Title: 12/13 PSI - Found Quantum Mechanics Lecture 14

Date: Jan 24, 2013 11:30 AM

URL: http://pirsa.org/13010083

Abstract:

Inconsistencies of the orthodox interpretation

By the collapse postulate (applied to the system)	By unitary evolution postulate (applied to isolated system that includes the apparatus)
Indeterministic and discontinuous evolution	Deterministic and continuous evolution
Determinate properties	Indeterminate properties

Responses to the measurement problem

1. Deny universality of quantum dynamics
   - Quantum-classical hybrid models
   - Collapse models

2. Deny representational completeness of ψ
   - ψ-ontic hidden variable models (e.g. deBroglie-Bohm)
   - ψ-epistemic hidden variable models

3. Deny that there is a unique outcome
   - Everett's relative state interpretation (many worlds)

4. Deny some aspect of classical logic or classical probability theory
   - Quantum logic and quantum Bayesianism

5. Deny some other feature of the realist framework?

Collapse theories

Posit a new dynamical evolution law:
either nonlinear or indeterministic or both

Recover unitary evolution and the collapse dynamics as special cases

Microscopic systems obey unitary dynamics to good approximation
Macroscopic systems obey collapse dynamics to good approximation

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Macroscopic systems obey collapse dynamics to good approximation

Motivations:
- Achieves realism
- Maintains representational completeness of ψ
- No "cut", i.e. one universal dynamics (unlike a hybrid model)

Nonlinear deterministic models

$|\uparrow\rangle|\text{“ready”}\rangle \rightarrow |\uparrow\rangle|\text{“up”}\rangle$

$|\downarrow\rangle|\text{“ready”}\rangle \rightarrow |\downarrow\rangle|\text{“down”}\rangle$

$(a|\uparrow\rangle + b|\downarrow\rangle)|\text{“ready”}\rangle \rightarrow a|\uparrow\rangle|\text{“up”}\rangle + b|\downarrow\rangle|\text{“down”}\rangle$

rather $(a|\uparrow\rangle + b|\downarrow\rangle)|\text{“ready”}\rangle \rightarrow |\uparrow\rangle|\text{“up”}_{a,b}\rangle$

or

$|\downarrow\rangle|\text{“down”}_{a,b}\rangle$

Final state depends on details of the initial state

Ignorance of those details implies subjective indeterminism

Linear indeterministic models

The goal:

$$(a|\uparrow\rangle + b|\downarrow\rangle)|\text{“ready”}\rangle \rightarrow |\uparrow\rangle|\text{“up”}\rangle \quad \text{with probability } |a|^2$$
$$\rightarrow |\downarrow\rangle|\text{“down”}\rangle \quad \text{with probability } |b|^2$$

The preferred decomposition issue

Into what states do collapses occur?

The trigger issue

When and how do collapses occur?

The Ghirardi-Rimini-Weber model

At most times:

$$i\hbar\frac{\partial}{\partial t}\psi(\mathbf{r}_1,...,\mathbf{r}_N,t) = H\psi(\mathbf{r}_1,...,\mathbf{r}_N,t)$$ Schrödinger's equation

Every τ/N time interval on average

$$\psi(\mathbf{r}_1,...,\mathbf{r}_N,t+dt) = \frac{1}{\sqrt{p(\mathbf{q}_k)}} G_{\mathbf{q}_k}(\mathbf{r}_k)\psi(\mathbf{r}_1,...,\mathbf{r}_N,t)$$ "Collapse"

where $G_{\mathbf{q}_k}(\mathbf{r}_k) = K\exp(-\frac{(\mathbf{r}_k-\mathbf{q}_k)^2}{2\sigma^2})$

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$$p(\mathbf{q}_k) = \int d\mathbf{r}_1...d\mathbf{r}_N \; |G_{\mathbf{q}_k}(\mathbf{r}_k)\psi(\mathbf{r}_1,...,\mathbf{r}_N,t)|^2$$

k is chosen uniformly at random

$\mathbf{q}_k$ is chosen by sampling from $p(\mathbf{q}_k)$

Two new fundamental constants:

$\tau \approx 10^{15}\mathrm{s} \approx 100$ million years — mean time between collapses for one particle

$\sigma \approx 10^{-7}\mathrm{m} \approx$ size of large molecule — Localization width

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In terms of density operators

$$\rho \to \frac{\sqrt{E^{(k)}(\mathbf{q}_k)}\rho\sqrt{E^{(k)}(\mathbf{q}_k)}}{\mathrm{Tr}(E^{(k)}(\mathbf{q}_k)\rho)}$$

Essentially a POVM measurement of approximate position

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Essentially a POVM measurement of approximate position

If k and q_k are unknown, then the effective evolution is

$$\rho \to \sum_k \int \mathrm{d}q_k \ \sqrt{E^{(k)}(\mathbf{q}_k)}\ \rho\ \sqrt{E^{(k)}(\mathbf{q}_k)}$$

Single particle in 1D

$$\psi(x) = \frac{\sqrt{3}}{2}\phi_a(x) + \frac{1}{2}\phi_b(x)$$

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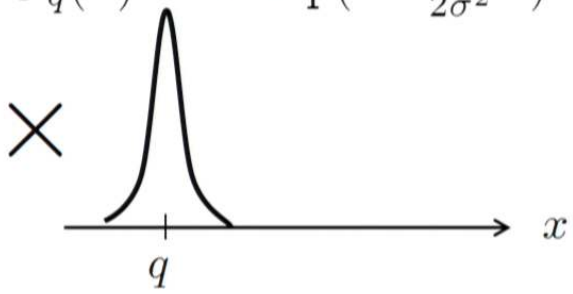
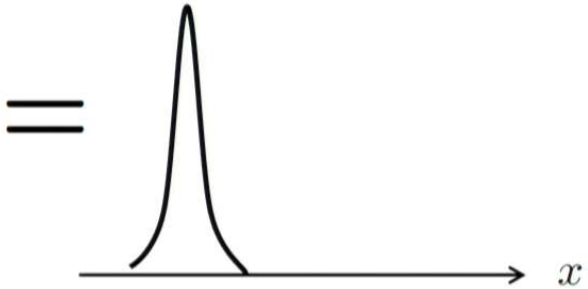
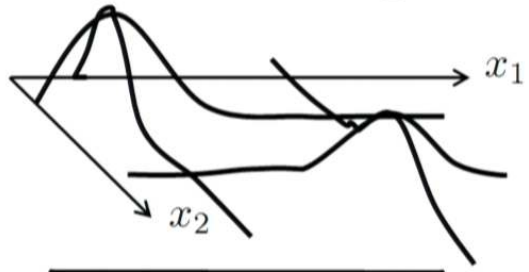
$$G_q(x) = K\exp(-\frac{(x-q)^2}{2\sigma^2})$$

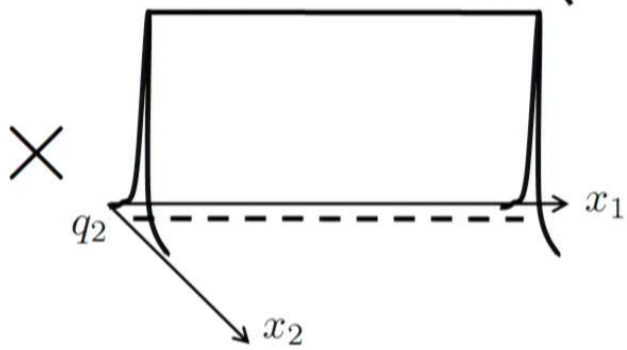




Two particles in 1D

$$\psi(x_1, x_2) = \frac{\sqrt{3}}{2}\phi_a(x_1)\chi_a(x_2) + \frac{1}{2}\phi_b(x_1)\chi_b(x_2)$$





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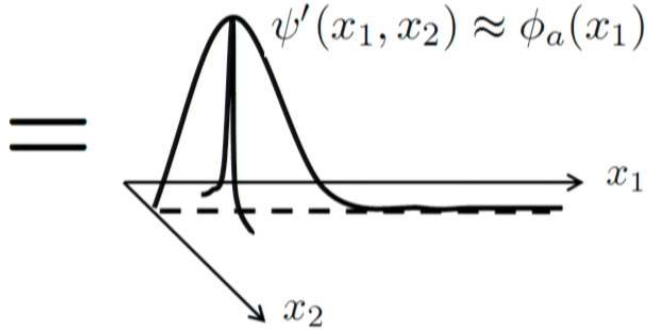

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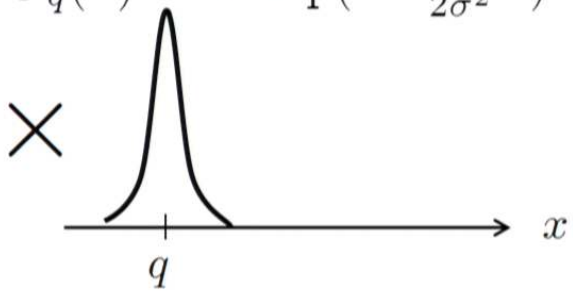

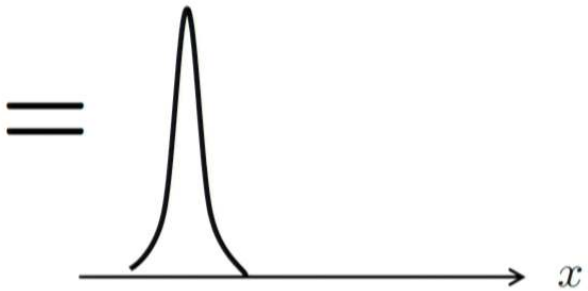

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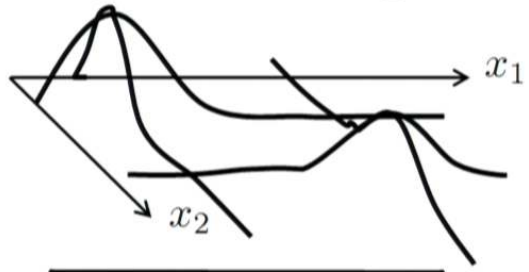

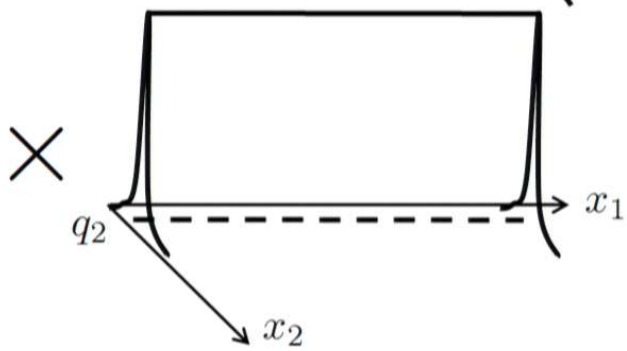

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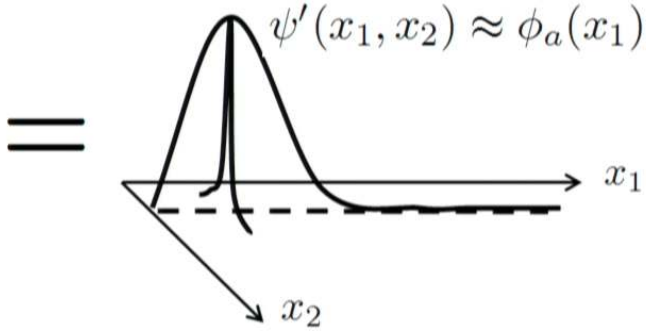
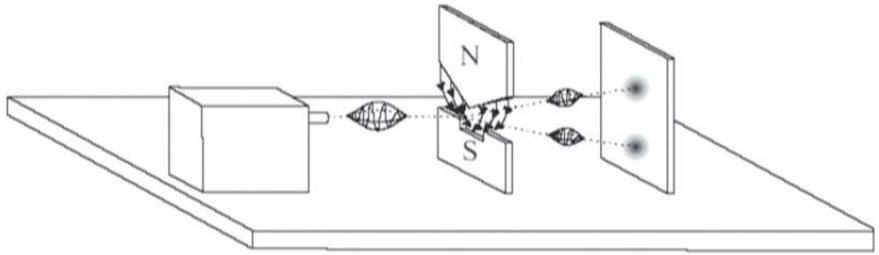
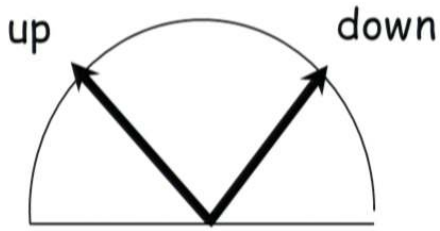
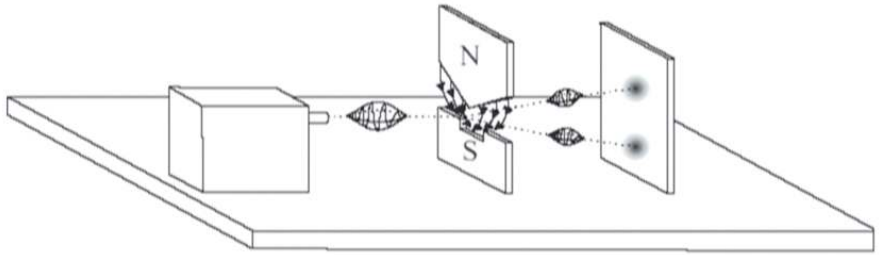
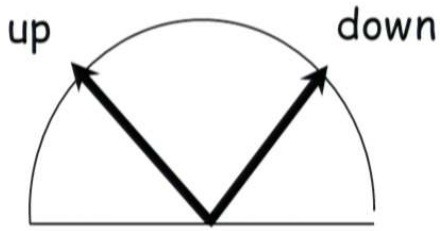






$$\psi = \alpha\ \phi_a(\mathbf{r}_1)\chi_a(\mathbf{r}_2, ..., \mathbf{r}_M) + \beta\ \phi_b(\mathbf{r}_1)\chi_b(\mathbf{r}_2, ..., \mathbf{r}_M)$$





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Suppose $\chi_a(...\mathbf{r}_k...)\chi_b(...\mathbf{r}_k...) \approx 0$ for macroscopic # of components

One particle is hit → wavefn' is localized in all coordinates

$$\psi' = \phi_a(\mathbf{r}_1)\chi'_a(\mathbf{r}_2, ..., \mathbf{r}_M) \quad \text{with probability } |\alpha|^2$$

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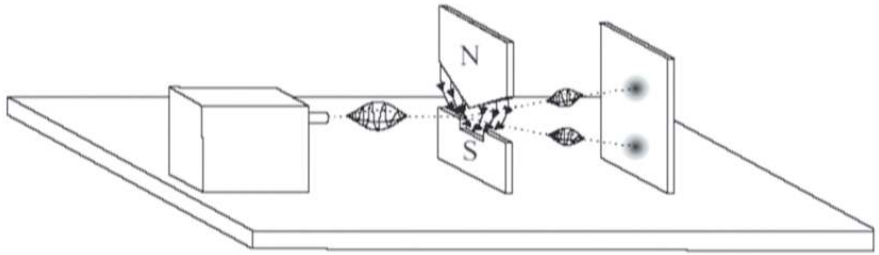

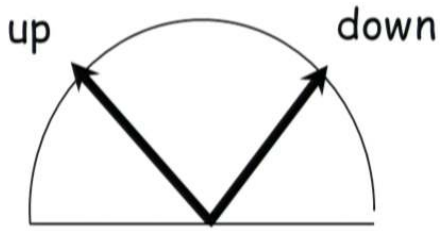

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For $M \approx 10^{20}$ particles

This happens every $\frac{10^{15}\mathrm{S}}{10^{20}} \approx 10^{-5}\mathrm{S}$

Constraints on parameters

τ too big → persistence of coherence of macro objects

τ too small → loss of coherence of micro objects

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τ too big → persistence of coherence of macro objects
τ too small → loss of coherence of micro objects

σ too big → delocalized macro objects
σ too small → excitation and heating

Experimental status

Difficult to distinguish fundamental collapse from decoherence
Difficult to detect anomolous heating

Continuous Spontaneous localization

Philip Pearle

Collapse is a continuous process governed by a randomly fluctuating field
"gambler's ruin"

Criticisms

What is the ontology in space-time? The "tails" problem.
Bell's "flashes" ontology

Failure of energy conservation

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An alternative way of accounting for any "anomolous decoherence"

The map corresponding to the "anomolous decoherence" is

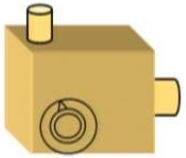
$$\rho \to \sum_k \int \mathrm{d}q_k \, \sqrt{E^{(k)}(\mathbf{q}_k)} \, \rho \, \sqrt{E^{(k)}(\mathbf{q}_k)}$$

This is a trace-preserving completely positive linear map

$$\rho \to \mathcal{T}(\rho) = \sum_\mu A_\mu \rho A_\mu^\dagger$$

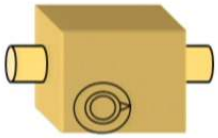
where the A_μ are linear operators satisfying $\sum_\mu A_\mu^\dagger A_\mu = I$

Church of the larger Hilbert space



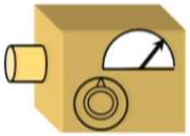
Density operator

ρ



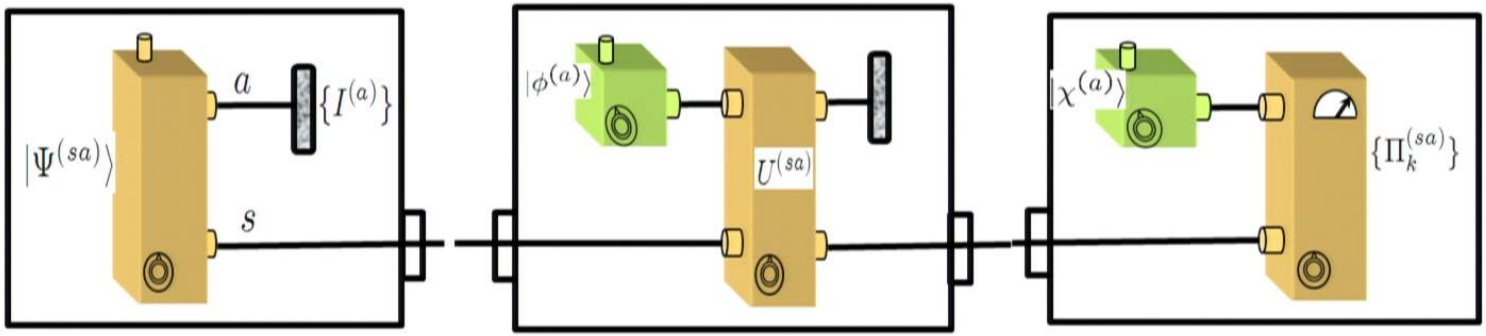
Trace-preserving completely positive linear map (CP map)

$\mathcal{T}$



Positive operator-valued measure (POVM)

$\{E_k\}$



Purification

$|\Psi^{(sa)}\rangle$

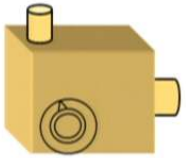
Stinespring dilation

$|\phi^{(a)}\rangle, U^{(sa)}$

Naimark extension

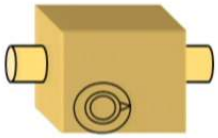
$|\chi^{(a)}\rangle, \{\Pi^{(sa)}\}$

Church of the larger Hilbert space



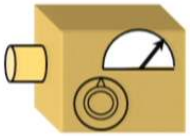
Density operator

ρ



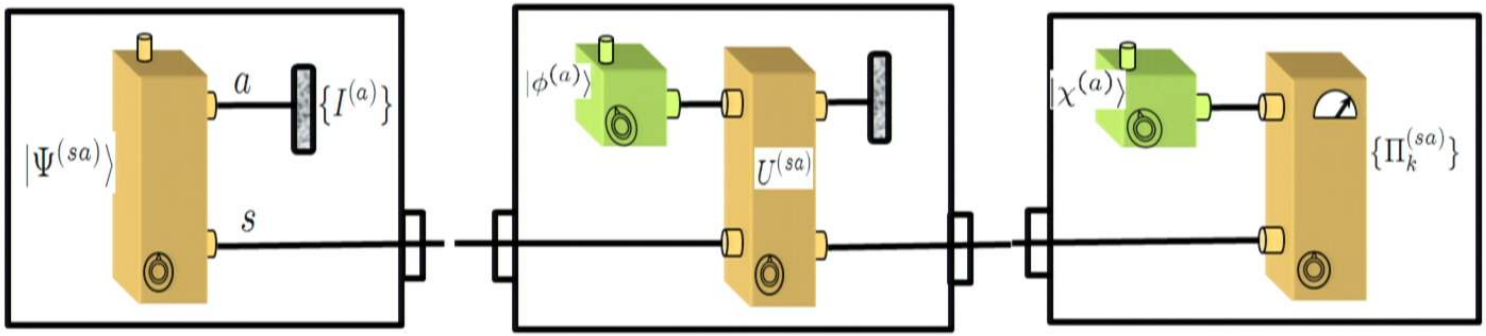
Trace-preserving completely positive linear map (CP map)

$\mathcal{T}$



Positive operator-valued measure (POVM)

$\{E_k\}$



Purification

$|\Psi^{(sa)}\rangle$

Stinespring dilation

$|\phi^{(a)}\rangle, U^{(sa)}$

Naimark extension

$|\chi^{(a)}\rangle, \{\Pi^{(sa)}\}$

GRW and CSL:
# of fundamental constituents in an object → rate of collapse

Other ideas for what induces dynamical collapse in macroscopic systems but not microscopic systems:

gravity

Complexity/entanglement

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