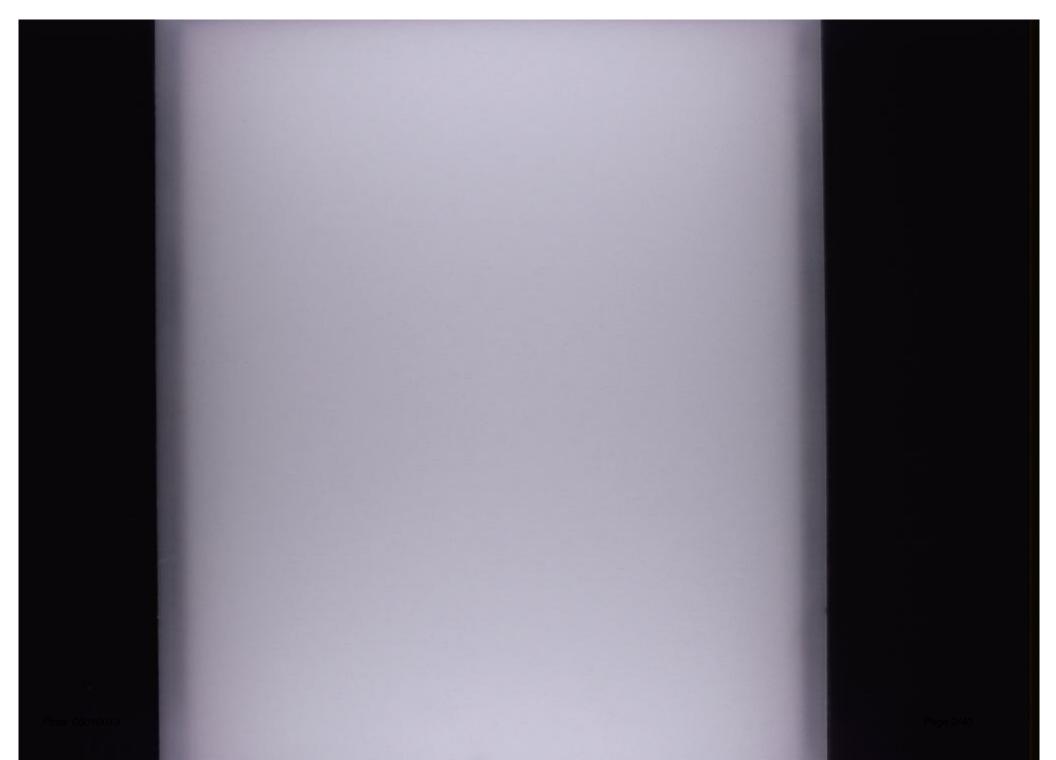
Title: Interpretation of Quantum Theory: Lecture 7

Date: Jan 25, 2005 02:15 PM

URL: http://pirsa.org/05010013

Abstract:

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The Measurement Problem

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Before the measurement, state is:

$$(\alpha | \uparrow \rangle + \beta | \downarrow \rangle) \otimes |$$
 "no result measured"

After the measurement, state seems to be:

...but is really one of

Status of the quantum state

Quantum theory seems to be about the unitary evolution of some "quantum state"

... but what is it?

"States" in physics usually are one of two things:

- some hopefully-complete description of the actual physical system
 (e.g. electric & magnetic field point on configuration space in classical physics)
- some partial, probabilistic, in-principleunnecessary description of the actual physical system (e.g. the probability distributions used in statistical mechanics)

Which one is the quantum state?

... both.

Before measurement, it's normally treated as a physical state: something that can interfere with itself, be manipulated in experiments, prepared in one way or another, etc.

After measurement, it's normally treated as a probabilistic state: we might say that the system is in state

but what we mean is that the system is in physical state

or

or ...

4

Possible resolutions of the problem

 Regard the state as always physical, and change the theory

Why change it?

Because if a state like

is physical, that seems to say that measurements we make don't have definite outcomes... and they do. (ask an experimentalist!)

So we could

- Change the dynamics so as to be nonlinear (e.g. GRWP collapse theory)
- Add "hidden variables" to say which term in the wave-function "corresponds to our actual measurements" (e.g. de Broglie-Bohm theory)

(5)

2. Regard the state as always probabilistic... and rewrite the theory to say what it's a probabilistic description of.

e.g. maybe there are hidden variables and they are probabilistically described by the wave-function, but in principle we could throw away the wave-function and just use the hidden variables.

1 & 2 are research programmes – no completed theory that realizes either of them.

Committed to redoing much of fundamental physics

(not necessarily a criticism!)

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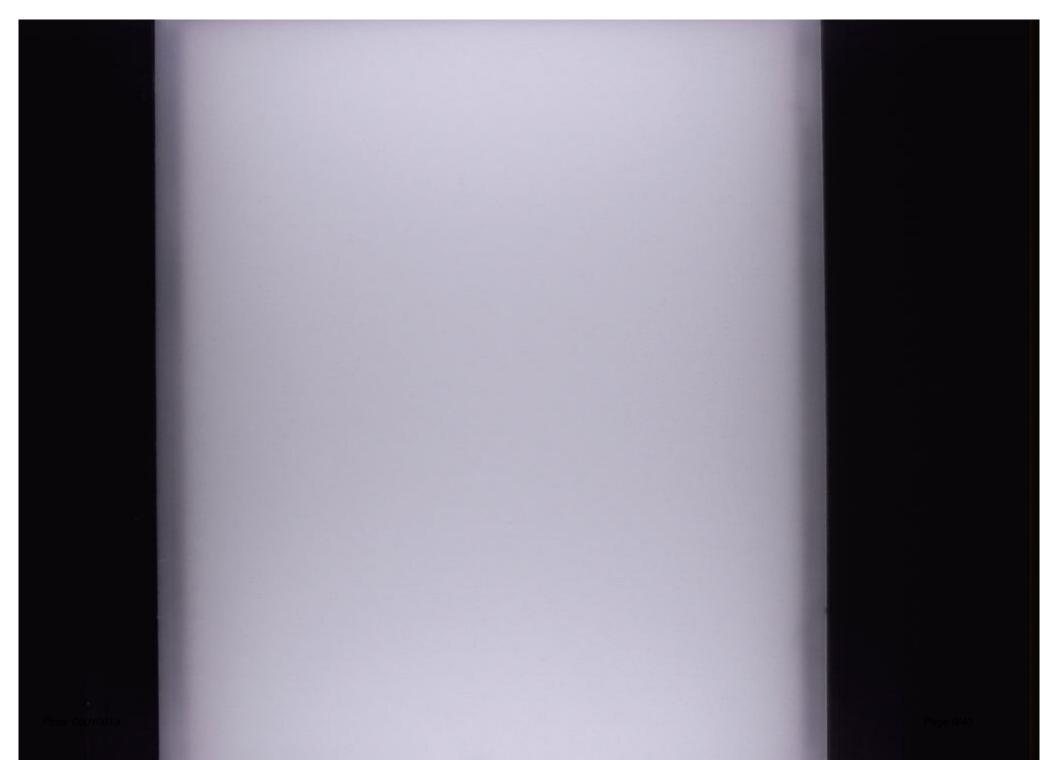
What if we don't want to redo fundamental physics?

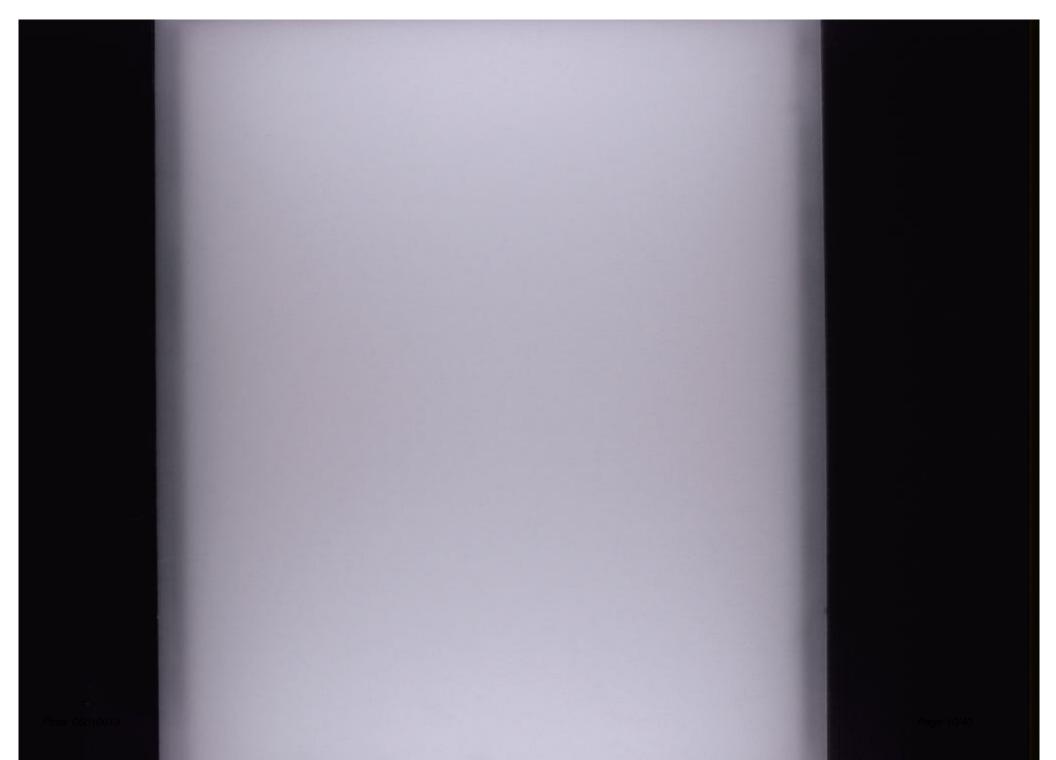
- ... then we need a theory in which
- a) the wavefunction description of reality is complete (or "as complete as possible" anyway)
- b) it evolves unitarily at all times.

We could then try resolution

- 3. The wavefunction is a probabilistic state but there is *no* physical state underlying it*
- e.g (some versions of) Copenhagen interpretation
 - ensemble interpretations (Ballentine) (some versions of) information-theoretic interpretations (Fuchs)
- * does this make sense? Exercise for the reader!

If you don't think it does, you're left with...





4. The Everett interpretation



- The quantum state is a physical state (no probabilistic / ensemble / ignorance interpretation of it; it's as real as the electric field)
 - The quantum state is a complete description of reality (no extra hidden variables)
 - The quantum state always evolves unitarily (no collapse)

Complete description!

... from the point of view of physical postulates, the Everett interpretation just says "take QM completely literally".

How can this make sense?



- Theory (apparently) predicts indefinite outcomes of experiments
- We don't see indefinite outcomes!

Central insight:

A state like

is correctly understood as describing two "worlds"

- isolated, or nearly isolated, chunks of reality
- · each approximately classical
- · in one we get one result, in one the other

hence "many-worlds interpretation"

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Problems

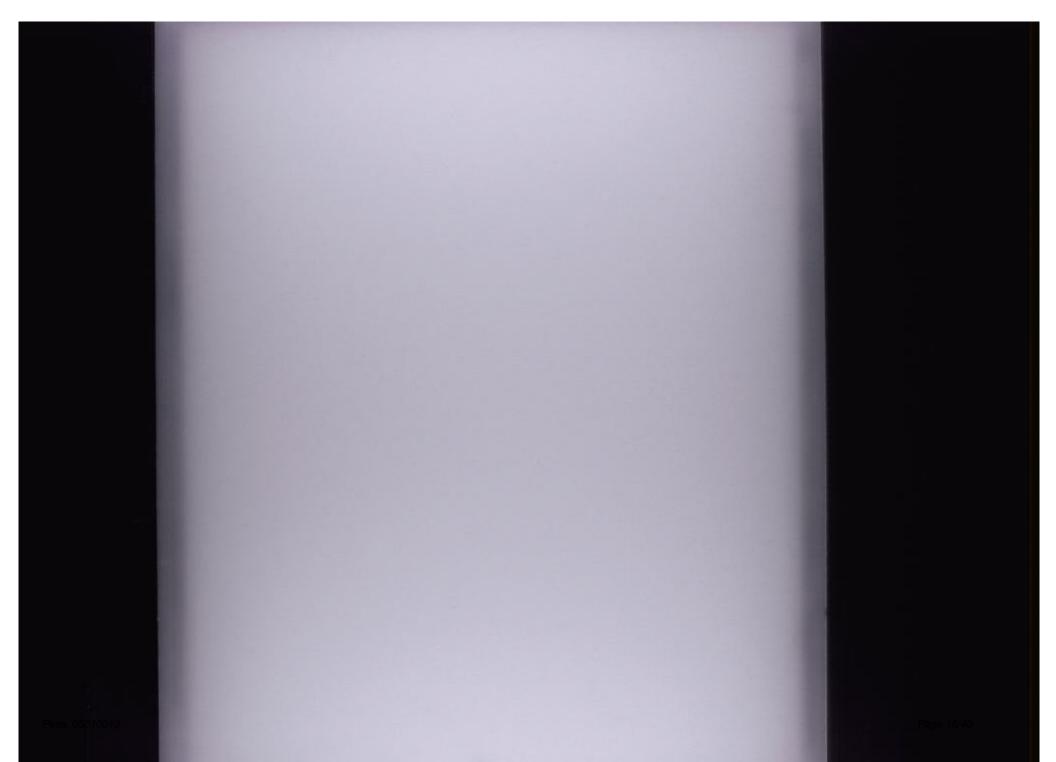


- 1. why does it make sense to regard a quantum state as describing multiple worlds?
- 2. does it even make sense to imagine ourselves splitting into multiple copies when measurement occurs?
- 3. What about probability?

Structure of lectures

Today: 1, 2 Thursday: 3

Also Thursday: nonlocality in the Everett interpretation.



Problems

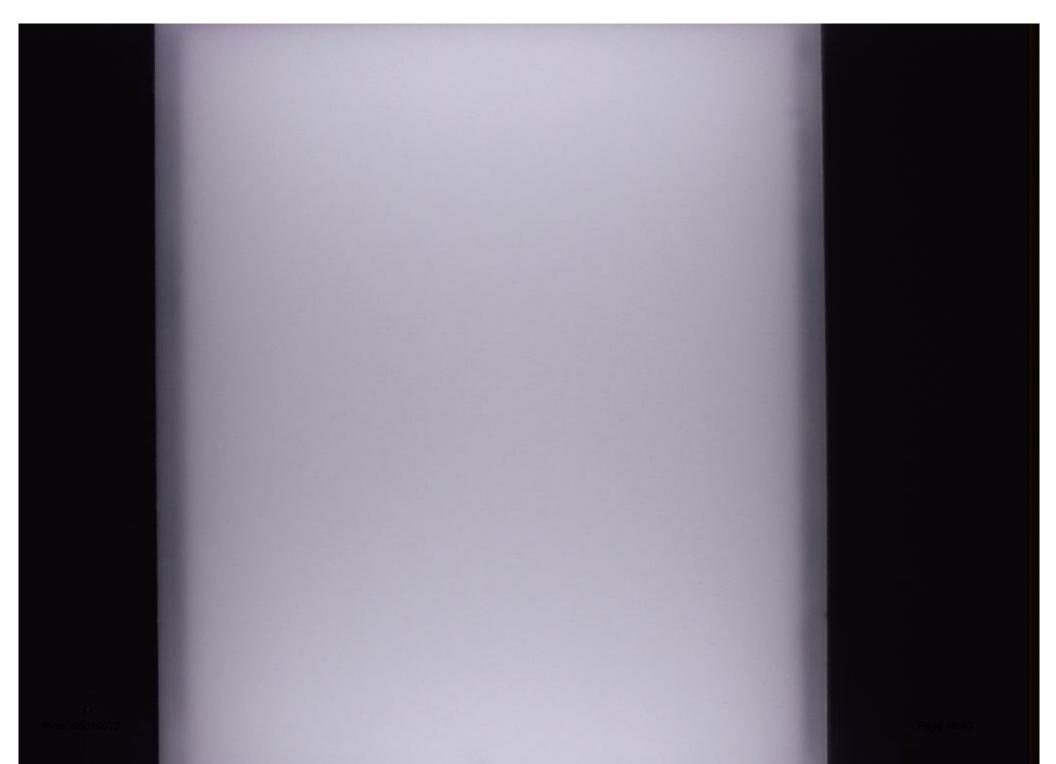


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The validity of "World" talk

$$|\psi\rangle = \frac{1}{\sqrt{2}} \left(|"| see spin up" \rangle + |"| see spin davn" \rangle \right)$$

- · Why are |" | see spin up" and | " | see spin down")
 the worlds?
- Why not $\alpha | "| see spin up" > + \beta | "| see spin down" >$ and $\beta^* | "| see spin up" > \alpha^* | "| see spin down" >$

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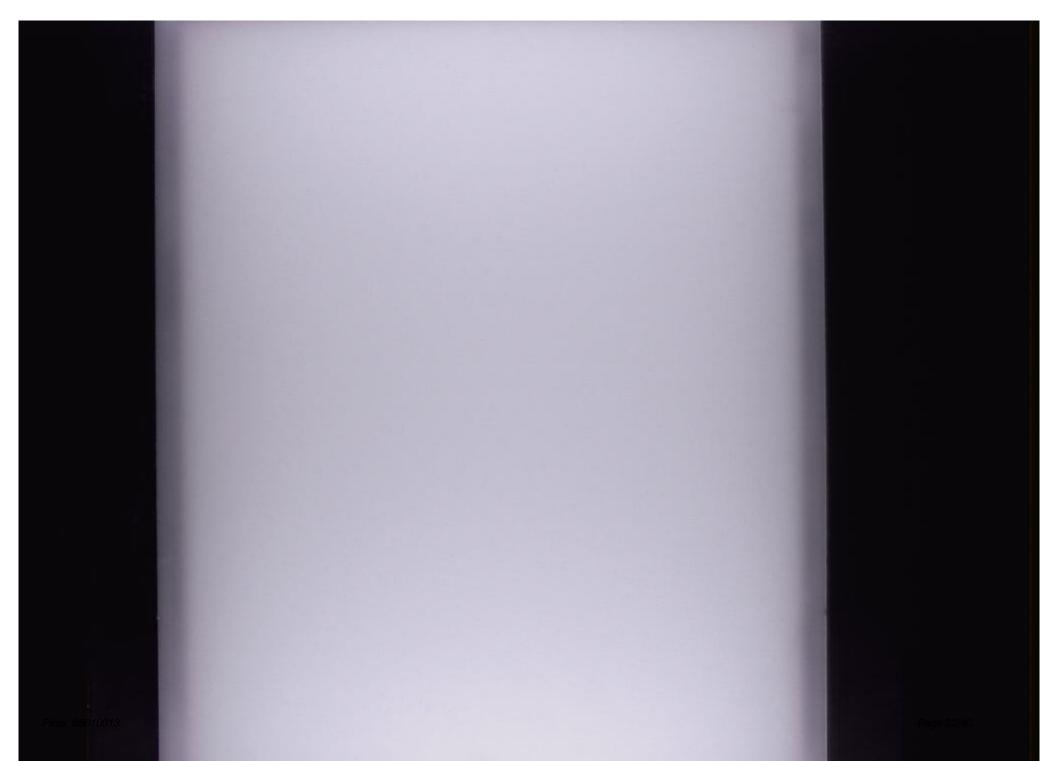
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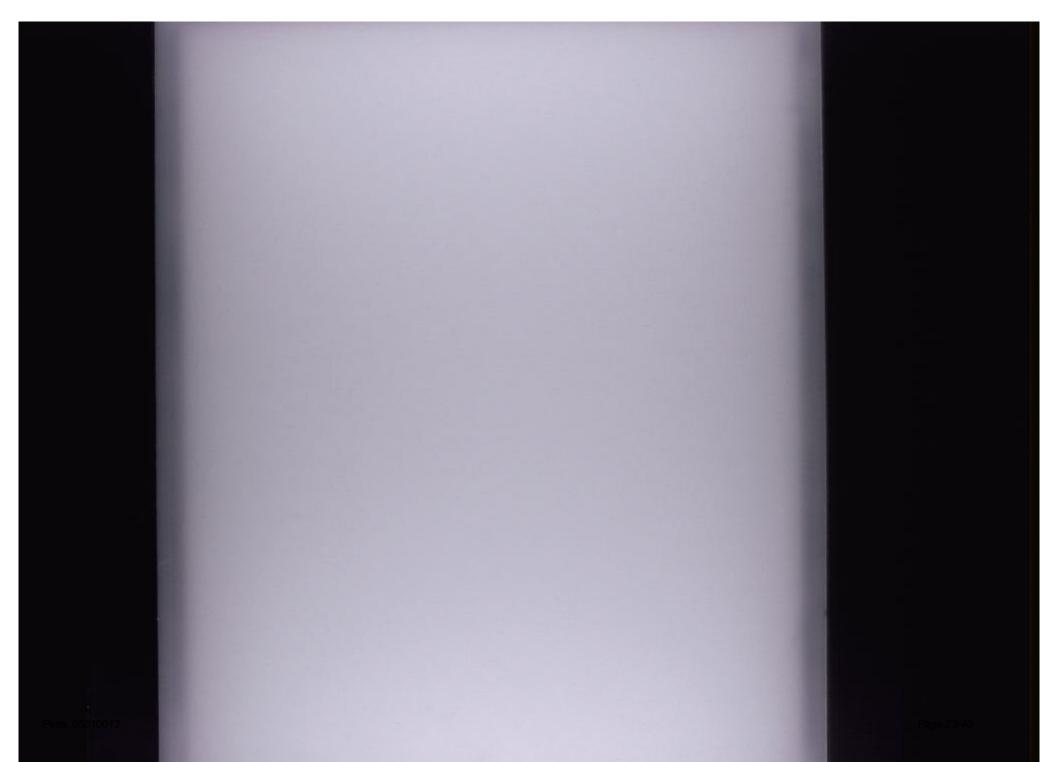
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The decoherence basis

We want a basis to pick out the worlds, such that each world is macroscopically definite.

Obvious candidate:

the basis preferred by decoherence

So:

Why not add a new physical postulate to QM:

"the quantum state, decomposed in the decoherence basis, describes an ensemble of worlds"

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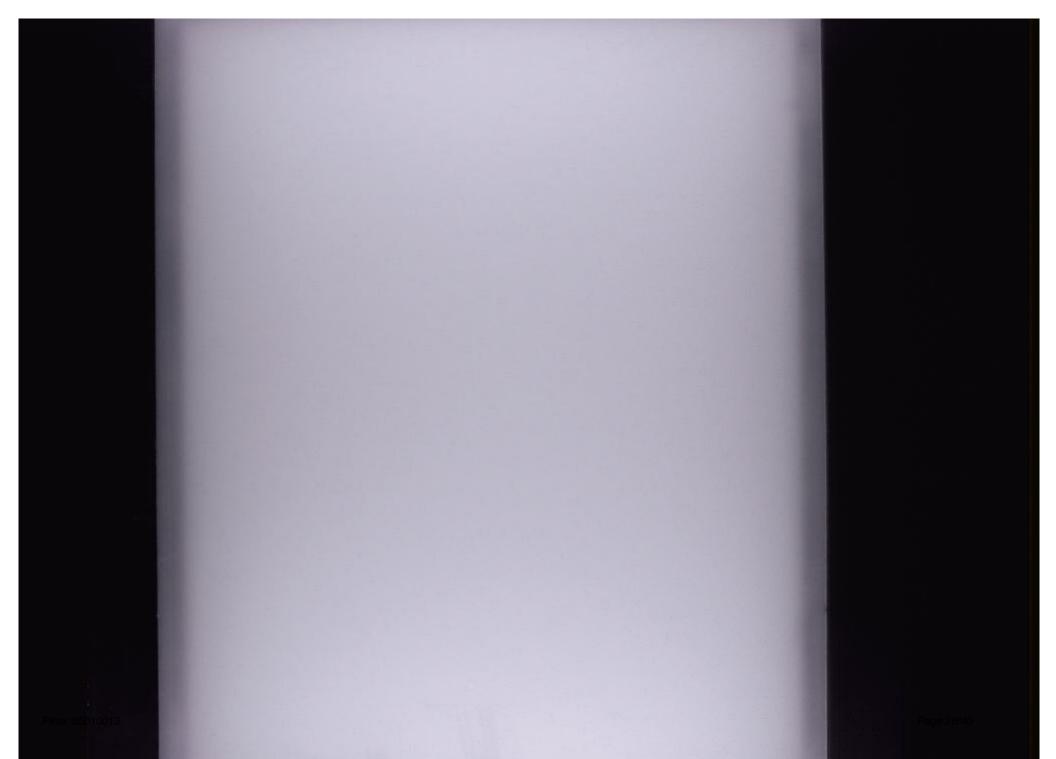
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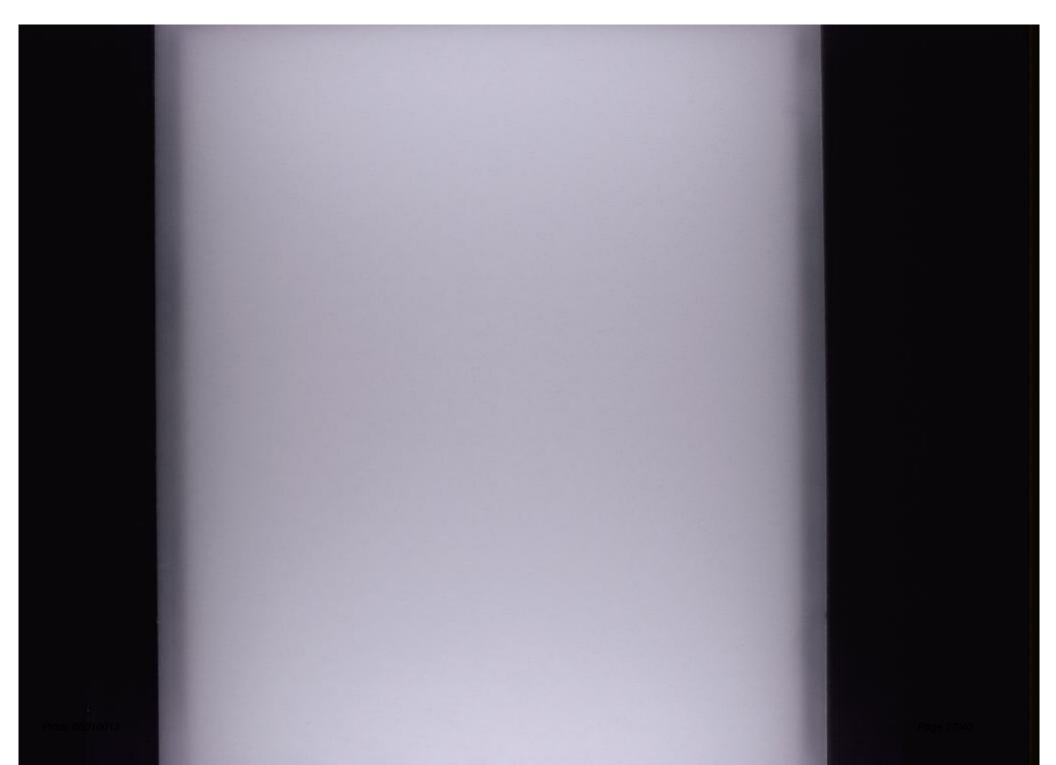
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So:

Why not add a new physical postulate to QM:

"the quantum state, decomposed in the decoherence basis, describes an ensemble of worlds"





2

NO!

- Decoherence is vague: it only approximately picks out a preferred basis,, and we don't want essential approximateness in our physical laws
- Decoherence is (or might be) ambiguous:
 no-one has succeeded in finding a
 microscopically-stateable set of rules to
 pick out the decoherence basis
- It misses the point: the advantage of the Everett interpretation is that it is an interpretation, not a recipe for new physics.

Instead what we need is an argument as to why, without any new physical postulate, it's already true that a decohered state is correctly described as an ensemble of worlds



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How to study tiger hunting patterns

Strategy 1: solve the 10³⁵ or so simultaneous differential equations that govern the dynamics of the atoms and electrons in the tiger's hunting grounds ... insane

Strategy 2: identify certain patterns within that swirl of molecules as cells etc, and use the language of cell biology, accepting a (small) reduction in theoretical accuracy

... still ludicrously hard

Strategy 3: identify certain patterns within the cell description as tigers, deer etc, and shift to the language of zoology & evolutionary adaptationism ... the norm

3 depends on 2 and 2 depends on 1, but we cannot abandon 3 and just use 1 or 2 without (a) losing all explanatory power, and (b) taking forever.



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Classical patterns in the quantum state

Applying this to quantum mechanics:

Macroscopic objects like cats, apparatus needles, people etc. are patterns instantiated, ultimately, in the positions and momentums of approximately-localised quantum-mechanical particles

... i.e. in expectation values of POVM operators O(p,q) that correspond to (fuzzy) measurements of position and momentum.

Decoherence tells us that if we have two such patterns, they will evolve independently. (Not a consequence of linearity alone – expectation values are quadratic in state.)

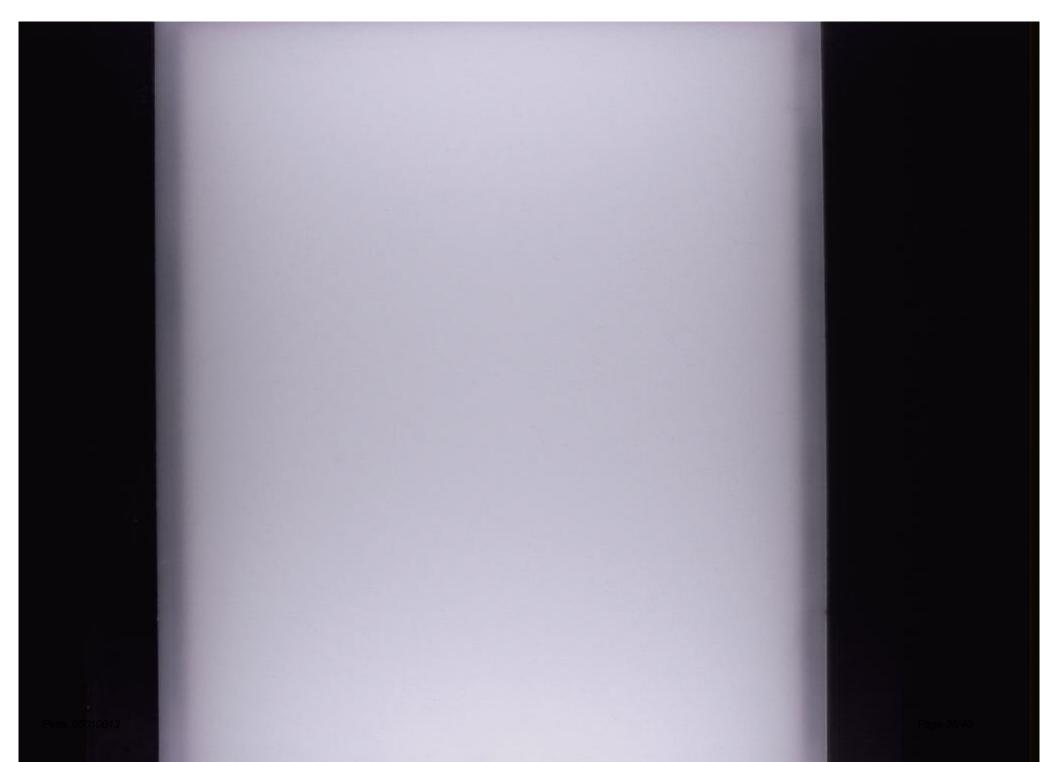
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Schrödinger Cat expt

(16)

The device

Begins in state l'initial">

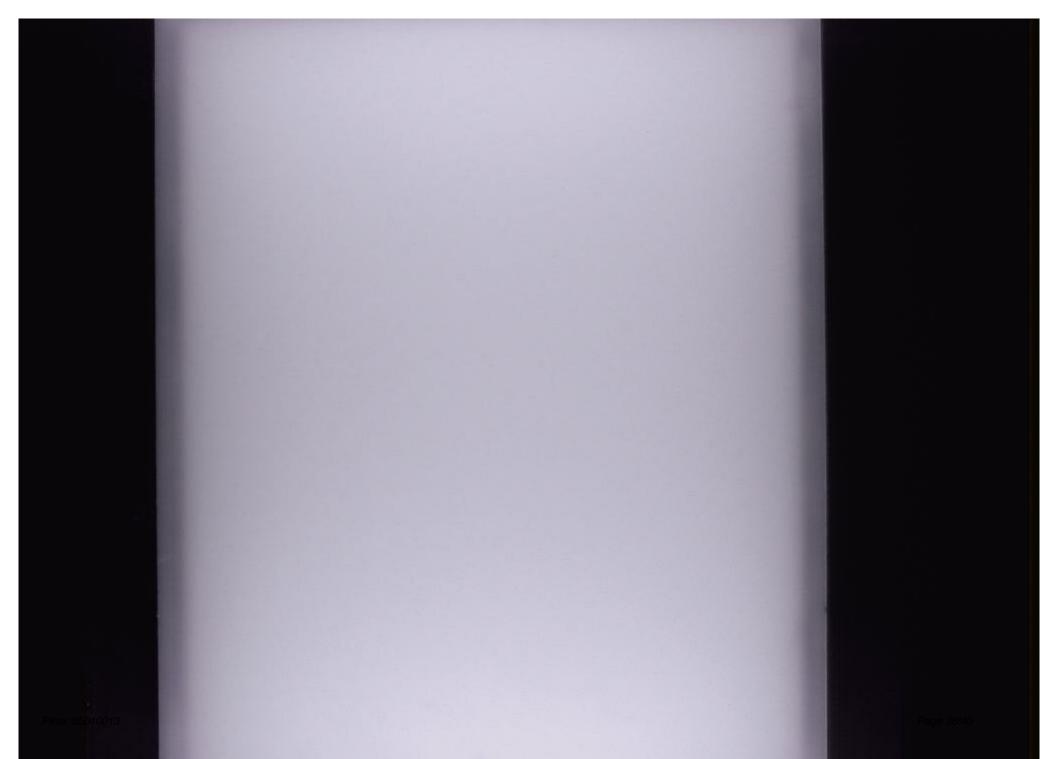
At 12 noon, is we input a spin- 2 particle the device executes

17>⊗ | "initial"> —> | ↑> ⊗ | "cyanide released"> | 1> ⊗ | "cat treat released">

Therefore is we put the device in the box with an unjustimate

- . If we input 17), it evolves into a dead cat
- . If we input II), it evolves into a live cat
- · If we input \(\frac{1}{12}(17)+12)\) it "evolves into a weight superposition"

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50...

- . If we input 17), there is a certain pattern (at, instartiated in the expedition values of 14)
- · If we input (4) there is a digreent such pattern (atz
- each evolving with no interprese from the other

... no "veird superportion"

... just two cats

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