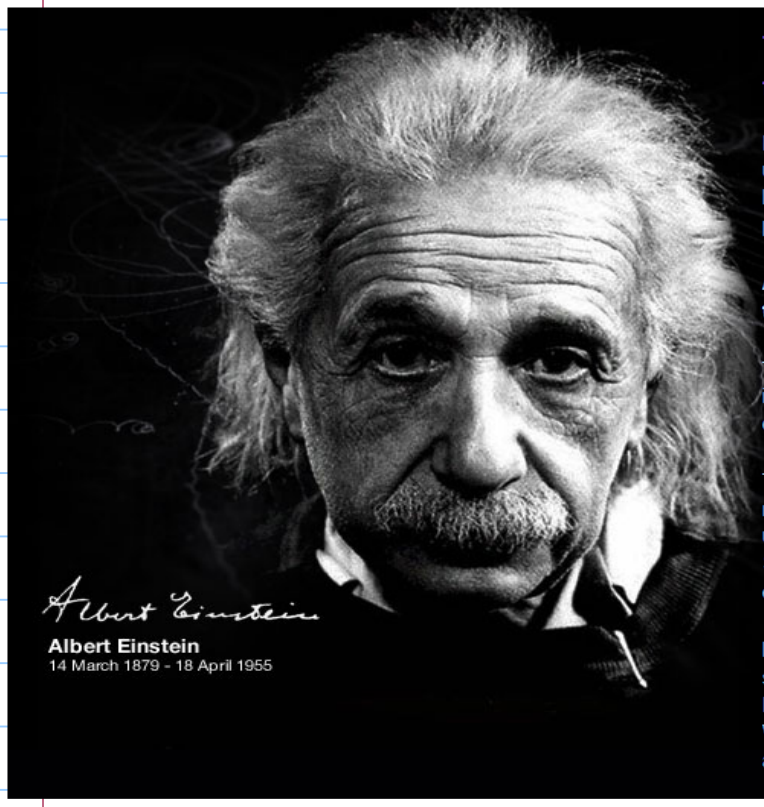
Welcome to the Infinite You.

You can probably imagine the looks I get when I describe Quantum Jumping to people: it's a technique for 'jumping' into alternate universes, meeting alternate versions of yourself, and using their wisdom and skills to live your ideal life.



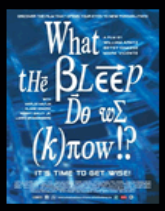
The smartest people in the world are trying to tell you something.

First of all, I wouldn't even dream of telling you about alternate universes and alternate selves if I wasn't sure of it myself. After all, I've told you about my background, and my life's work in helping people achieve mental and spiritual enlightenment…

And there's no way I'd throw away a lifetime of credibility and trust by telling you something that wasn't true.

The real clincher, though, lies in the discoveries of the most intelligent people in the world. Nobel prize winners, professors, quantum physicists—If you can't trust them, who else is left?

There's countless other intellectuals that have made discoveries in the possibility of alternate universes, including the world-famous **Professor Stephen Hawking**, **Professor Alan Guth**, and even **Albert Einstein** himself.



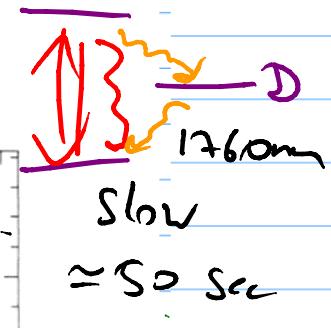
If you need more proof, just search Google for scientific theories like **String Theory** and **M-Theory**, or watch the film "What The Bleep Do We Know!?". Once you do, you'll be as convinced as I am that alternate universes do indeed exist.

VOLUME 56, NUMBER 26 PHYSICAL REVIEW LETTERS 30 JUNE 1986

Shelved Optical Electron Amplifier: Observation of Quantum Jumps

Warren Nagourney, Jon Sandberg, and Hans Dehmelt
Department of Physics, University of Washington, Seattle, Washington 98195
(Received 5 May 1986)

493 nm



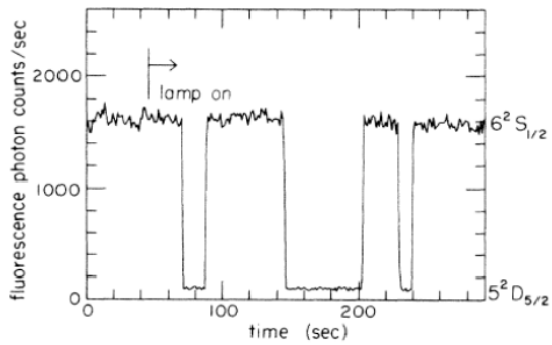


FIG. 2. A typical trace of the 493-nm fluorescence from the $6^2P_{1/2}$ level showing the quantum jumps after the hollow cathode lamp is turned on. The atom is definitely known to be in the shelf level during the low fluorescence periods.

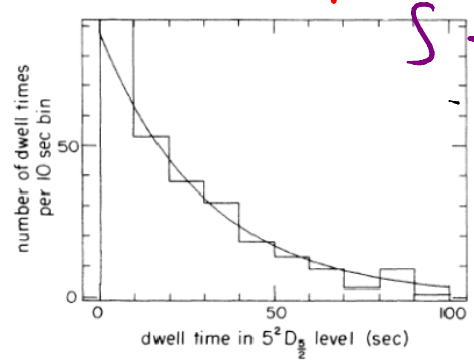
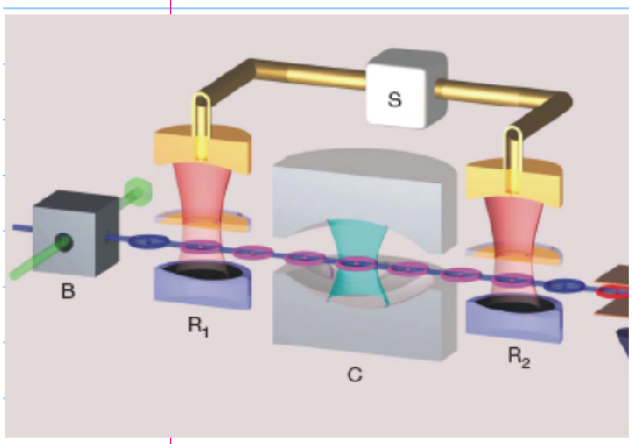


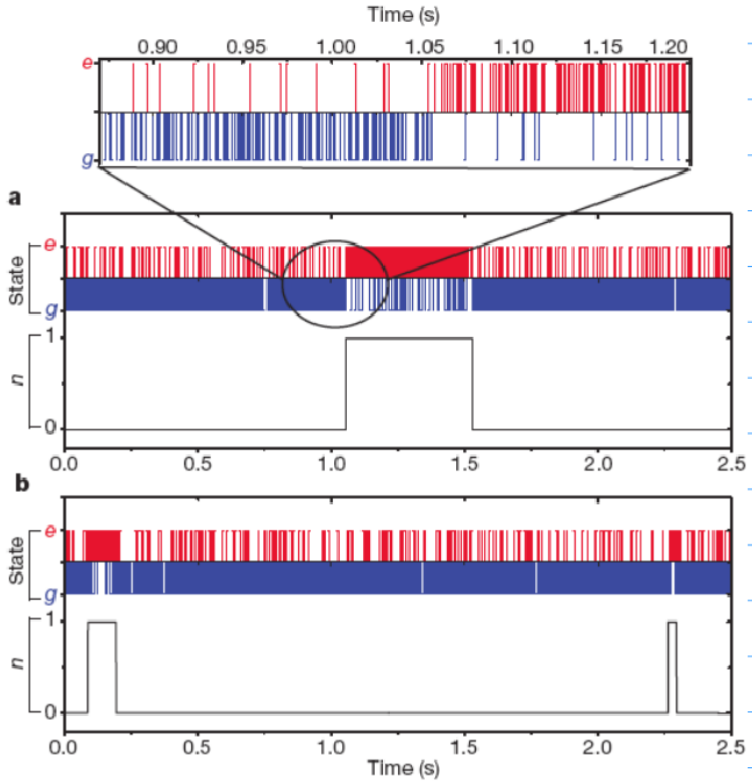
FIG. 3. Histogram of distribution of dwell times in the shelf level for 203 "off" times. A fitted theoretical (exponential) distribution for a metastable lifetime of 30 sec is superposed on the experimental histogram.

Quantum jumps of light recording the birth and death of a photon in a cavity

Nature 446, 297 (2007) - March 15

Sébastien Gleyzes[1], Stefan Kuhr[1]†, Christine Guerlin[1], Julien Bernu[1], Samuel Deléglise[1], Ulrich Busk Hoff[1], Michel Brune[1], Jean-Michel Raimond[1] & Serge Haroche[1,2]





Now: "Description" of single quantum systems

Warning! not unique

∞ ways to unravel density matrix dynamics

here: ∞

(2) QMCWF

Gedanken experiments: perform measurements

after time step dt, toss coin for spon. em

p YES $\longrightarrow$

$1-p$ NO $\longrightarrow$

Change of WF by measurement

$|i\rangle = |g\rangle$ stays forever

$|i\rangle = |e\rangle$ photon observed $\rightarrow |g\rangle$

no photon observed $\rightarrow |e\rangle$

$$|i\rangle = \frac{1}{\sqrt{2}}\left(|g\rangle + |e\rangle\right)$$

photon obs $\rightarrow |g\rangle$

no photon obs

$$\frac{1}{\sqrt{2}}\left(|g\rangle + |e\rangle\right) \quad A$$

$$\frac{1}{\sqrt{2}}\left(|g\rangle + e^{-(\Gamma/2)t}|e\rangle\right) \quad B$$

something else $\quad C$

50/50 superposition of $|g\rangle$, $|e\rangle$

$\Gamma^{-1} = 10$ ns

1s : no photon observed

$|g\rangle$ ✓ A

$\alpha|g\rangle + \beta|e\rangle$ B

after a looong time

$|g\rangle$

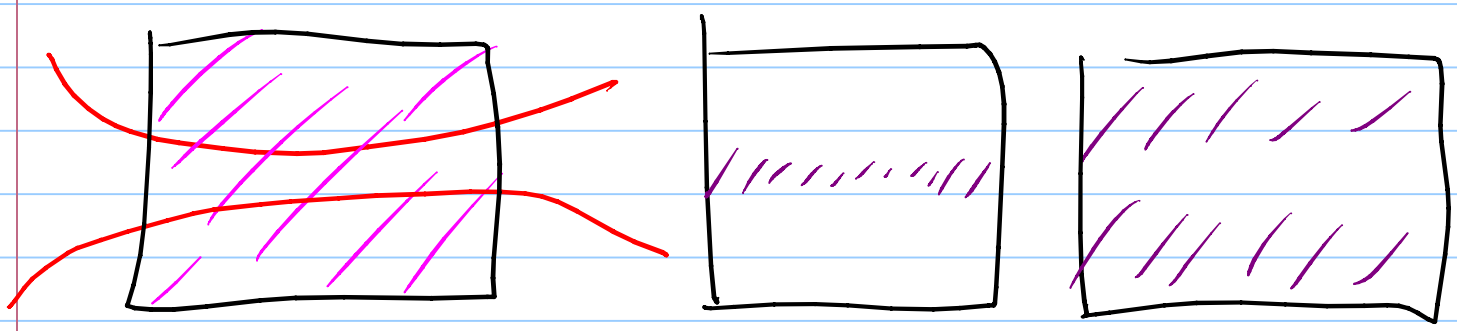
50% of the cases with photon

50% without

A zero measurement modifies the WF

(Dicke, A. J Phys. 49, 926 (1981))

YES NO



initial WF

$$|\psi(t)\rangle = \left(\alpha|g\rangle + \beta|e\rangle\right) \otimes |0\rangle$$

$\omega^{-1} < dt \ll \Gamma^{-1}, \Omega^{-1}, \delta^{-1}$

at most one spont. em during dt

$$|\psi(t+dt)\rangle = \left(\alpha'|g\rangle + \beta'|e\rangle\right) \otimes |0\rangle + |g\rangle \otimes \sum_{k,\varepsilon} \beta_{k,\varepsilon} |k,\varepsilon\rangle$$

$$= |\psi^{(0)}\rangle + |\psi^{(1)}\rangle$$

time-dependent perturbation theory
(Wigner-Weisskopf approach)

$$\beta' = \beta e^{-(\Gamma/2)dt} \longrightarrow 1 - \frac{\Gamma}{2} dt$$

$$dp = \langle \psi^{(1)} | \psi^{(1)} \rangle = \Gamma \, dt \, |\beta|^2$$

$$\langle \psi^{(0)} | \psi^{(0)} \rangle = 1 - dp$$

α', β' evolution of the WF occurs with a non-Hermitian Hamiltonian

$$H = H_0 - i\frac{\Gamma}{2} |e\rangle\langle e|$$

Procedure:

1. compute $dp = \Gamma\, dt\, |\langle e|\psi\rangle|^2$
2. ε rand $[0,1]$
3. if $\varepsilon < dp$ then $|\psi\rangle \to |g\rangle$
4. else $|\psi\rangle \longrightarrow \dfrac{e^{-iH\,dt}|\psi\rangle}{\sqrt{1-dp}}$
5. goto 2

Claim: QMCWF $\hat{=}$ OBE

Proof: show $\rho(t) = \overline{|\psi(t)\rangle\langle\psi(t)|}$

$$
\begin{aligned}
\rho(t+dt) &= dp\,|g\rangle\langle g| + (1-dp)\frac{e^{-iH\,dt}|\psi\rangle\langle\psi|e^{+iH^\dagger dt}}{1-dp} \\
&\approx dp\,|g\rangle\langle g| + (1-iHdt)\rho(t)(1+iH^\dagger dt) \\
&\approx dp\,|g\rangle\langle g| + \rho(t) - i(H\rho(t) - \rho(t)H^\dagger)dt \\
&= \Gamma dt\langle e|\rho(t)|e\rangle\,|g\rangle\langle g| + \rho(t) - i(H\rho(t) - \rho(t)H^\dagger)dt \\
&= \Gamma dt|g\rangle\langle e|\rho(t)|e\rangle\langle g| + \rho(t) - idt\,[H_0,\rho(t)] - \tfrac{\Gamma}{2}dt\,(|e\rangle\langle e|\rho(t) + \rho(t)|e\rangle\langle e|)
\end{aligned}
$$

Writing this as a coarse-grained differential equation, taking the limit of small dt, we find

$$
\begin{aligned}
\frac{d}{dt}\rho(t) &\approx \frac{\rho(t+dt)-\rho(t)}{dt} \\
&= -i\,[H_0,\rho(t)] - \tfrac{\Gamma}{2}\,(|e\rangle\langle e|\rho(t) + \rho(t)|e\rangle\langle e|) + \Gamma|g\rangle\langle e|\rho(t)|e\rangle\langle g|\,.
\end{aligned}
$$

This is the optical Bloch equation.

Extensions:

- Polarization
  if photon is detected
  second random # determines
  σ^+, σ^-, π

- recoil: random number for direction
  $\vec{k} \rightarrow$ recoil

General QMCWF

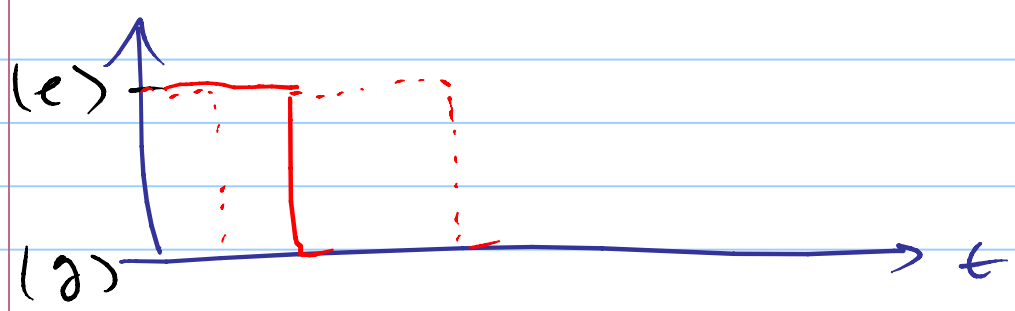
$$\dot{\rho} = -i[H, \rho] + \sum_k L_k \rho L_k^\dagger - \frac{1}{2} L_k^\dagger L_k \rho - \frac{1}{2} \rho L_k^\dagger L_k$$

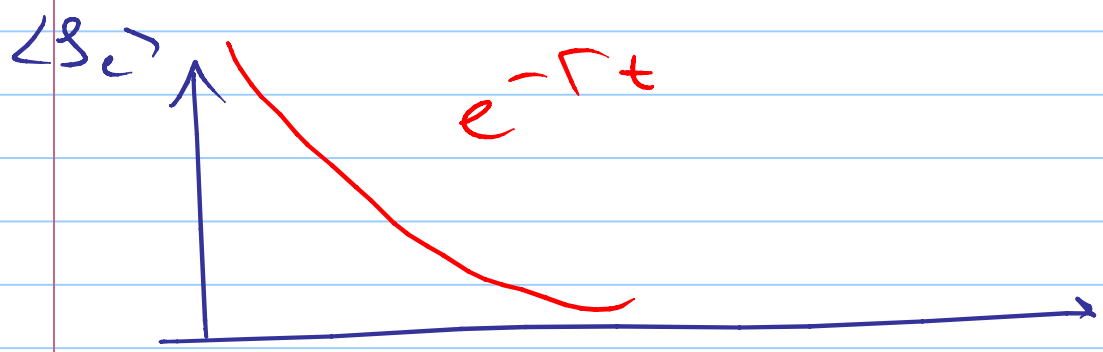
$$H = H_0 - \frac{i}{2} \sum L_k^\dagger L_k$$

General QMCWF Procedure:

1. Compute $dp = \Sigma_k \, dp_k$, and $dp_k = dt \langle \psi | L_k^\dagger L_k | \psi \rangle$
2. Let $0 \leq \epsilon \leq 1$ be a uniformly distributed random #
3. If $\epsilon < dp$ then $|\psi\rangle \leftarrow L_k |\psi\rangle / \sqrt{dp_k/dt}$ with k randomly chosen with probability dp_k/dp
4. Else $|\psi\rangle \leftarrow \left[e^{-iH\,dt} / \sqrt{1 - dp} \right] |\psi\rangle$
5. Go to 1

Spontaneous em.: $L = \sqrt{\Gamma}\,\sigma_-$





Dephasing

$$\rho(0) = \begin{bmatrix} a & b \\ b^* & c \end{bmatrix}$$

$$\rho(t) = \begin{bmatrix} 1 - c e^{-t/T_1} & b e^{-t/T_2} \\ b^* e^{-t/T_2} & c e^{-t/T_1} \end{bmatrix}$$

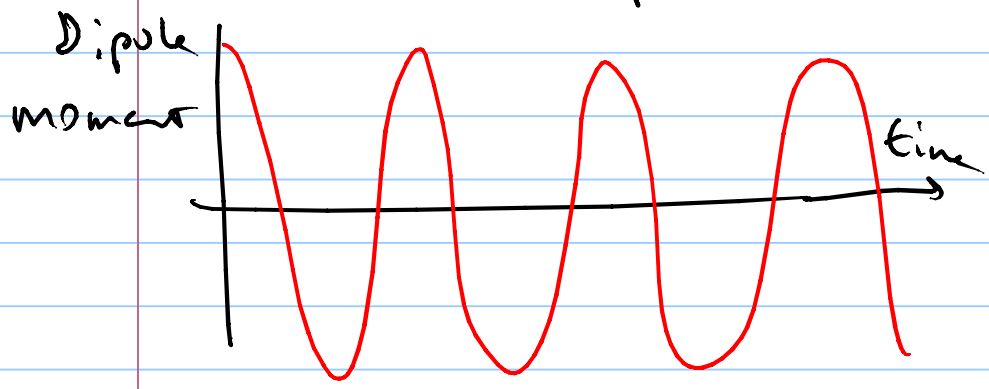
T_1 : energy loss $\qquad 1/\Gamma$

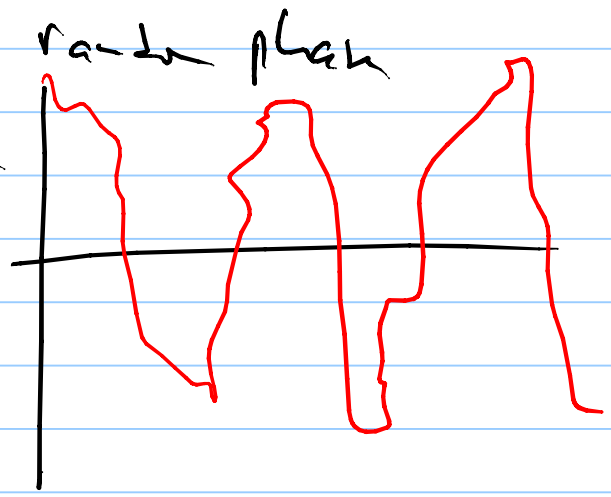
T_2 : dephasing $\qquad 2/\Gamma$
loss of coherence
"phase damping"

HW #6, Problem 3

3 examples of T_2 processes

- random phase
- elastic collisions $\qquad$ projects onto $|e\rangle$
- random phase flips $\qquad |e\rangle \to -|e\rangle$





elastic coll. in $|e\rangle$ random phase flips

See Wiki for animations

Discussion

Which model is correct?
All or none?

Freedom of interpretation arises from unitary degree of freedom, how the photon is detected