Consciousness and the Collapse of the Wave Function

David Chalmers and Kelvin McQueen

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

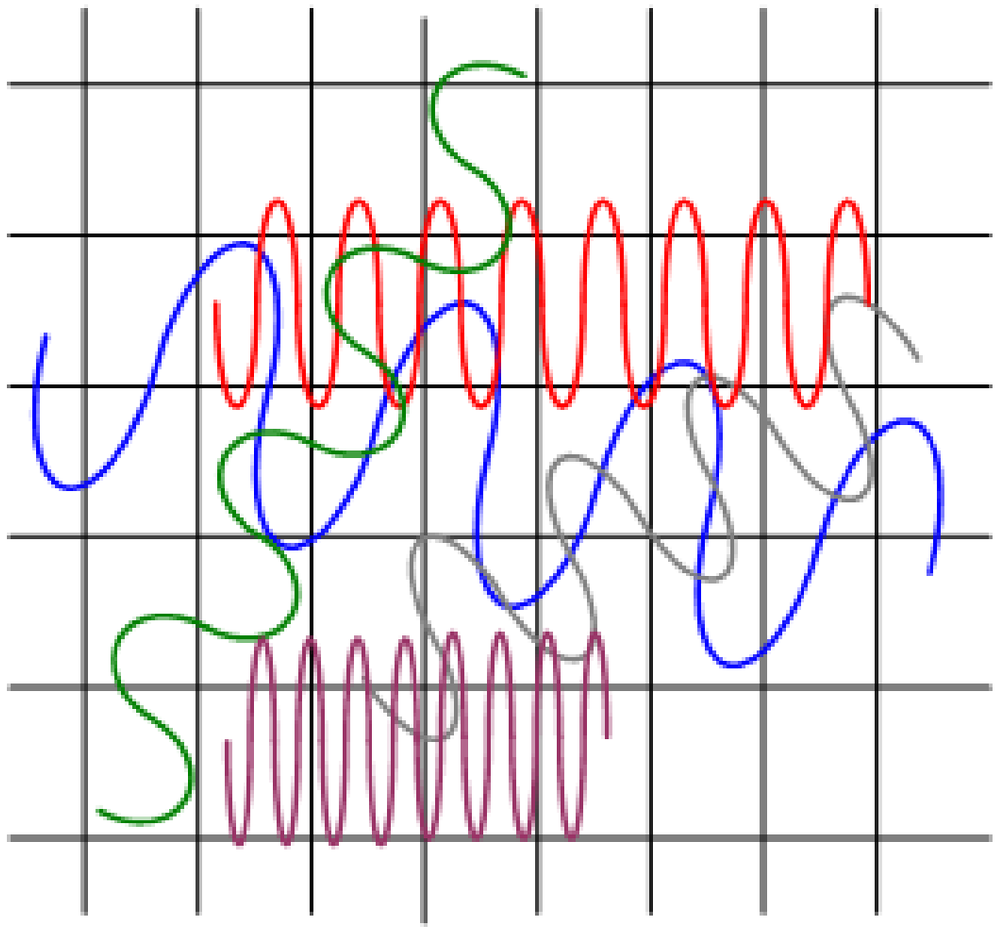
Shrodinger Wave Function

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

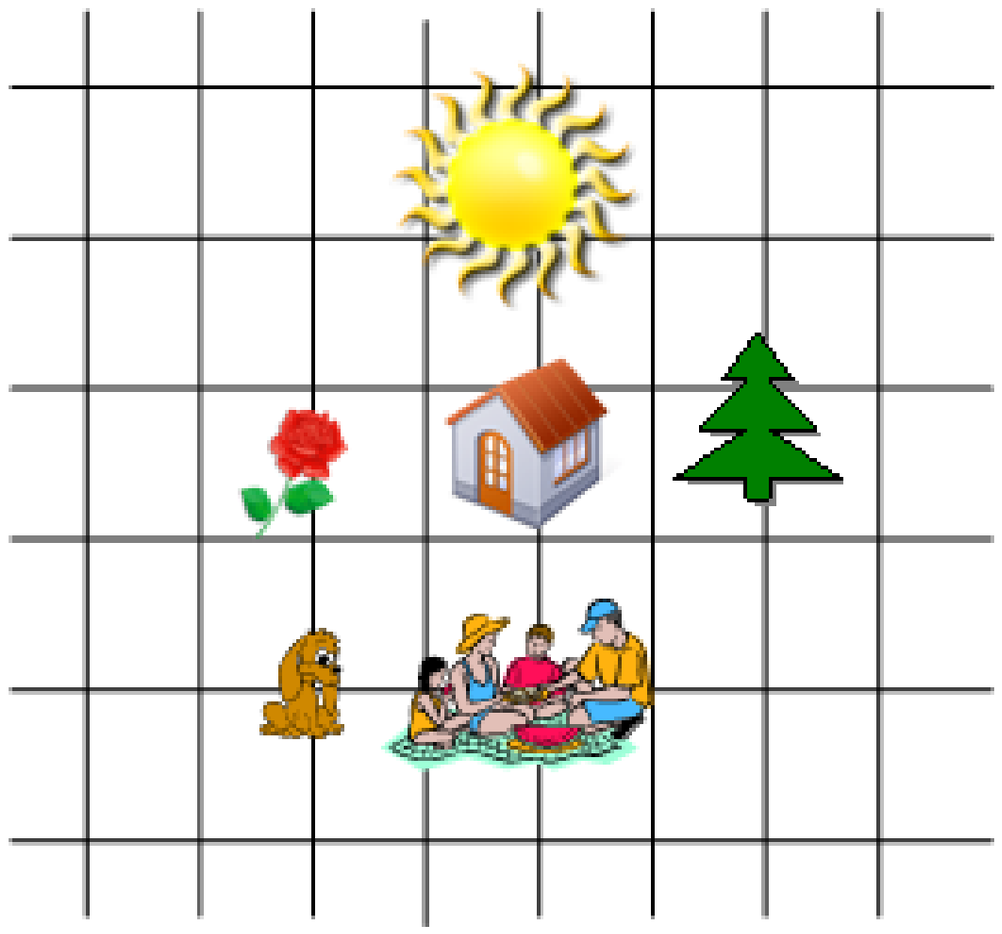
Position

Energy

Potential Energy



COLLAPSE OF THE WAVEFUNCTION



Textbook quantum mechanics

- Quantum mechanics posits two laws of nature:
  - The Schrödinger equation
    - Deterministic
  - The collapse postulate
    - Indeterministic

Textbook quantum mechanics

- When does each law apply?
- Textbook answer:
  - Schrödinger equation applies to non-measured systems.
  - Collapse postulate applies to measured systems.

The measurement problem

- Preliminary analysis:
  - Notion of “measurement” not well defined.
  - Measurement is not a good candidate for a fundamental physical process.

The measurement problem

- The problem runs deeper…
  - Quantum systems are typically in **superpositions** of distinct values for a given property.
    - Schrödinger equation describes deterministic evolution of superpositions.
    - Collapse postulate describes indeterministic transition to familiar definite states.

Superposition

- Particles are typically:
  - In superpositions of different positions.
  - In superpositions of different states of momentum.
  - In superpositions of being both spin-up and spin-down.
  - And so on.

Wave Functions

- Quantum states are described by wave functions.
- Wave-function Ψ for particle in a superposition of being *here* and being *there* is a weighted sum:

$$|\Psi> = a_1|\text{here}> + a_2|\text{there}>$$

- (The “|>” signifies a vector)
- a_1 and a_2 are numbers: “amplitudes”. The sum of the squares of their absolute values is always one:

$$|a_1|^2 + |a_2|^2 = 1.$$

The Born Rule

- A particle in this state…

$$|\Psi> = a_1|here> + a_2|there>$$

...has a $|a_2|^2$ probability of being located *there* given a position measurement.

- A particle in this state:

$$|\Psi> = |here>$$

..is in a definite position. It is located *here* with probability one.

Schrödinger equation

- Deterministic
- Tends to evolve definite states into superpositions.
  - E.g. rapidly spreads position superpositions....
    t1: |here>
    t2: a_1|here> + a_2|there> + a_3|elsewhere>
    ...where $|a_1|^2 + |a_2|^2 + |a_3|^2 = 1$.
- Linear: spreads superpositions *from one system to another* (“entanglement”).

Linearity

- Suppose system S is subject to certain forces and constraints so that:
  - If S's initial state is |A> then S's later state is |A'>
    - And:
  - If S's initial state is |B> then S's later state is |B'>

- Linearity then entails:
  - If S's initial state is $a_1|A> + a_2|B>$
    then S's later state is $a_1|A'> + a_2|B'>$

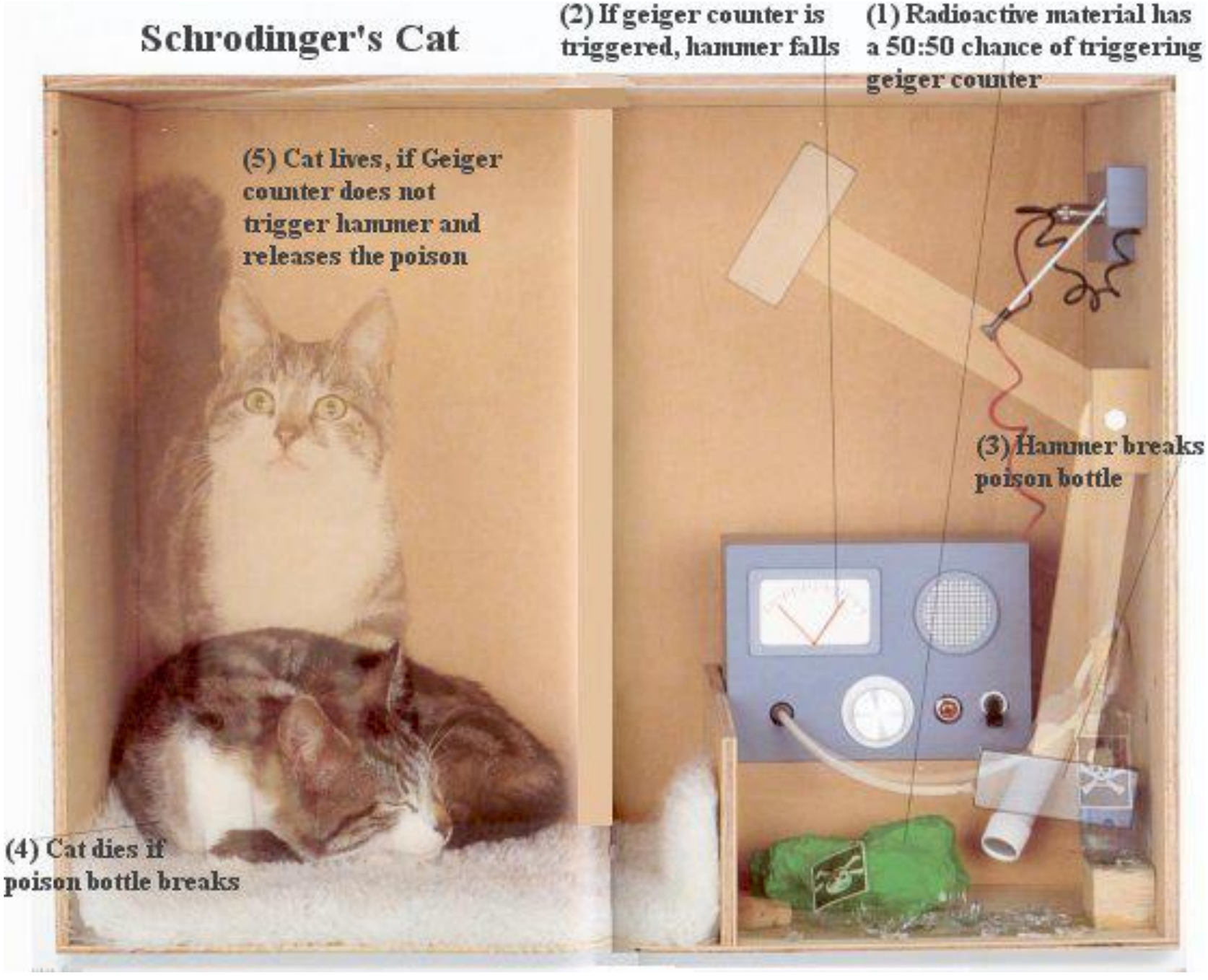
Entanglement

- Let S be a cat in a box whose life or death is determined by whether a (poisonous-gas releasing) device measures a particle to be *here* or *there*:

  |alive>|here> → |alive>|here>
  |alive>|there> → |dead>|there>

- Linearity then entails:
  - If initial state is: |alive>(a_1|here> + a_2|there>)
    - Equivalently: a_1|alive>|here> + a_2|alive>|there>
  - Then later state is: a_1|alive>|here> + a_2|dead>|there>
    - The cat's life is entangled with the particle's position!

Schrödinger’s cat



Source of the problem

- (i), (ii), & (iii) are mutually inconsistent.
  - (i) The wave-function of a system is complete i.e. specifies all of its the physical properties.
  - (ii) The wave-function always evolves via a linear equation (Schrödinger equation).
  - (iii) Measurements always (or at least usually) have single definite outcomes.
- Textbook QM denies (ii) with “collapse on measurement” yielding the measurement problem.

Standard Solutions

- Hidden-variables (Bohm):
  - Denies (i): Particles have definite positions all along
- Spontaneous collapse (GRW):
  - Denies (ii): Collapses happen randomly
- Many worlds (Everett):
  - Denies (iii): Macro superpositions interpreted as multiple macro systems

Face-Value Solutions

- 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

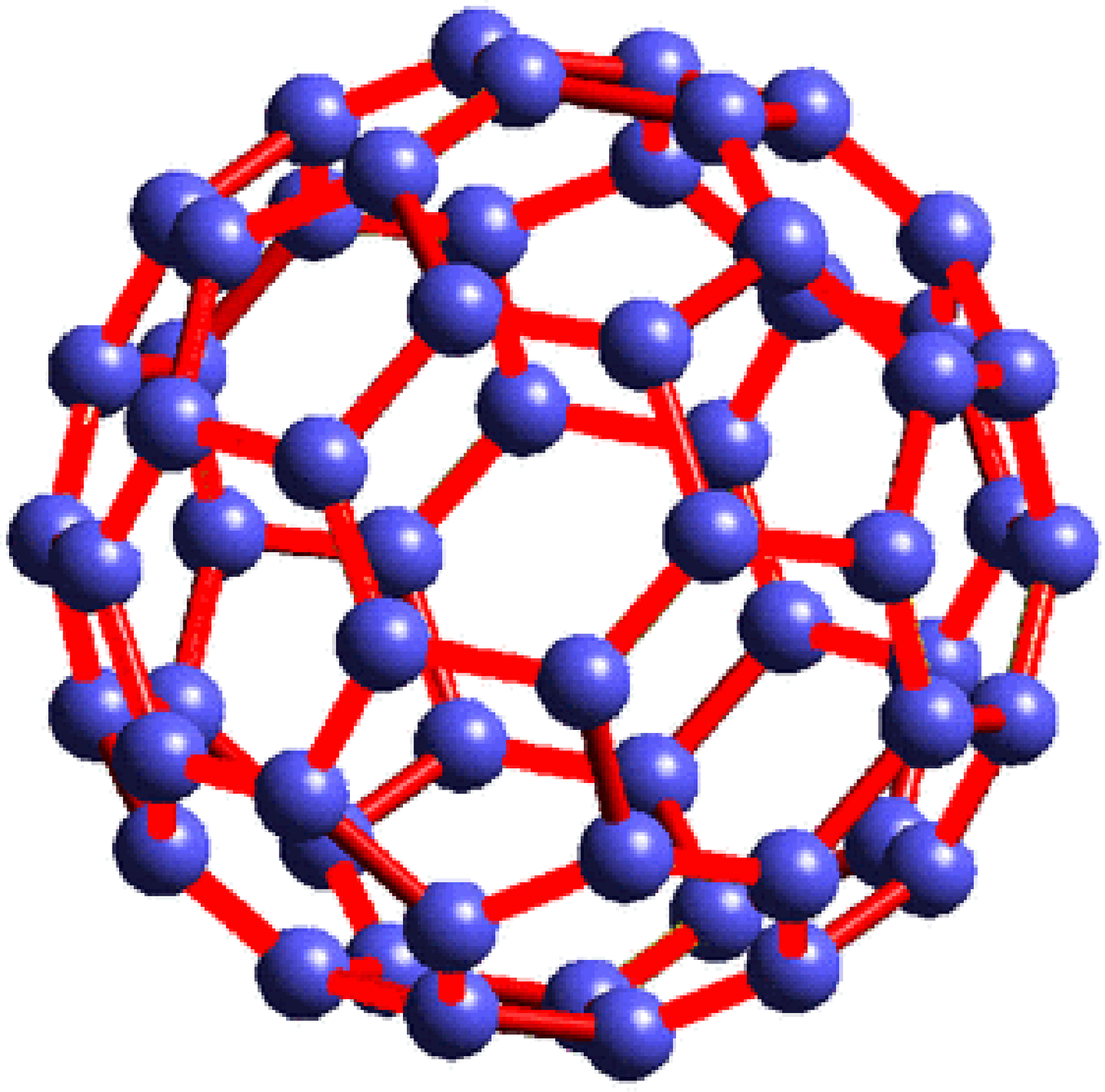
- The M-particle in effect acts as a measuring instrument.
- If an M-particle is in a slit of the double-slit experiment, it collapses the position of a superposed photon.
- M-particle = Medusa particle (everything it looks at turns to stone).

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

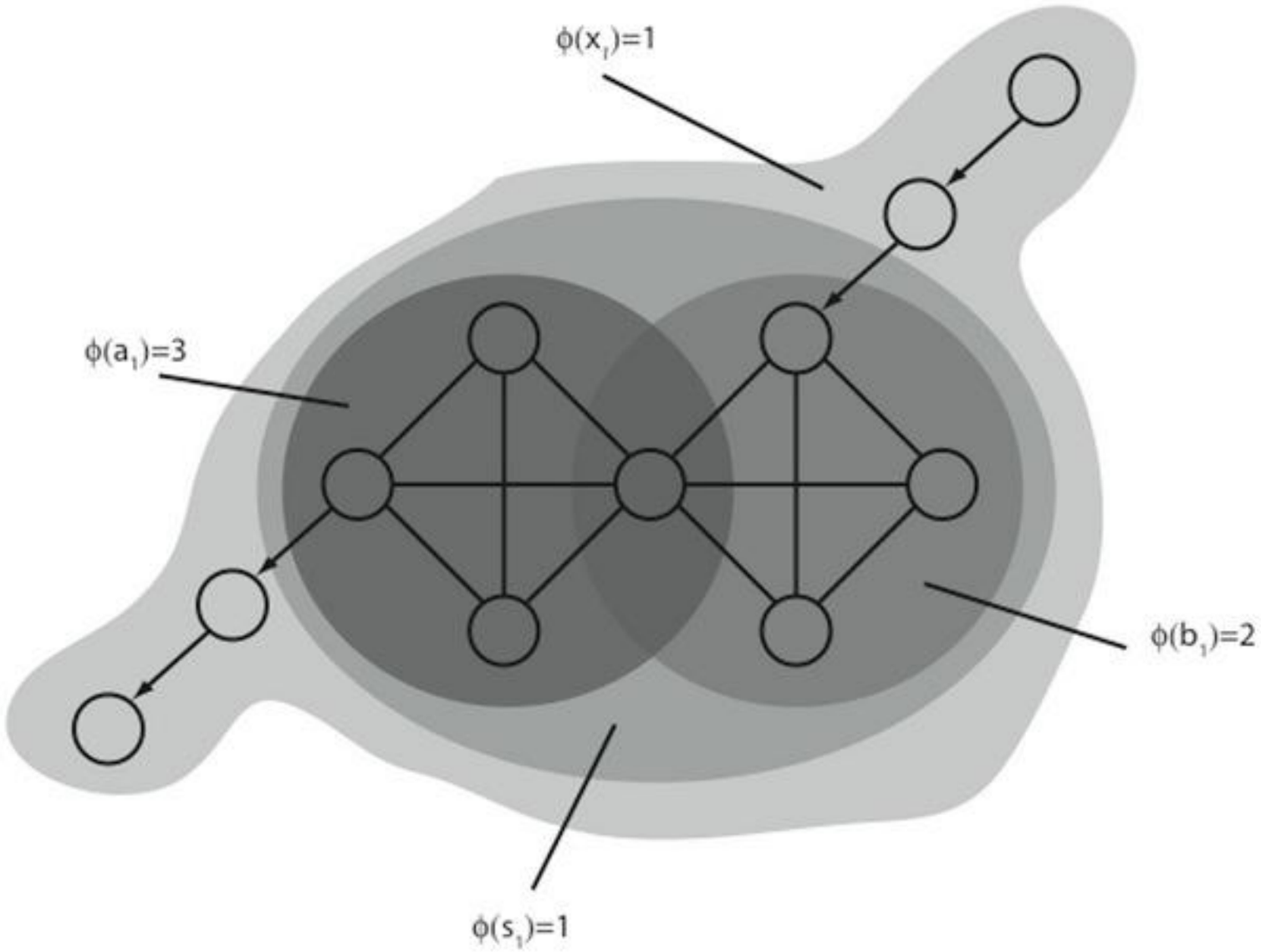
Constraints on M-Properties

- 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 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

Loewer's Objection

- Criteria for collapse are imprecise
  - No they're not
- Early universe won't be in an eigenstate
  - Yes, it will be in the null eigenstate
- Quantum tunneling will produce consciousness too soon
  - No, any more than it will produce brains too soon (miniscule probability)

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 change, or even evolve in the first place

Quantum Zeno Effect

- Mathematically, the “survival” probability for a quantum system to remain in its present state tends to 1 as the number of measurements of that state (over some time) tends to infinity.

- Problem: if (its as if) a system’s M-property is being continuously measured then the system will be stuck with a particular value for that property.

- But then consciousness cannot be an M-property since our states of consciousness change!

Representationalist solution

- Consciousness is not continuously measured, rather, consciousness measures and thereby collapses represented properties. (Stapp's view.)
- Problem: requires realist representationalism about the structure of consciousness.

Everett-inspired solution

- Many worlds: Sufficiently complex wave functions generate “branches” – independently and classically evolving components of the wave function that resemble “worlds”.
- Perhaps we can define the physics-to-consc laws so that they correlate certain classical “in-branch” dynamics to consciousness, overriding the QZE.

Intermittent measurements?

- QZE is a consequence of *continuous* measurement.
  - Consciousness freezes if it’s as if it’s being continually measured.
- Weaken continuous to intermittent?
  - Problem: we just get approximate QZE.
    - But this may depend on the system we’re dealing with!

Quantum Anti-Zeno Effect

- QAZE: some systems, if frequently measured, are *forced to change states*, and evolve classically.
    - These systems must be undergoing sufficiently complex environment interactions.
- If the neural correlate of consciousness satisfies these conditions, and undergoes frequent collapse (due to relation to consc) then this would trigger classical evolution of the NCC.
    - Speculative – require detailed calculations to confirm this.

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?