Consciousness and the Collapse of the Wave Function

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Two Questions

- What is the place of consciousness in nature?
- What is the reality behind quantum mechanics?

Consciousness

- If consciousness can't be explained in physical terms, then it is nonphysical and fundamental.
- But if the physical domain is closed, consciousness can't play a causal role.

Quantum Mechanics

- Quantum mechanics postulates a wavelike reality where things don't have definite properties, but we experience a world with definite properties.
- How can this be explained?

Second derivative with respect to X

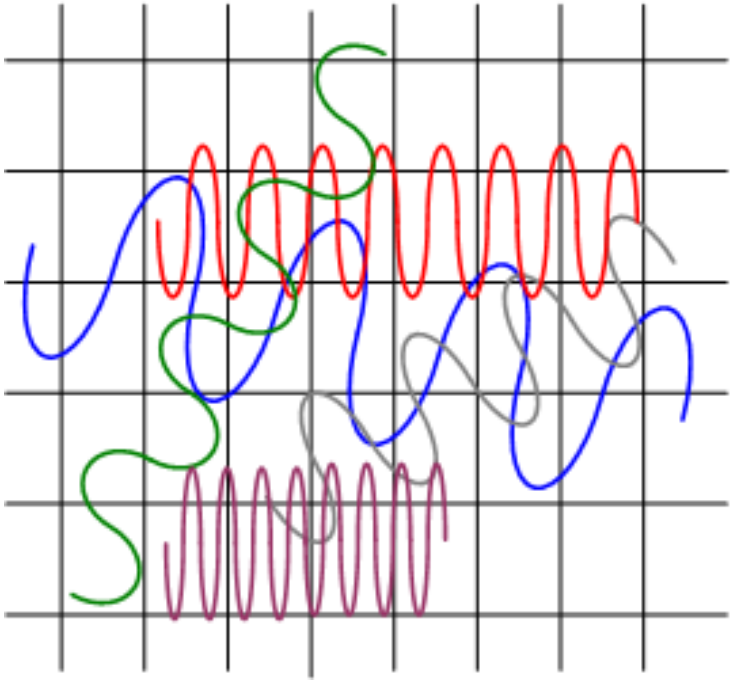
Shrodinger Wave Function

$$\frac{\partial^2 \psi}{\partial x^2} + \frac{8\pi^2 m}{h^2}(E - V)\psi = 0$$

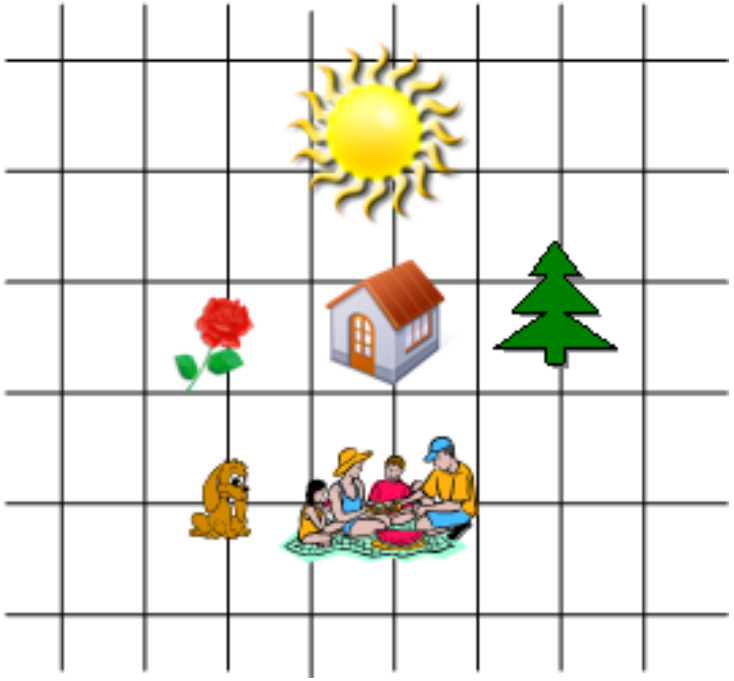
Position

Energy

Potential Energy

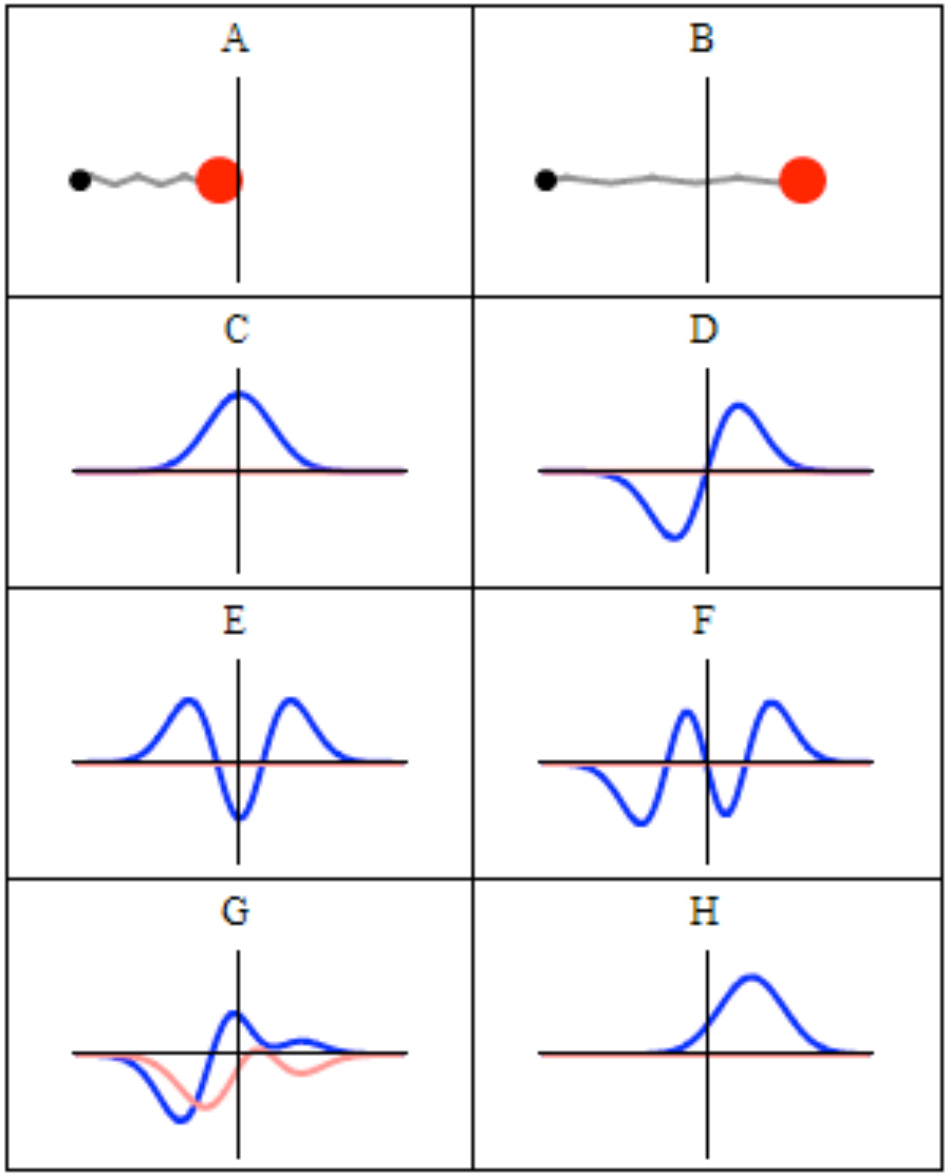


COLLAPSE OF THE WAVEFUNCTION



The Wave Function

- In classical physics, systems are described by definite values
  - A particle's position is specified by a definite location.
- In quantum mechanics, systems are described by wave functions.
  - A particle's position is specified by a wave function, with different amplitudes for different locations.

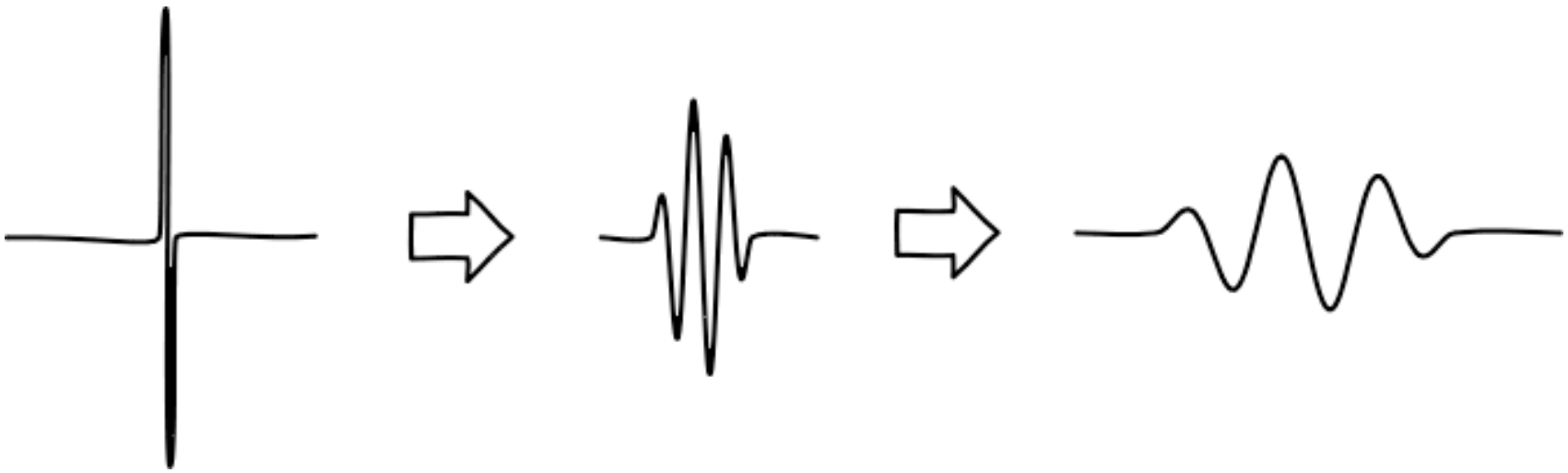

A
B
C
D
E
F
G
H

Superposition

- Sometimes a wave function will specify a definite position (all the amplitude at one position).
- But often it will specify multiple positions (nonzero amplitude at many positions).
- Then the particle is in a *superposition* of different positions.

The Schrodinger Equation

- The wave function usually evolves according to the Schrodinger equation
- Systems that start in definite states tend to evolve into superpositions.



$$H(t)|\psi(t)\rangle = i\hbar\frac{\partial}{\partial t}|\psi(t)\rangle$$

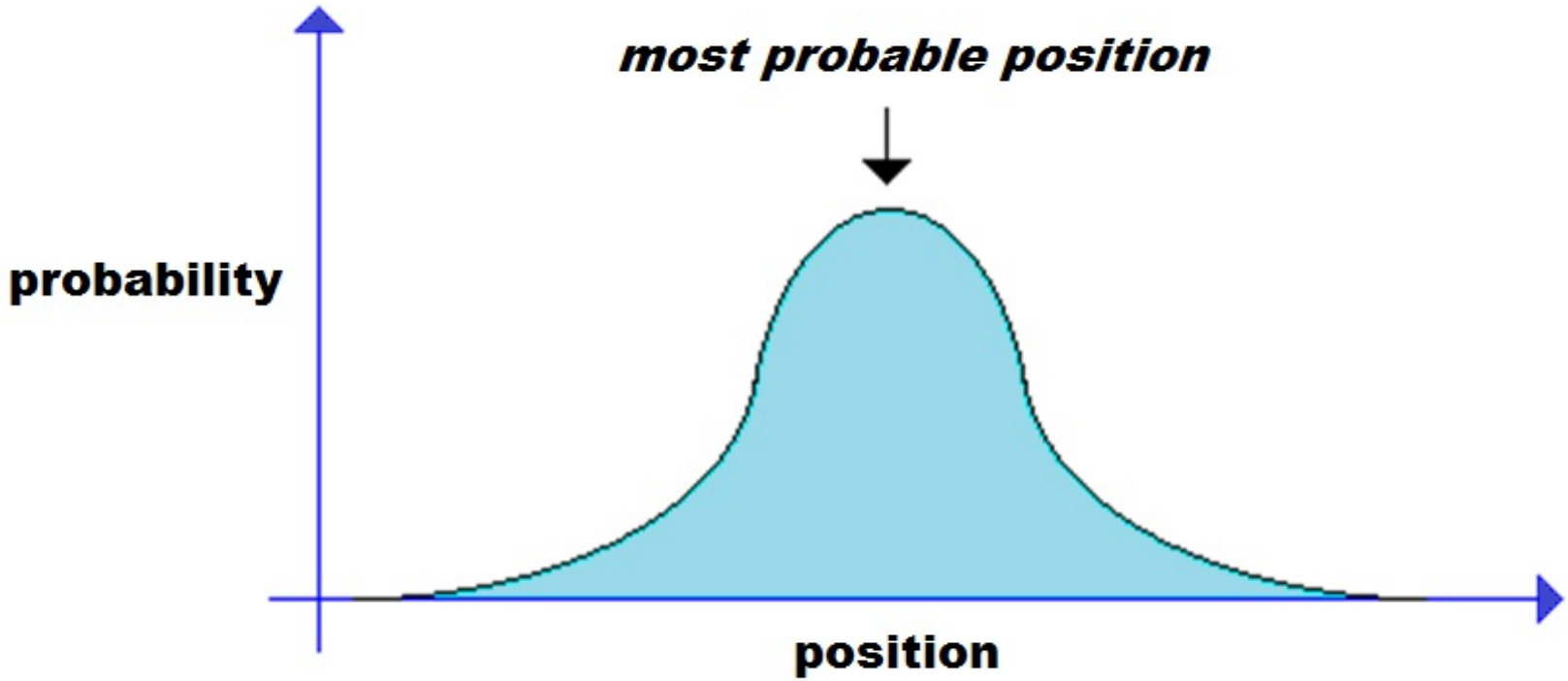
Measurement

- When one measures a quantity (such as position), one always observes a definite result.
- When a system is in a superposition of values, the measurement might reveal any of these values, probabilistically.

The Born Rule

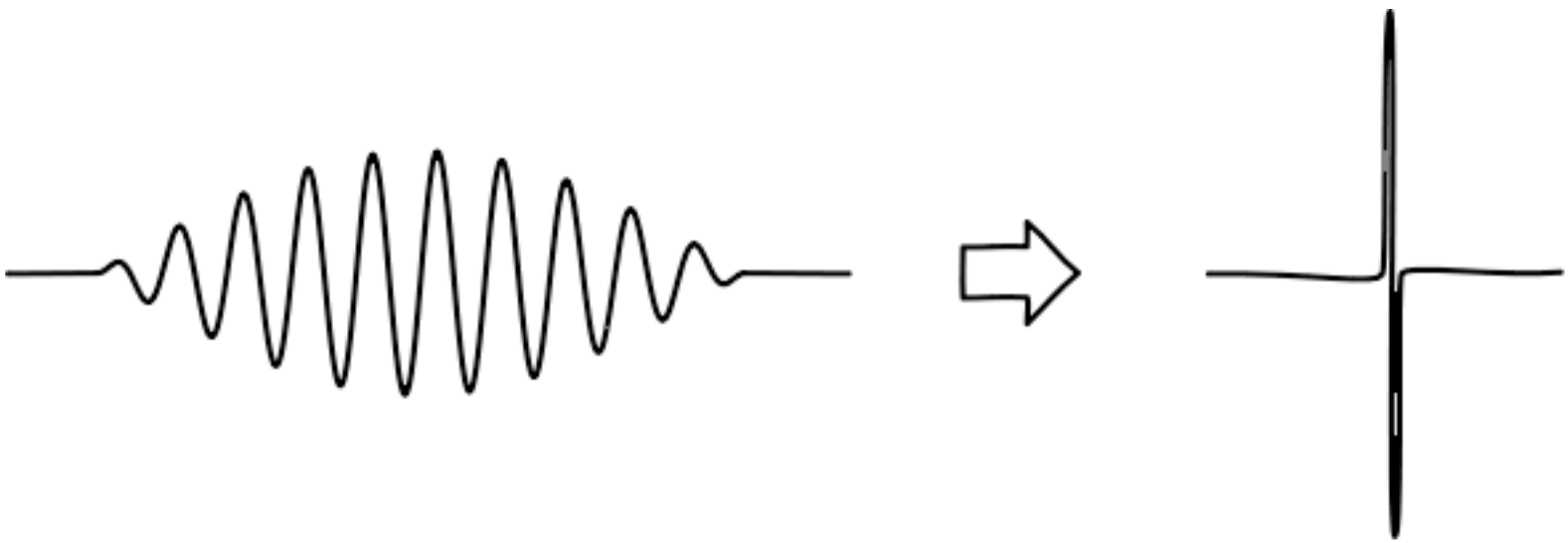
- If one measures position, the probability of finding that the particle is at that position is given by the Born rule.
- The probability depends on the wave function's amplitude at that position.

Quantum Wave Function



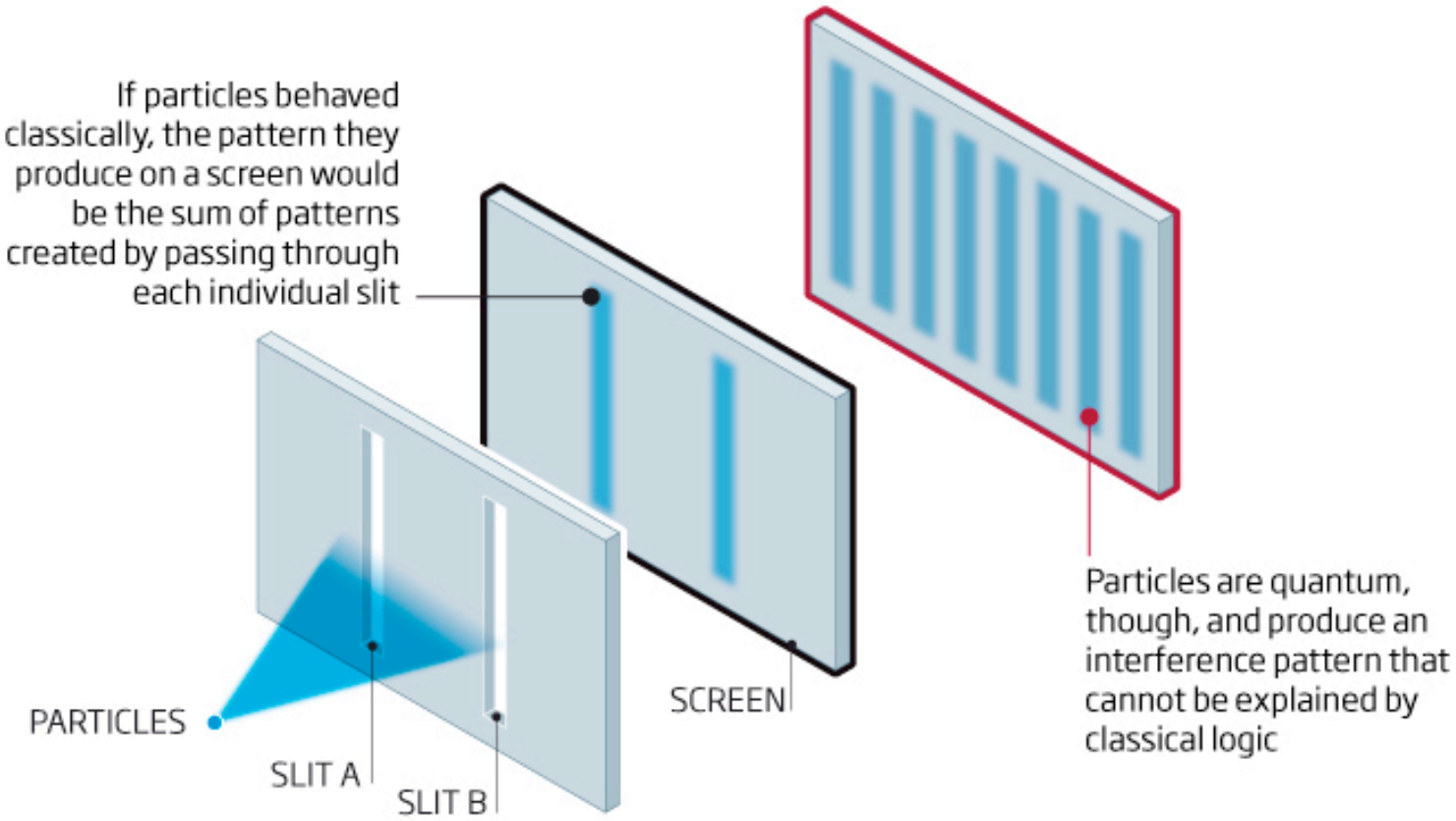
Collapse

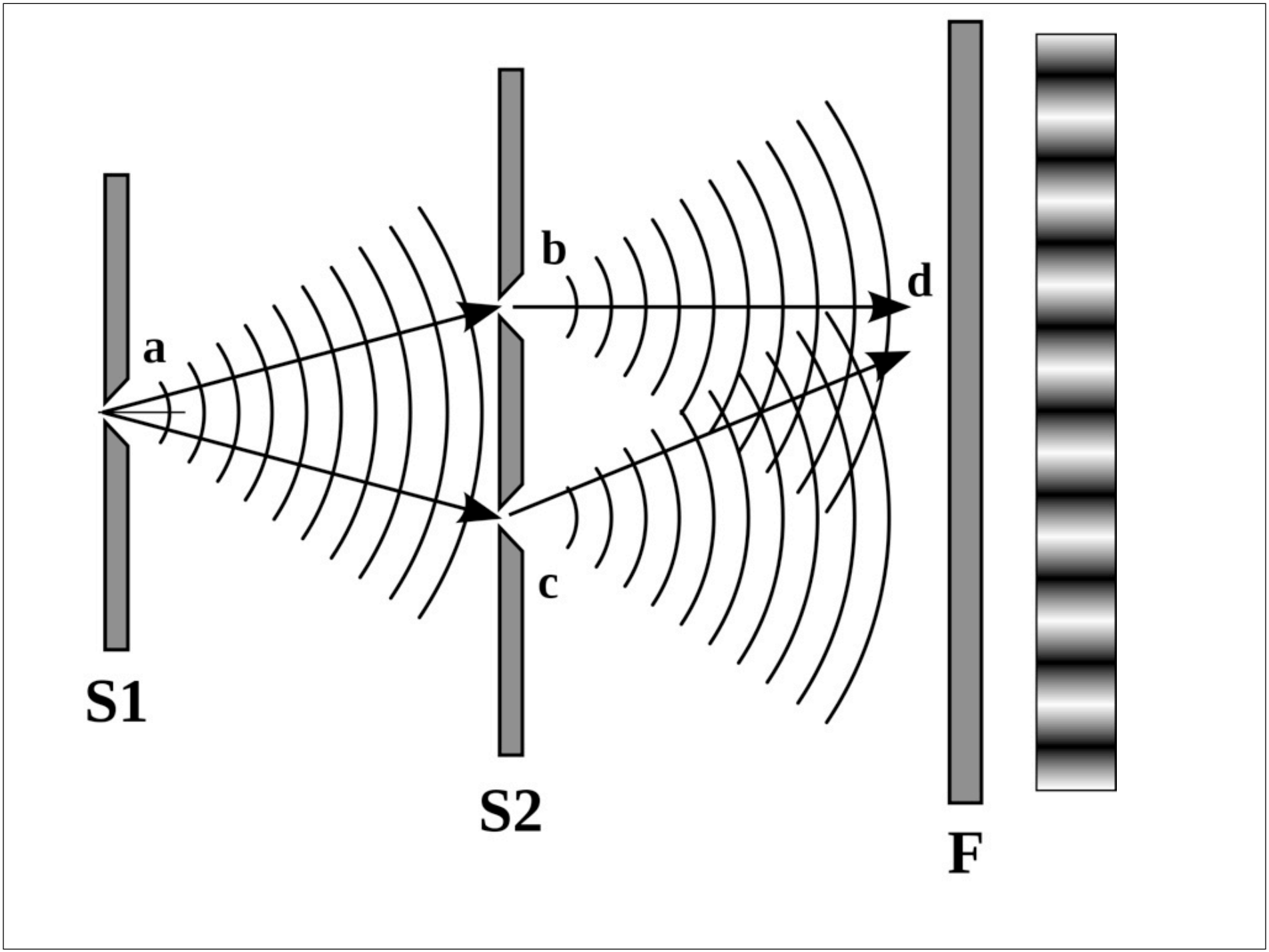
- After measurement, the wave function enters a new state corresponding to the measurement result.
- Initially: a superposition of position.
- After: a definite position (an eigenstate).
- This process is often called *collapse*.



The famous double slit experiment

This experiment illustrates the difference between quantum and classical mathematics




a
b
c
d
S1
S2
F

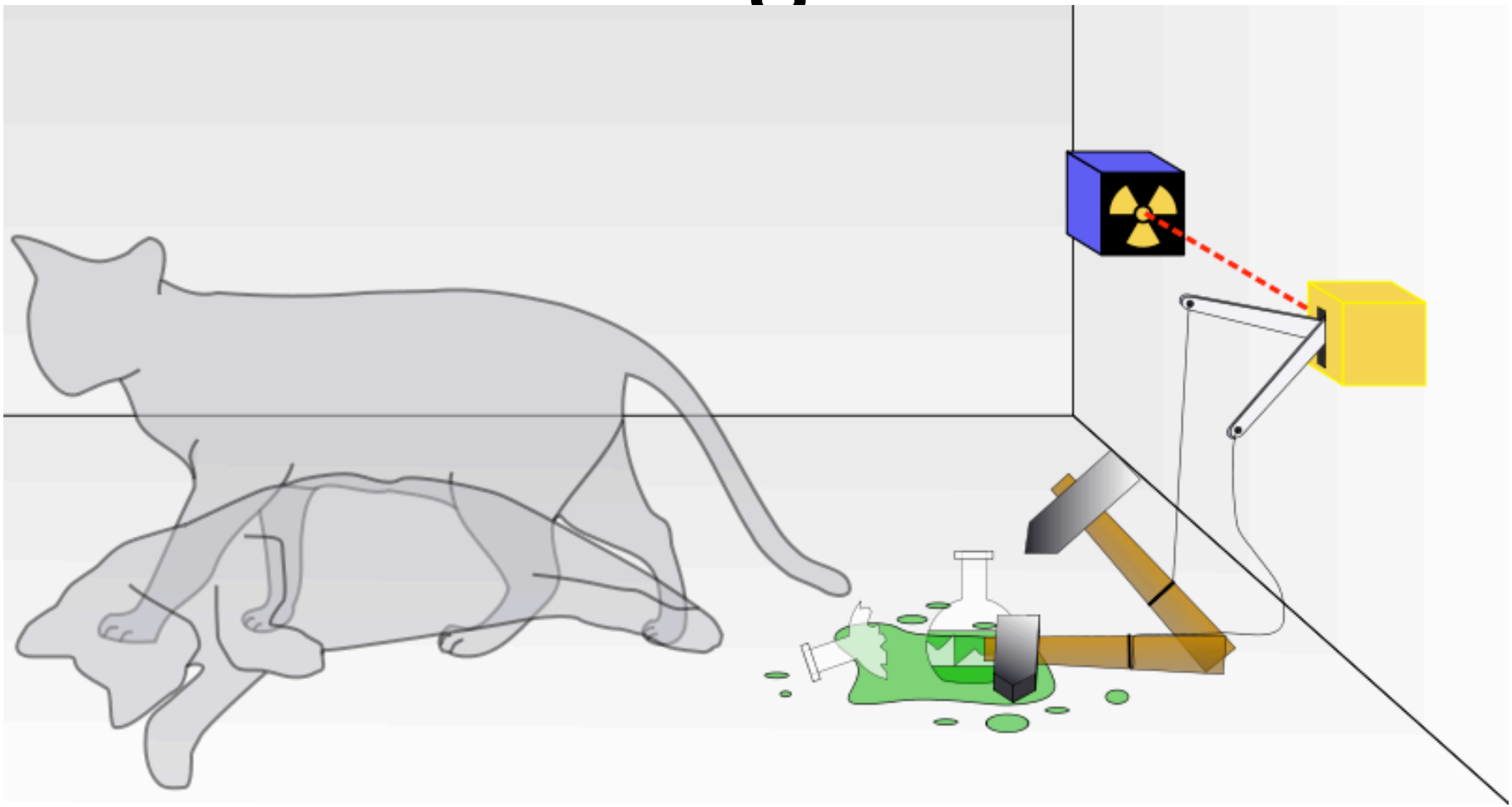
Formalism and Reality

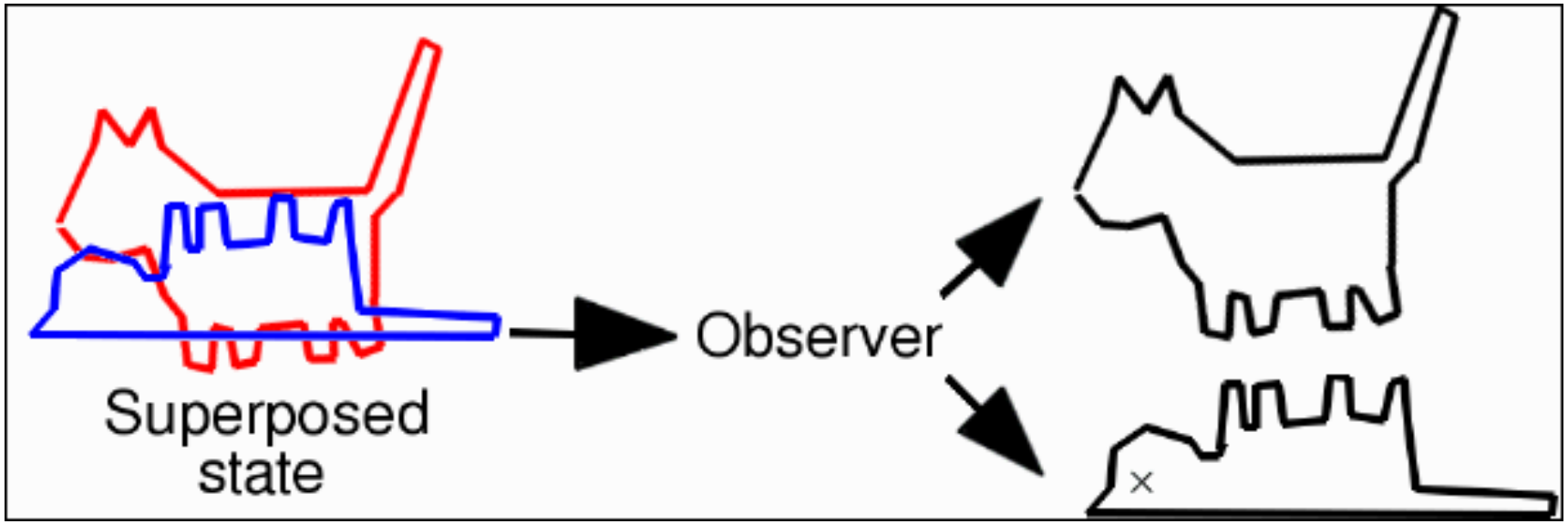
- Something like this story is standard formalism for predicting measurement results in quantum mechanics.
- But what is really going on in reality?

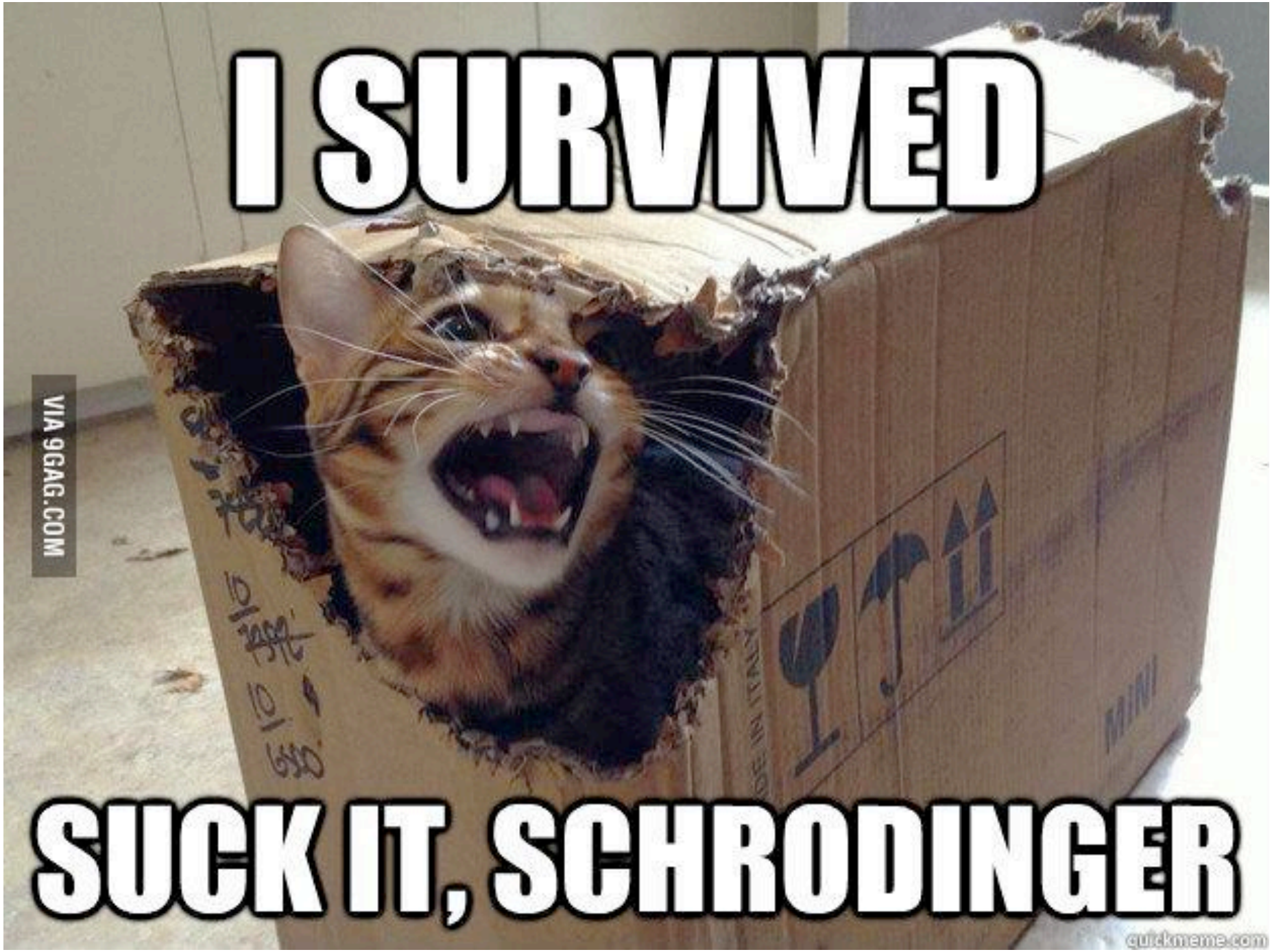
The Measurement Problem

- The formalism says collapse takes place on measurement; but measurement is an imprecise notion.
- What is measurement?
- And how can it play a fundamental role in physical dynamics?

Schrodinger's Cat




Superposed
state
Observer


I SURVIVED
SUCK IT, SCHRODINGER
VIA 9GAG.COM
quickmeme.com

Alternative Interpretations

- Hidden-variables (Bohm):
  - Particles have definite positions all along
- Many worlds (Everett):
  - Even macro systems are in superpositions
- Spontaneous collapse (GRW):
  - Collapses happen randomly

Face-Value Interpretations

- Collapses happen in reality, triggered by measurement events.
- One needs to precisify the notion of measurement and clarify the basic principles.

Two Options

- Measurement = observation by consciousness.
  - Consciousness triggers collapse
- Measurement = a physical process
  - A physical process triggers collapse

A Difficulty

- On the standard approach, one needs to precisify (i) "measurement event", (ii) "measuring a quantity Q".
- (ii) makes things difficult and seems to require a sort of intentionality.

Alternative Approach

- Alternative: focus on a special class of *measurement devices* and their *measurement properties*.
- E.g. pointer locations or meter readings or macroscopic locations are special
  - They never enter into superpositions
- Then: precisify "measurement property".

M-properties

- Hypothesis: There are special properties, m-properties (m-quantities or m-observables).
- Fundamental principles: m-properties can never be superposed.
  - A system's wave function is always in an eigenstate of the m-operator.

Superposition

- Whenever an m-property enters a superposition, it collapses to definiteness.
- Whenever it is about to enter a superposition, it collapses to definiteness.
- Probabilities are given by Born rule for the associated m-operator.

What are M-Properties

- One could in principle take any property to be an m-property.
- Different choices of m-properties yield different interpretations.

M-Particles

- Illustrative idea: m-properties = position of special particles, m-particles.
  - Fundamental or not (e.g. molecules)
- Law: M-particles always have definite positions

Dynamics

- Dynamics given by mathematics of continuous strong measurement of m-quantities.
- As if: someone external to the system was constantly measuring m-quantities.

Entanglement

- Whenever a superposed property becomes (potentially) entangled with an m-property, that property collapses.
- E.g. a photon with superposed position interacts with an m-particle
  - The m-particle probabilistically collapses to definite position, so does the photon.

Superposition Dynamics

- Initially: Photon is in superposition P1 + P2, M-particle is in location M.
- Photon interacts with M-particle in a way that would produce P1.M1 + P2.M2
- M-particle collapses onto M1 or M2
- Result: P1.M1 (or P2.M2). Photon collapses too!

M-Particles as Measurers

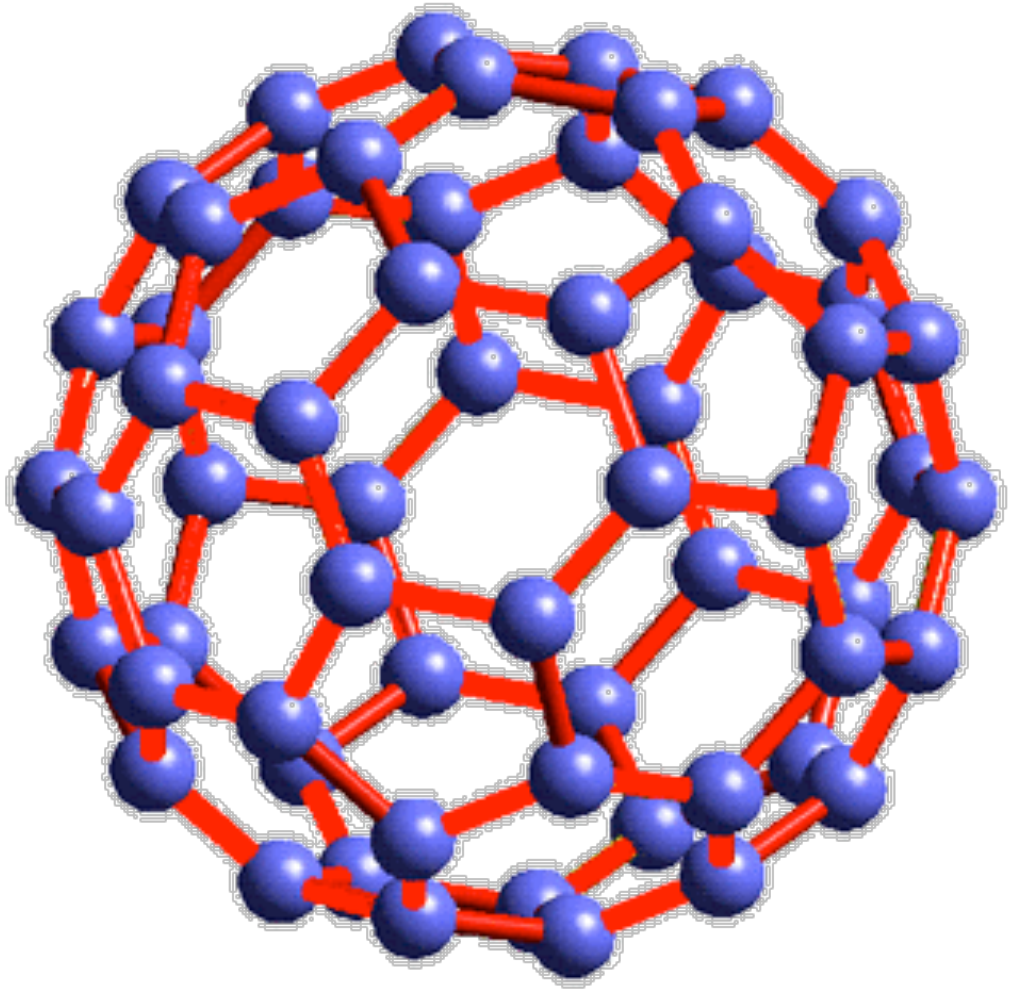
- The M-particle in effect acts as a measuring instrument.
- If an M-particle is in a slit of the double-slit experiment, it collapses the position of a superposed photon.
- M-particle = Medusa particle (everything it looks at turns to stone).

Medium Rare M-Particles

- M-Particles would need to be rare enough
  - So that superpositions could persist, yielding the interference effects we see
- But they can't be too rare
  - E.g. found in macro systems or brains, so that measurements always yield results

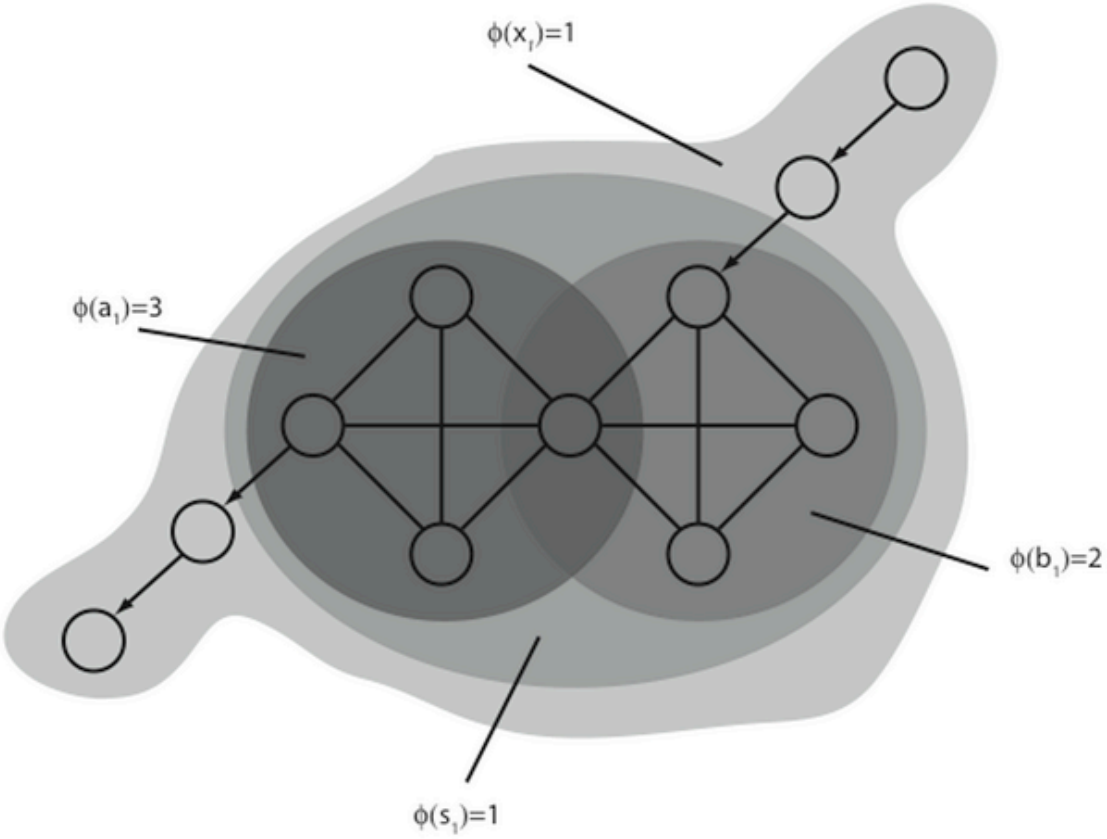
Constraints on M-Properties

- Same constraints on m-properties
- Rare enough that observed interference effects don't involve m-properties
  - Rules out position, mass, buckyballs
- Common enough that measurements always involve m-properties
  - At least present in brains



Some Candidates

- Configurational properties of complex systems (e.g. molecular shape)
- Molecular energy (above a threshold)
- Tononi's phi (above a threshold)
- Mental properties (e.g. consciousness).



$$ei(x_1; P) = -\sum_{i=1}^{k}\sum_{\mu_0^{(i)}} p(\mu_0^{(i)}|x_1)\,\log p(\mu_0^{(i)}|\mu_1^{(i)}) - H(X_0|x_1)$$

$$\Phi(x_1) = \min_{P} \frac{ei(x_1; P)}{\nu_P}$$

Different Predictions

- Different hypotheses yield different empirical predictions
  - Interferometer: try to prepare a system in a superposition of m-properties, see if interference effects result.
- Very hard to test! (So far: buckyballs?)
  - But in principle makes all this testable.

Objections

- Is energy conserved?
- Is this compatible with relativity?
- Are there infinite long tails?
- What about the quantum Zeno effect?
- Are m-properties fundamental?

Consciousness and Collapse

- Consciousness collapses the wave function?
  - von Neumann (1932), London and Bauer (1939), Wigner (1961), Stapp (1993)
- Never made rigorous.

Consciousness as an M-Property

- Hypothesis: consciousness is an m-property
- I.e. consciousness can never be superposed
- Whenever consciousness is about to enter a superposition, the wave function collapses

Entanglement with Consciousness

- Take a superposed electron: S1 + S2
- We consciously perceive it, potentially yielding S1.C(S1) + S2.C(S2)
- Consciousness collapses probabilistically to C(S1) [say], electron collapses to S1
- Result: definite state S1.C(S1).

Virtues of Consciousness as M-Property

- Conceptual: clarifies measurement
- Epistemological: saves observation data
- Explanatory: explains nonsuperposability
- Metaphysical: fundamental property in law
- Causal: physical role for consciousness

Physicalism and Dualism

- This is consistent with physicalism
  - Consciousness is complex/physical
- Also consistent with dualism
  - Consciousness is fundamental/nonphysical
- Not consistent with panpsychism!

Causal Closure

- Philosophers often reject dualism because physics is causally closed, leaving no role for consciousness.
- In fact, physics leaves a giant causal opening in the collapse process.
- Perfectly suited for consciousness to fill!

Physics and Philosophy

- Physicists often reject consciousness-collapse because of dualism
- Philosophers often reject dualism because of incompatibility with physics
- Independent reasons for rejection needed!

Property Dualism

- Consciousness is a fundamental property, involved in fundamental psychophysical laws
  - Epiphenomenalism: unidirectional laws, physics to consciousness
  - Interactionism: bidirectional laws

Bidirectional Laws

- Physics-to-consciousness law:
  - Physical quantity P (e.g. Tononi: high-phi) yields consciousness
- Consciousness-to-physics law
  - Consciousness is never superposed
  - C-collapse yields P-collapse

Worry: Macro Superpositions

- Worry: Unobserved macroscopic systems will be in superpositions
- Response: This depends on the complexity of property P; but if so, so be it.

Worry: Indistinguishability

- C-Collapse is empirically equivalent to P-collapse: P (e.g. high-phi) is an M-property
  - Quantum zombie worlds?
- Response: C-collapse has extra explanatory, metaphysical, and causal virtues.

Test for Consciousness

- An empirical criterion for consciousness?
- Say we find empirically that property P is associated with collapse
- This will give us (perhaps nonconclusive) reason to accept that P is the physical correlate of consciousness
  - Especially if P is independently plausible as a correlate, e.g. high-phi.

Worry: Causal Role in Action

- What about a causal role in action?
- Consciousness collapses brain states that lead to action (.red causes ‘I’m seeing red’)
- Collapses of agentive experience yield an especially direct role

Worry: Dice-Rolling Role

- Consciousness is just rolling quantum dice
  - Yielding probabilistic outcomes the same as in quantum zombies
  - Doesn't make us more likely to behave intelligently or say 'I'm conscious'
- But: at least it's playing/explaining the role

Worry: Quantum Zeno Effect

- Quantum Zeno Effect: Frequent quantum measurement makes it hard for measured quantities to change
- Worry: continuous collapse of consciousness will make it hard (probability zero) for consciousness to evolve

Quantum Zeno Effect

- How to handle Quantum Zeno Effect?
  - Work through the math (some change in measured quantities is possible).
  - Alternative frameworks: discrete time, ongoing collapse by localization

Conclusion

- C-collapse interpretations promise simultaneously
  - an attractive, empirically testable interpretation of QM
  - an attractive approach to the mind-body problem.
- A place for the mind in nature?