Consciousness and the collapse of the wave function

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Two questions…

(1) What is the place of consciousness in nature?

(2) What is the physical reality described by quantum mechanics?

Structure of talk

- The problem of quantum reality
- Potential solution: m-property theory
- Consciousness as the m-property
- Implications for philosophy of mind

The problem of quantum reality

Textbook quantum mechanics

- The Schrödinger equation
  - Describes a *deterministic* law.

- The collapse postulate
  - Describes an *indeterministic* law.
  - Originally stated in:
    - Neumann, John von. 1955. *Mathematical Foundations of Quantum Mechanics*. Princeton University Press. (German original: 1932.)

When does each law apply?

- The Schrödinger equation
  - Describes a *deterministic* law.
  - **Applies to <u>unmeasured</u> systems.**

- The collapse postulate
  - Describes an *indeterministic* law.
  - **Applies to <u>measured</u> systems.**

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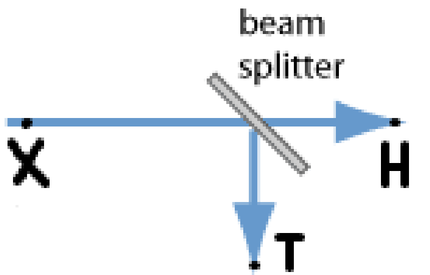
The measurement problem

- Measurement is not a good candidate fundamental physical process.
- The notion of "measurement" is not well defined.

Quantum mechanics in practice

- Schrödinger evolution of particle *p*:

$$|\mathbf{X}\rangle_p \rightarrow \alpha|\mathbf{H}\rangle_p + \beta|\mathbf{T}\rangle_p$$



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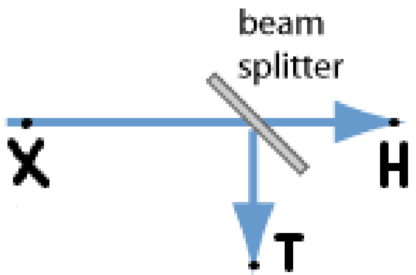
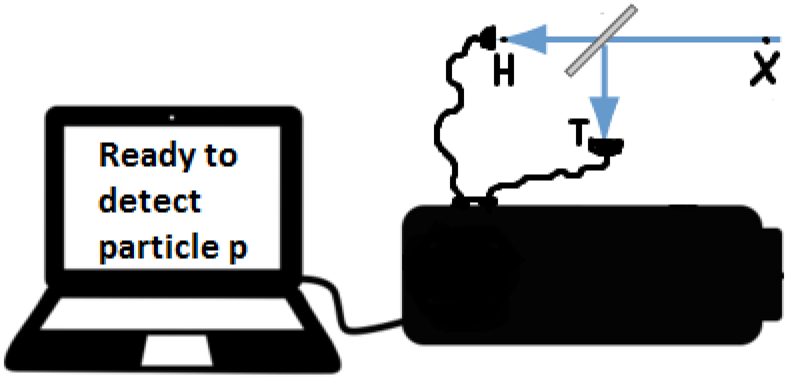


- Schrödinger evolution of particle *p* and device *d*:

  $(\alpha|H>_p + \beta|T>_p)|\text{"Ready"}>_d$



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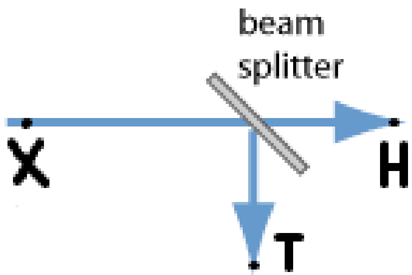

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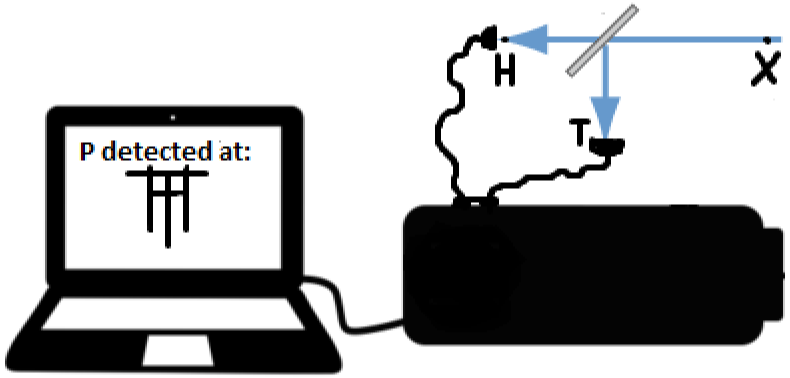

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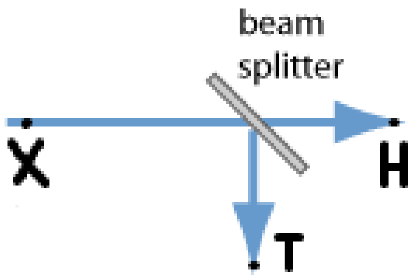

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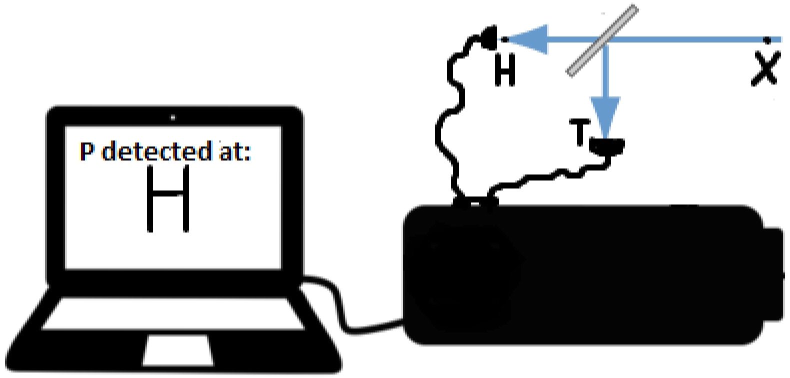
- Indeterministic collapse:

$$\alpha|H\rangle_p|\text{“H”}\rangle_d + \beta|T\rangle_p|\text{“T”}\rangle_d \rightarrow |H\rangle_p|\text{“H”}\rangle_d \ (\textbf{or } |T\rangle_p|\text{“T”}\rangle_d)$$



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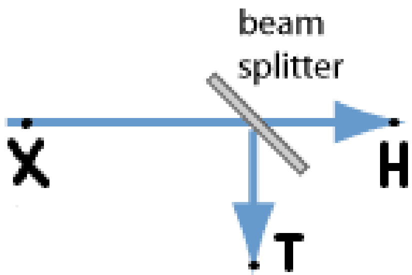

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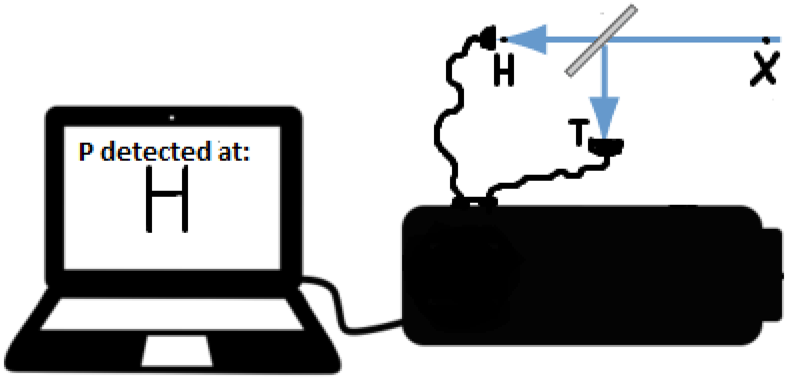
- Probability of *p* being detected...

  Here = $|\alpha|^2$

  There = $|\beta|^2$



The problem of quantum reality

- (i), (ii), & (iii) are mutually inconsistent:
  - (i) The wave-function of a system specifies all of its physical properties.
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    - $|H>_p |\text{“Here”}>_d$

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Solutions

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    - Bohmian mechanics, Qbism, TSVF, etc.
- **(ii) The wave-function always evolves via Schrödinger equation.**
  - **Denied by**:
    - Textbook quantum mechanics,
    - **M-property theory**
    - Stapp's theory, Orch OR, etc.
- (iii) Measurements always have single definite outcomes.
  - **Denied by**:
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M-property theory

Taking the textbook literally

- What is more fundamental?

- A measurement *property*?
  - Textbook “measuring devices” possess a distinctive property responsible for collapse.
    - M-property theory

- The measurement *process?*
  - Requires fundamental intentionality?
    - Stapp’s “posing a question to nature”.

Stapp's theory

- Stapp's (2011: p24) additions to textbook QM:
  - Process 3: collapse postulate (textbook QM).
  - Process 2: Schrödinger equation (textbook QM).
  - Process 1: posing a question to nature.
  - Process 0: "some process that is not described by quantum theory, but determines the [process 1] 'free-choice'".

- Problems:
  - No account or process 0 (and hence, of process 1).
  - So, no account of why (or when) process 3 occurs.
  - So, no solution to problem of quantum reality.

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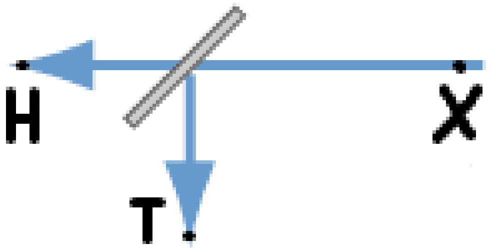

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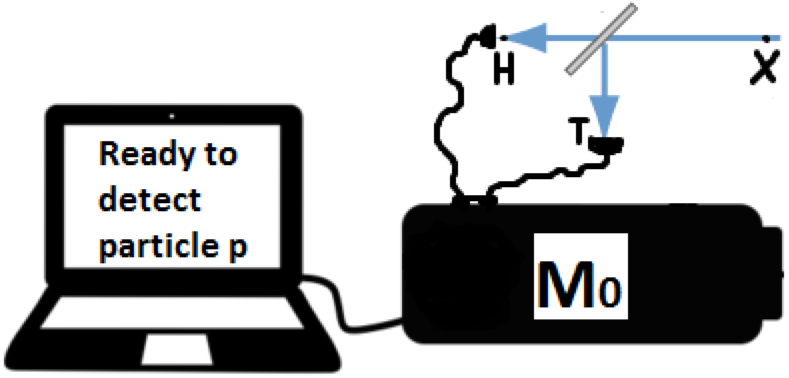

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  - Schrödinger evolution of device (with m-property) + particle:

    $(\alpha|H\rangle_p + \beta|T\rangle_p)|\text{“R”}/M_0\rangle_d$

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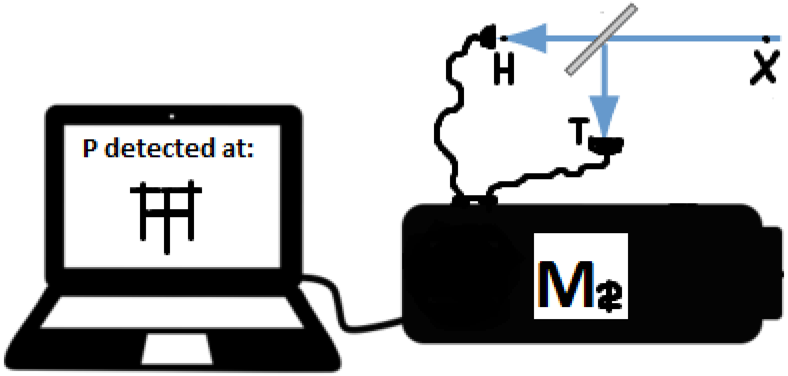

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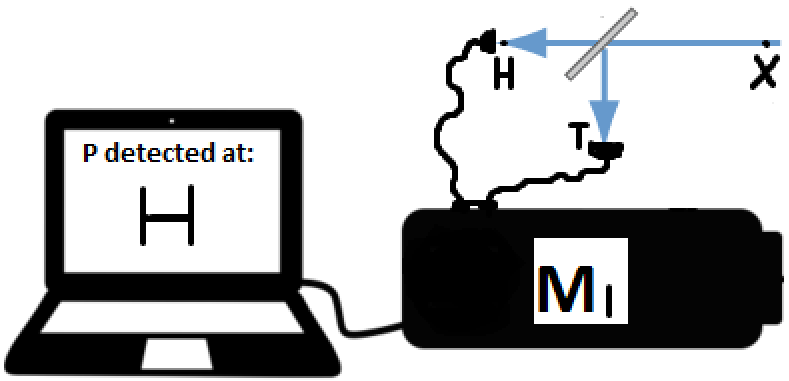

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  - Indeterministic collapse:

$$\alpha|H\rangle_p|\text{“H”}/M_1\rangle_d + \beta|T\rangle_p|\text{“T”}/M_2\rangle_d \rightarrow$$

$|H\rangle_p|\text{“H”}/M_1\rangle_d$ (with probability $|\alpha|^2$); **or**
$|T\rangle_p|\text{“T”}/M_2\rangle_d$ (with probability $|\beta|^2$).

Constraints on candidate M-properties

- The m-property cannot be too common
  - Isolated particles seldom collapse.
- The m-property cannot be too rare
  - Measurement outcomes always collapse.

- Many candidates fit these constraints...
  - An as-yet undiscovered property?
  - Configurational properties?
  - Spacetime curvature? (Penrose, Diósi)
  - Integrated information?
  - Consciousness?

Constraints on basic law of M-properties

- M-properties cannot *absolutely* refuse superposition due to **quantum Zeno effect** (**QZE**).
  - **QZE**: frequent quantum measurement makes it hard for measured properties to change.

- QZE problem for absolute m-properties:
  - For any property P, if a system evolves from initial value v1, to v2, it must evolve through superpositions of v1 and v2, such that the probability of initial value v1 continuously decreases *from one*.
    - But then if P is an absolute m-property, P cannot evolve – it will continuously collapse to initial value.

- Solution: Basic law revised: superpositions are *unstable*...

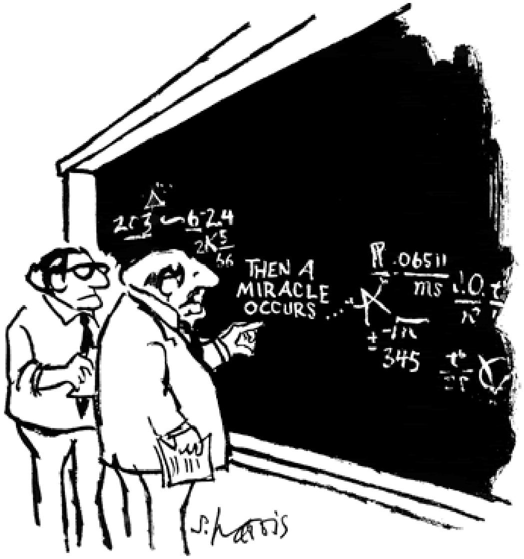
Candidates for describing "instability"

- M-property superpositions become more unstable...
  - as the system possesses more of the m-property.
    - The more of the m-property a system possesses the higher the probability that its particles collapse to definite positions.
      - Kremnizer & Ranchin [2015], Ghirardi et. al. [1987].
  - as the superposition components reach a difference threshold.
    - If m-property = spacetime curvature, then threshold = curvature difference between components.
      - Penrose [2014], Diosi [1987].
    - If m-property = consciousness, then threshold = distance in qualia space between components.
- Precise experiments required to further narrow down candidate m-properties and instability laws.

Consciousness as the m-property

Consciousness causes collapse

- London and Bauer (1939), Wigner (1967).



"I think you should be more explicit here in step two."

- Never developed rigorously:
  - No clear account of collapse.
  - No clear definition of consciousness.
- Solution:
  - Account of collapse given by m-property theory.
  - Only need account of *physical correlates* of consciousness.

Physical correlates of consciousness

- Candidate theory of correlates: Tononi's integrated information theory (IIT).
  - Amount of consciousness measured by Φ = amount of integrated information.

- How this makes the theory precise:
  - Consciousness supervenes (nomologically or metaphysically) on its physical correlates.
  - Consequently, if consciousness superpositions are unstable then so are superpositions of physical correlates.
    - Given IIT, Φ–superpositions will be unstable.
    - Experimentation: compare collapse rate of systems with different Φ–values using conventional tests of modern collapse theories (Feldman & Tumulka [2012], Bassi et. al. [2013]).

Philosophy of mind implications

Two interpretations

- Physicalist interpretation
  - Consciousness is nothing but integrated information (II).
  - Fundamentally, II causes collapse.

- Interactionist interpretation
  - II is just a measure of consciousness.
  - Fundamentally, consciousness causes collapse.

Two interpretations

- Physicalist interpretation
  - Consciousness is nothing but integrated information (II).
  - Fundamentally, II causes collapse.
    - Hard problem remains: why should II yield consciousness?

- Interactionist interpretation
  - Consciousness only nomologically supervenes on II.
  - Fundamentally, consciousness causes collapse.
    - Hard problem does not arise.
    - Causal closure objection undercut.
    - Interactionism made rigorous.

Thanks for your attention!

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Formalism: the Lindblad equation

- The Schrödinger equation can be recast as the Liouville equation for the system's density matrix:

$$\frac{d}{dt}\rho(t) = -\frac{i}{\hbar}[H, \rho(t)]$$

- Effects of *external* systems can be added (Lindblad equation):

$$+\sum_{n,m=1}^{N^2-1} h_{n,m}(L_n\rho(t)L_M^\dagger - \frac{1}{2}(\rho(t))L_M^\dagger L_n + L_M^\dagger L_n\rho(t)))$$

The Kremnizer & Ranchin [2015] eqn.

- The most general non-linear quantum integrated information collapse equation:

$$\frac{d}{dt}\rho(t) = -\frac{i}{\hbar}[H, \rho(t)] + \sum_{n,m=1}^{N^2-1} h_{n,m}(\Phi(\rho(t)))\Big(L_n\rho(t)L_m^\dagger - \frac{1}{2}\Big(\rho(t)L_m^\dagger L_n + L_m^\dagger L_n\rho(t)\Big)\Big)$$

- $h_{n,m}$ = Hermitian matrix elements that are continuous functions of the integrated information of ρ (all zero when $\Phi(\rho(t)) = 0$).
- $\{L_k\}$ is a basis of operators on the N-dimensional system Hilbert space, which determine collapse basis.