E. F. Doneny / BSC Physics: Copenhagen Interpretation, measurement ... Decoherence.

Note Title 3/16/2006

That $|\Psi(x)|^2$ = prob density ≡ Born Interpretation of Schrö Equat & Ψ.

what is Ψ? don't know.

what is $\sqrt{\text{probability}}$

don't know that either.

So accepted interpretation is

Ψ = wavefunct, then don't know

but

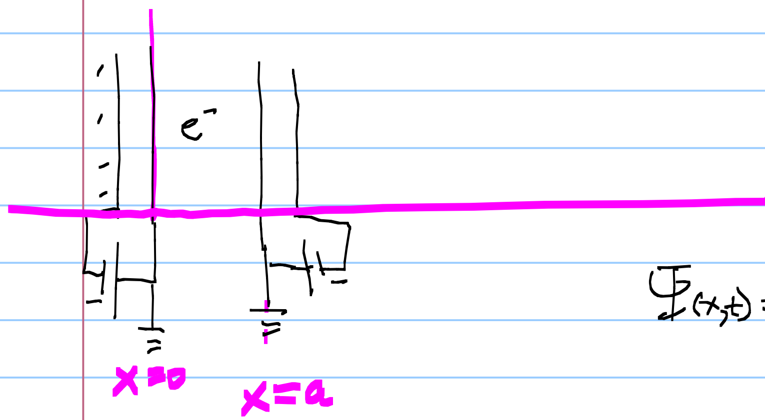
$\Psi^* \Psi$ = probability density.

1954 Nobel Prize

Olivia's Grand Dad.

See AJP article
73, (11) 999 - 1008
(2005)

So what do we do?



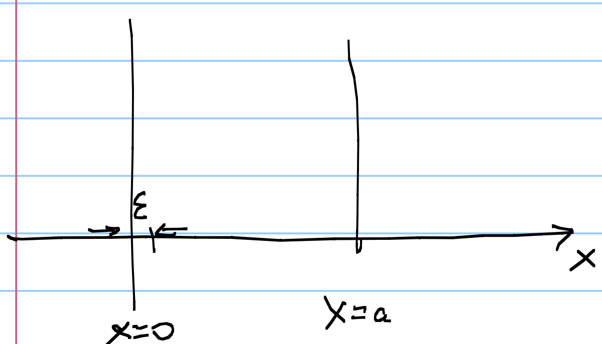
$\hat{H}\Psi = i\hbar \frac{\partial \Psi}{\partial t}$

Solve

get

$$\Psi(x,t) = \begin{cases} \sqrt{\frac{2}{a}} \sin\left(\frac{\pi x}{a}\right) e^{-\frac{i\hbar \pi^2 t}{2ma^2}} & 0 \le x \le a \\ 0 & \text{otherwise} \end{cases}$$

Then ask .... what is the prob that upon measuring the result you be that the e^- was within distance, ε, of the left hand wall?



So $|\Psi|^2 = \frac{\text{prob}}{\text{length}}$

$|\Psi(x)|^2 dx =$ prob in bin size dx

So

$$P(0 \le x \le \varepsilon) = \int_{x=0}^{\varepsilon} \Psi^*(x)\Psi(x)\, dx$$

$$= \int_0^{\varepsilon} \frac{2}{a} \sin^2 \frac{\pi x}{a}\, dx$$

$$= \frac{\varepsilon}{a} - \frac{1}{2\pi} \sin\left(\frac{2\pi\varepsilon}{a}\right)$$

Now if $\varepsilon \ll a$

Then $\sin(x) = 0 + x + 0 - \frac{x^3}{3}$

So $\sin \frac{2\pi\varepsilon}{a} = + \frac{2\pi\varepsilon}{a} - \left(\frac{2\pi\varepsilon}{a}\right)^3 \frac{1}{3}$

&

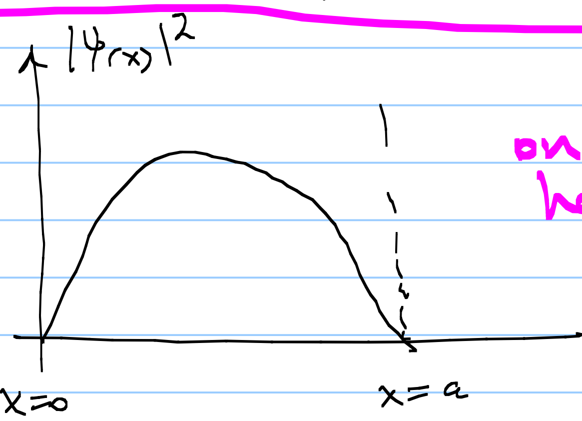
$$\text{prob} = \frac{\varepsilon}{a} - \frac{1}{2\pi}\left(\frac{+2\pi\varepsilon}{a} - \left(\frac{2\pi\varepsilon}{a}\right)^3 \frac{1}{3}\right) = \frac{\varepsilon}{a} - \frac{\varepsilon}{a} + (2\pi)^2 \left(\frac{\varepsilon}{a}\right)^3 \frac{1}{3} = \frac{(2\pi)^2}{3}\left(\frac{\varepsilon}{a}\right)^3$$

works perfectly!

talk about pre-measurement

Schroeder waits until Sect 8.8 on measurement theory here (pg 187)

I'll do a bit here



Quantum mechanics "says" before measurement, all you can say is that

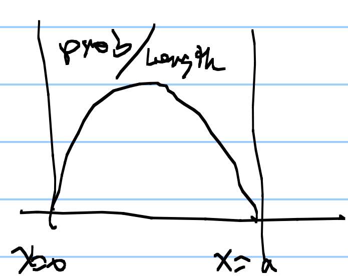
This is the probability distribution function for where the particle is!

That's it. Q.M. says it is in superposition of this entire distribution function

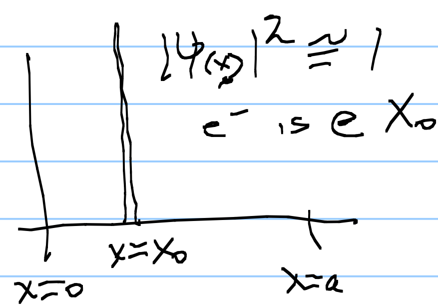
Until the measurement!

Once a measurement is made---- and it is where it is, It is said that the wavefunction instantly collapses into the state to which it was measured!

Before measurement



after measurement



This is called the collapse of the wavefunction!

$$\boxed{\Psi^*_{\text{all } x}\,\Psi_{\text{all } x} = \text{Everything}} \xrightarrow[\text{measure}]{} \Psi^*_{(x_0)}\,\Psi_{(x_0)}$$

↑ its @ x_0.

Idea:

Spin = ↑ or ↓

$$\Psi_{spin} = |\uparrow\rangle + |\downarrow\rangle \xrightarrow[\text{measure}]{} |\uparrow\rangle \text{ or } |\downarrow\rangle$$

Schrödinger's Cat

$$|\text{dead}\rangle + |\text{alive}\rangle \xrightarrow[\text{measure}]{} |\text{dead}\rangle \text{ or } |\text{alive}\rangle$$

ALL called Copenhagen Interpretation of Quantum Mechanics!

See

problems?

w/ Copenhagen? → 1) Hidden Variables --→ Q.M. IS actually deterministic, and only our Ignorance makes it appear random!

*actually local hidden variables

1) Spooky action, (AE 1935 EPR paper

Local part means no faster than Light signal

See Scherrer pg 187 sect 8.8 measurement theory

Today -- well that's the way it is

John Bell 1965 ⇒ Local hidden variable theories are incompatible w/ observed experimental results

Alain Aspect 1980

today 1990 Quantum Teleportation & Quantum Computer

Also: Many world's Interpretation of Q.M.
1957 Hugh Everett (princeton student of wheeler)
↳ to Avoid ? of wavefunction Collapse ((copenhagen)
what if they never really callapse?

Resolution?

Decoherence!

|Universe⟩ + |dead⟩ + |alive⟩ → |dead⟩ + |univ⟩ ; |alive⟩ + |univ⟩

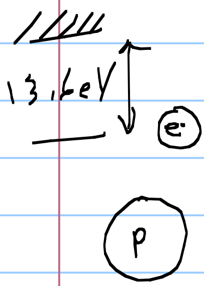
look

Coherence = Superposition state (cat
$|d\rangle + |a\rangle$ @ same time

But as soon as "measurement" is made, it Decoheres

e^-'s can keep (coherent) for a while ··· seconds
cat = 10^{23} decoheres quickly $\sim 10^{-20}$ seconds
so
Quickly becomes $|dead\rangle$ or $|alive\rangle$

More on Coherence/DeCoherence



Keep away from all interactions
stay away from $\vec{E}$ & $\vec{M}$ = $\hat{H}'$ ≤ 13.6eV

Then $\Psi_{e^-} = \frac{1}{\sqrt{2}}\left[|\uparrow\rangle + |\downarrow\rangle\right]$

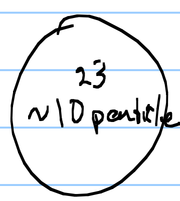
it is in Both states. = Coherent Superposition

* apply external $\vec{B}$ field ⇒ measurement &
e⁻ becomes
either $|\uparrow\rangle$ or $|\downarrow\rangle$ w/ respect
to the field,

* called
Space Quantization! BIG Surprise
(see Townsend for Great Story on this)

So
(e⁻) very much wavelike ∿∿∿>
very Quantum mechanical

Now take Tennis Ball

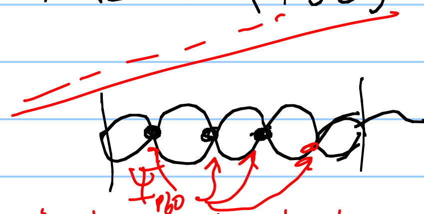


if each = ∿∿∿> Then all together
e⁻
~10^{23} incoherent Ψ_{e^-}
doesn't look
wavelike at all! Looks
like decoherent particle.

Now resolve Schrö's Cat w/ Decoherence ...

Dave DeMille --> Quantum PC

molecule (PbO) = $|\uparrow\rangle + |\downarrow\rangle$ = coherent Ψ_{PbO}



standing wave way off resonance

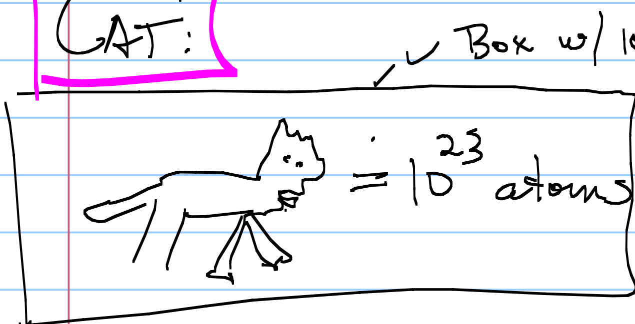
in troughs of standing wave ↑ ≈ 10,000 of them.

↳ Varying $\vec{E}_{ext}$ he can apply to talk to each PbO individually

Dave can keep these PbO's $|\uparrow\rangle + |\downarrow\rangle$ (10K of them) for about 5 seconds.

"He can keep them coherent, ie from DeCohering, for 5 seconds" because he TRIES not to measure them!

CAT:



The E&M radiation from the Box & interactions between all particles

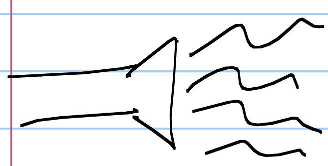
⟹ Measurements so

Quickly decohere the 10^{23} atoms into 1 collapsed observed state = Dead or alive ⟹

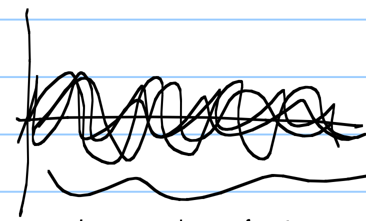
Finally ... one more example of Coherent Q.M. states

The Laser!

Flash Light

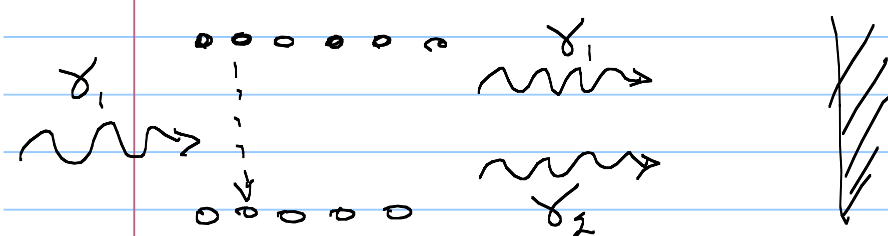


10^{23} γ's but all out of time & angle phase



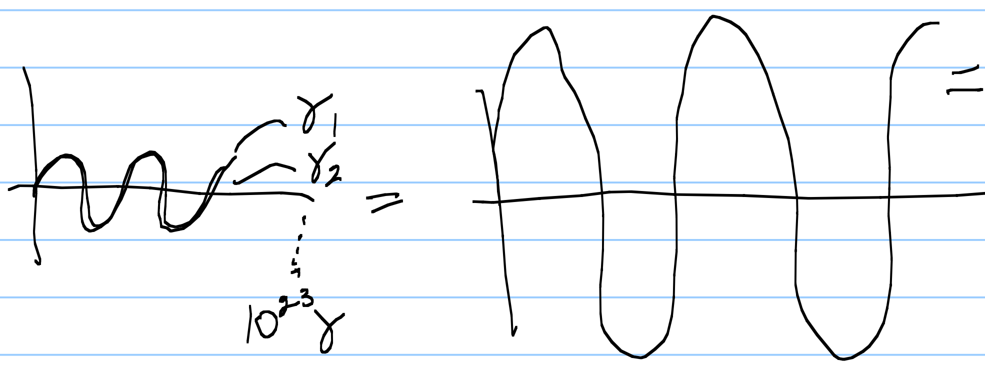
Looks like incoherent Light!

Laser ...



stimulated emission produces exact copy of γ $\Rightarrow$ all starting @ same time & angle

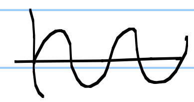
after many trips back & forth between mirror you get buildup of identical COHERENT photons



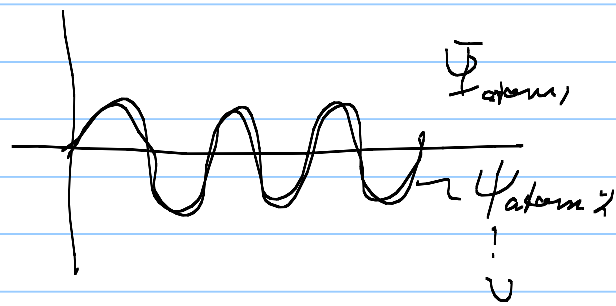
= VERY WAVE-LIKE

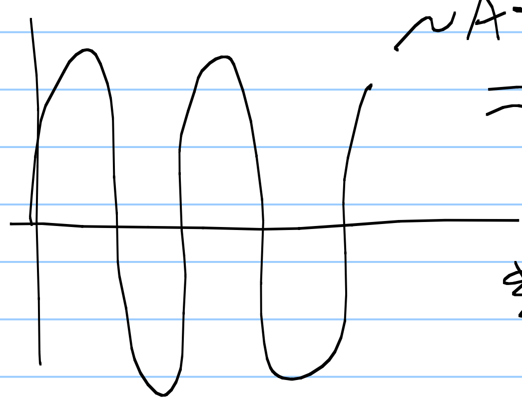
So Laser = purely Q.M. coherent superposition of γ's

2000 ---> Coherent Superposition of atom's

Ψ_{atom} = 

BEC = Atom Laser





~ Atom Laser = pure Quantum mechanical & all wavelike.

KEY is Laser & BEC = Macroscopic SIZE

So Great to study fundamental Q.M.