Title: Foundations of Quantum Mechanics - Lecture 1

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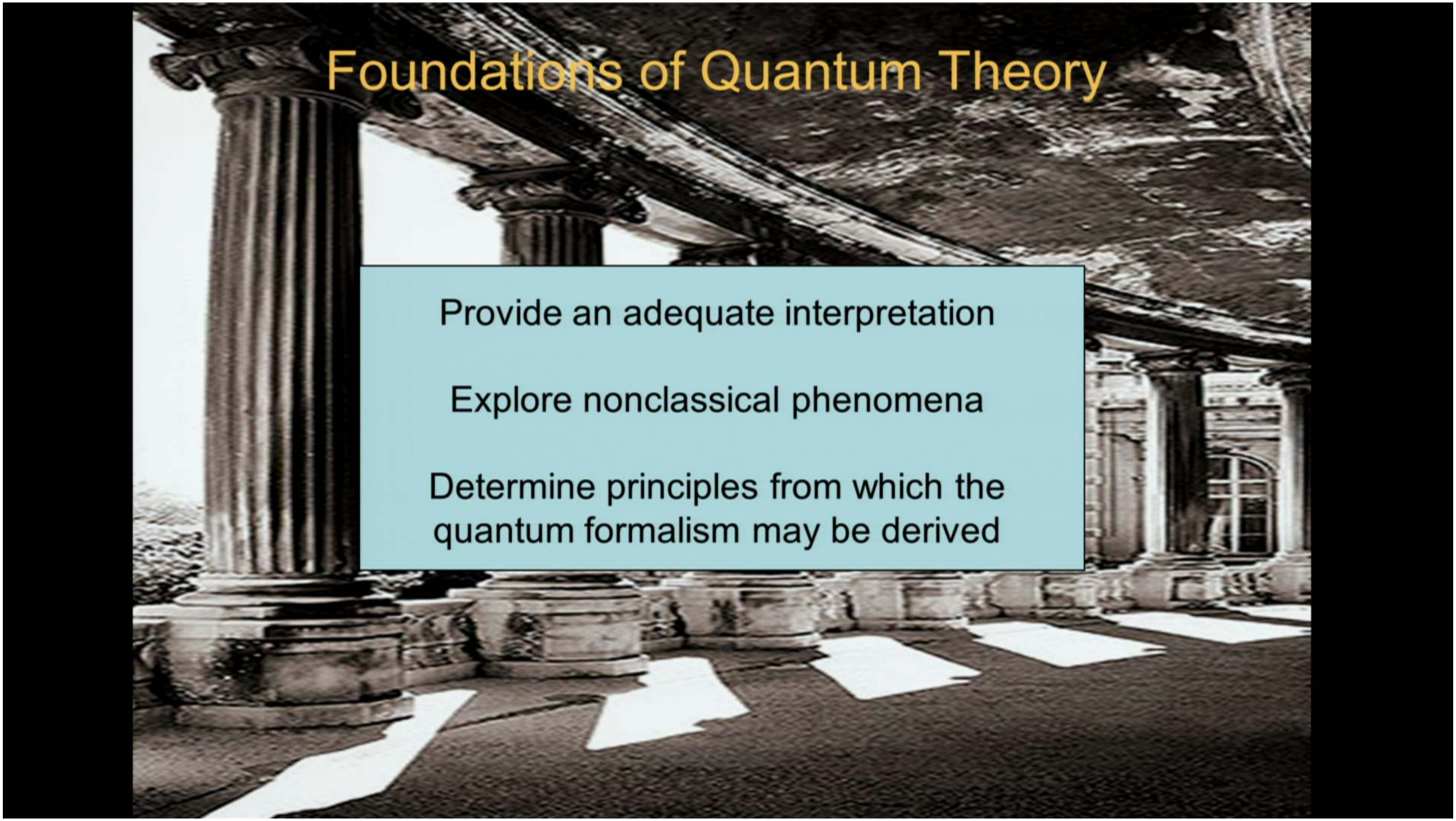
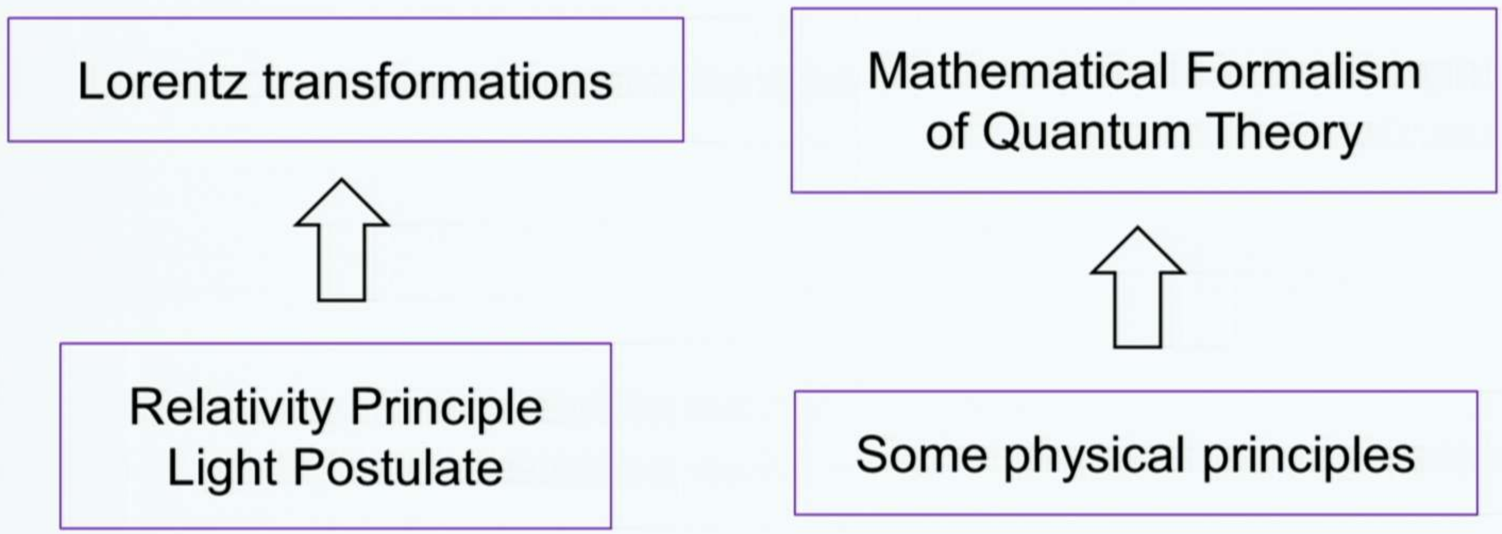
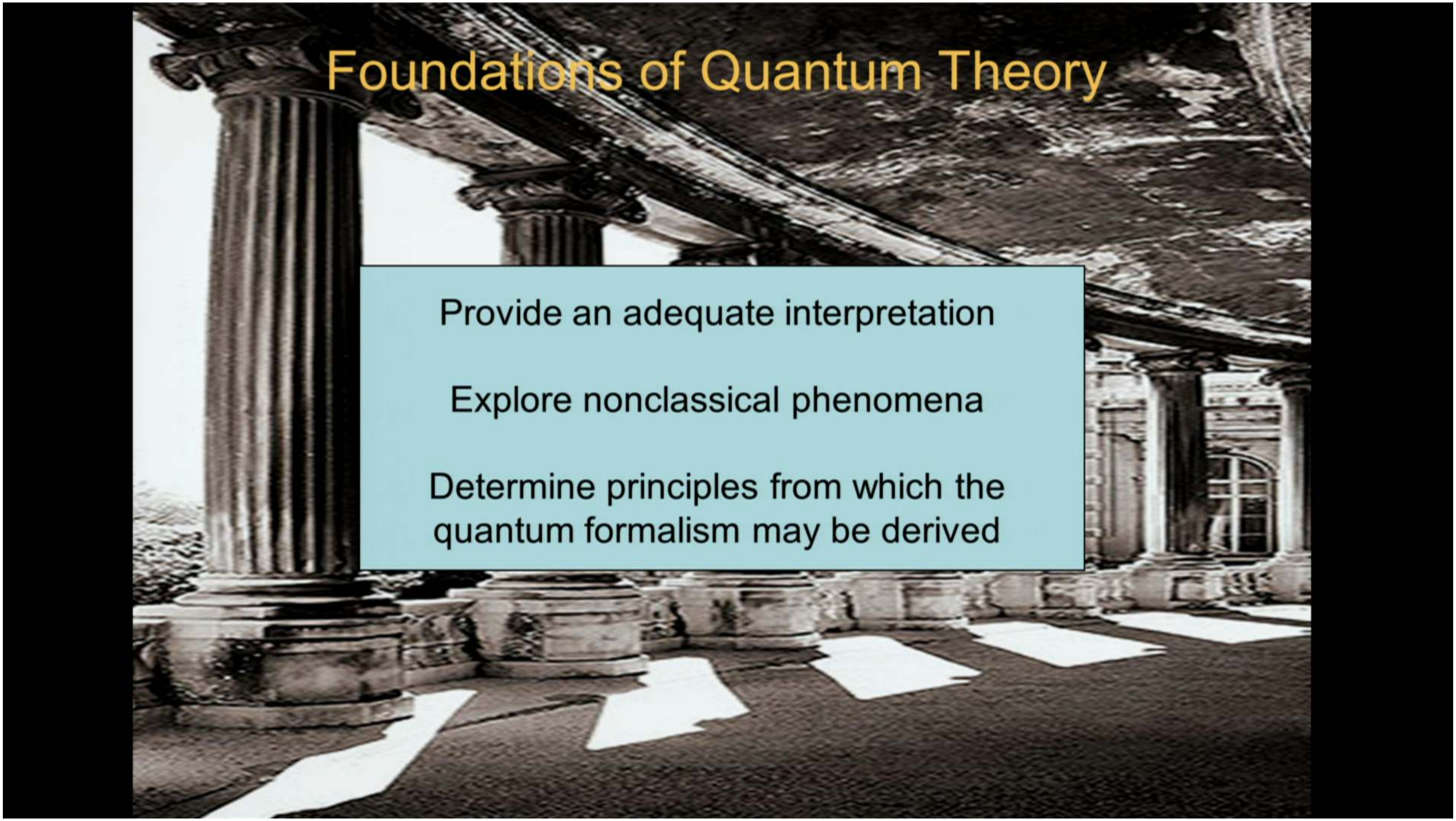
Abstract:


Foundations of Quantum Theory
Provide an adequate interpretation
Explore nonclassical phenomena
Determine principles from which the quantum formalism may be derived


Lorentz transformations
Relativity Principle
Light Postulate
Mathematical Formalism of Quantum Theory
Some physical principles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What's the problem?

"Orthodox" postulates of quantum theory

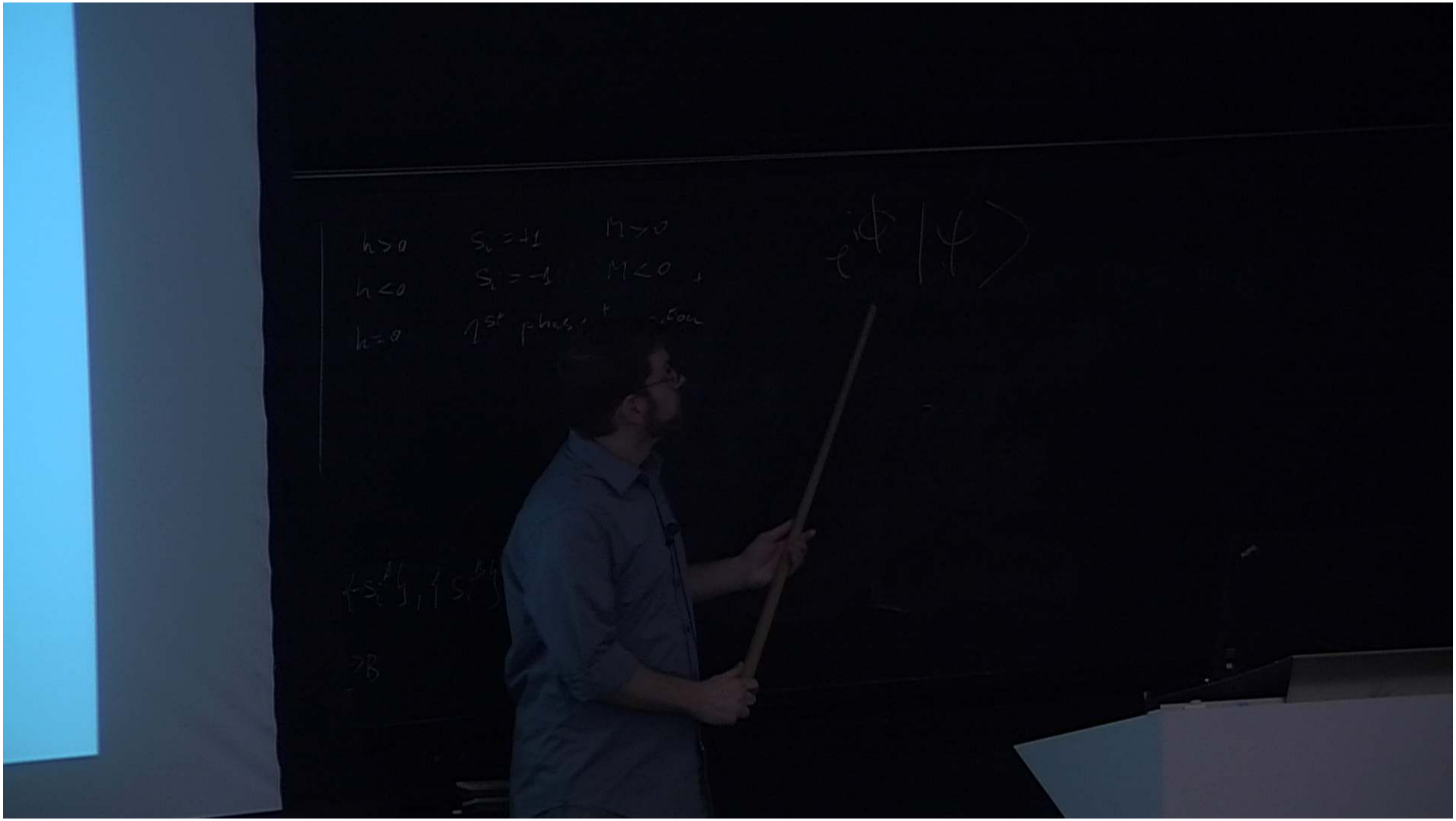
Representational completeness of ψ. The rays of Hilbert space correspond one-to-one with the physical states of the system.

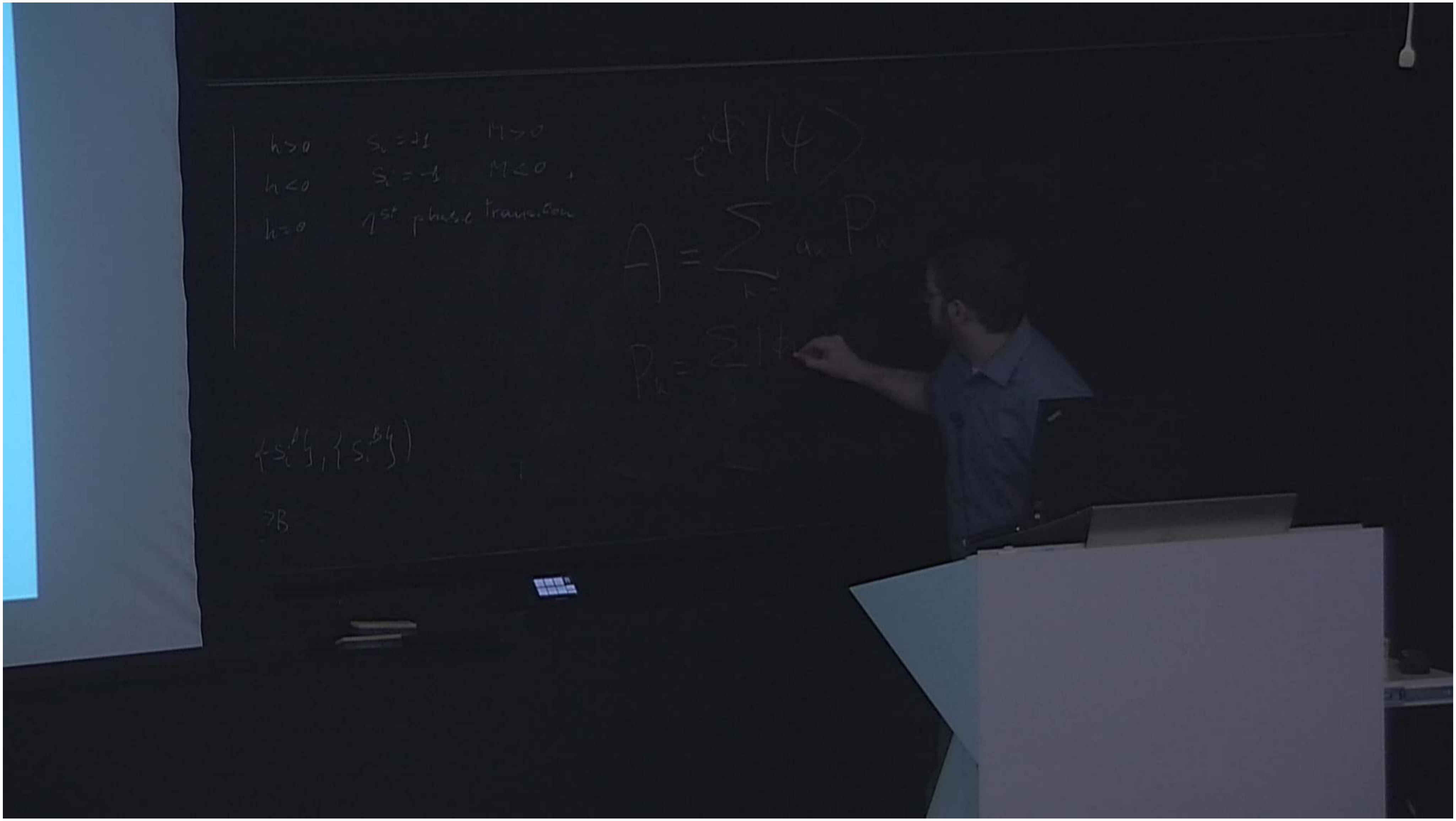
Measurement. If the Hermitian operator *A* with spectral projectors $\{P_k\}$ is measured, the probability of outcome *k* is $\langle\psi|P_k|\psi\rangle$. These probabilities are objective -- indeterminism.

Evolution of isolated systems. It is unitary, $|\psi\rangle \rightarrow U|\psi\rangle = e^{-\frac{i}{\hbar}Ht}|\psi\rangle$ therefore deterministic and continuous.

Evolution of systems undergoing measurement. If Hermitian operator *A* with spectral projectors $\{P_k\}$ is measured and outcome *k* is obtained, the physical state of the system changes discontinuously,

$$|\psi\rangle \rightarrow |\psi_k\rangle = \frac{P_k|\psi\rangle}{\sqrt{\langle\psi|P_k|\psi\rangle}}$$


h > 0 S_i = +1 M > 0
h < 0 S_i = -1 M < 0



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First problem: the term "measurement" is not defined in terms of the more primitive "physical states of systems". Isn't a measurement just another kind of physical interaction?

Two strategies:

(1) Realist strategy: Eliminate measurement as a primitive concept and describe everything in terms of physical states

(2) Operational strategy: Eliminate "the physical state of a system" as a primitive concept and describe everything in terms of operational concepts

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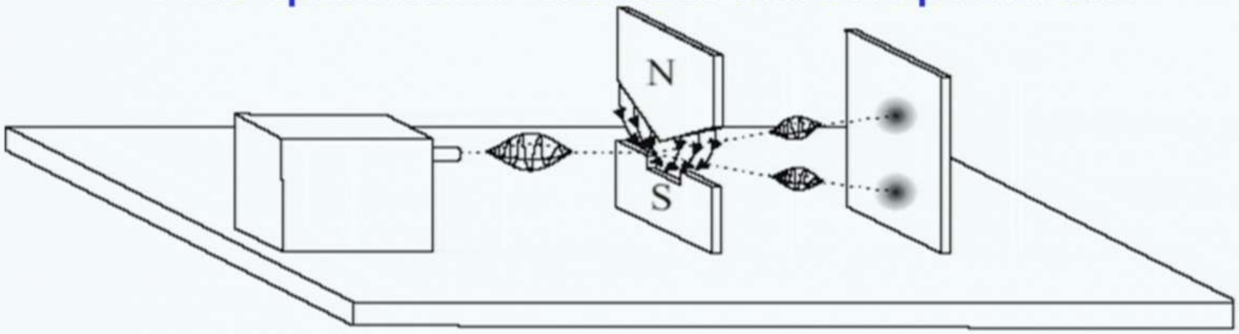
Inconsistencies of the orthodox interpretation

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

The quantum measurement problem



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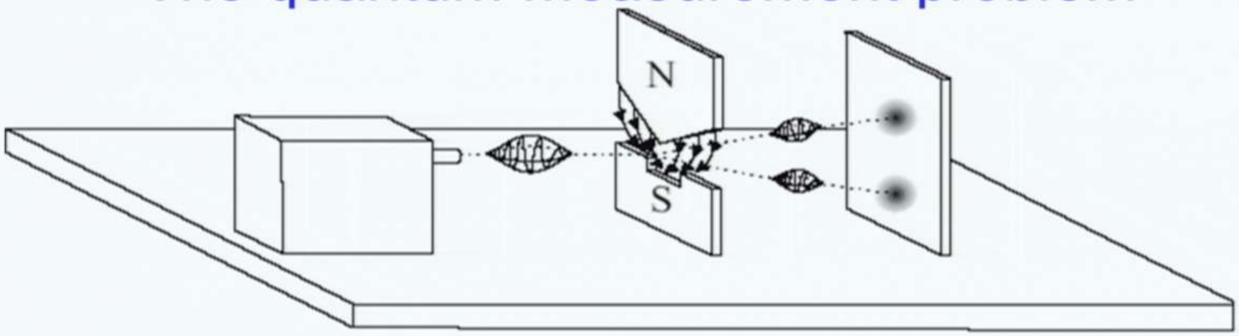

If the measurement apparatus is treated externally

$$a|\uparrow\rangle + b|\downarrow\rangle \;\to |\uparrow\rangle \text{ with probability } |a|^2$$
$$\to |\downarrow\rangle \text{ with probability } |b|^2$$

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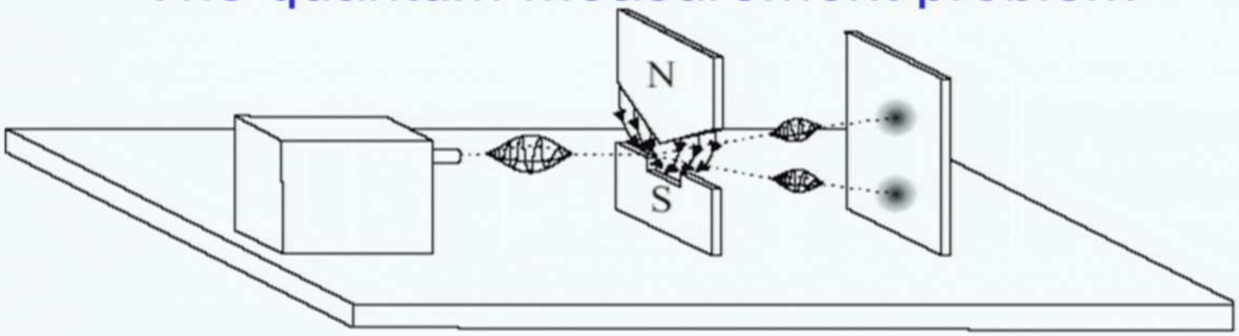

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If the measurement apparatus is treated internally

$$|\uparrow\rangle \otimes |\text{"ready"}\rangle \;\to U(|\uparrow\rangle \otimes |\text{"ready"}\rangle) = |\uparrow\rangle \otimes |\text{"up"}\rangle$$
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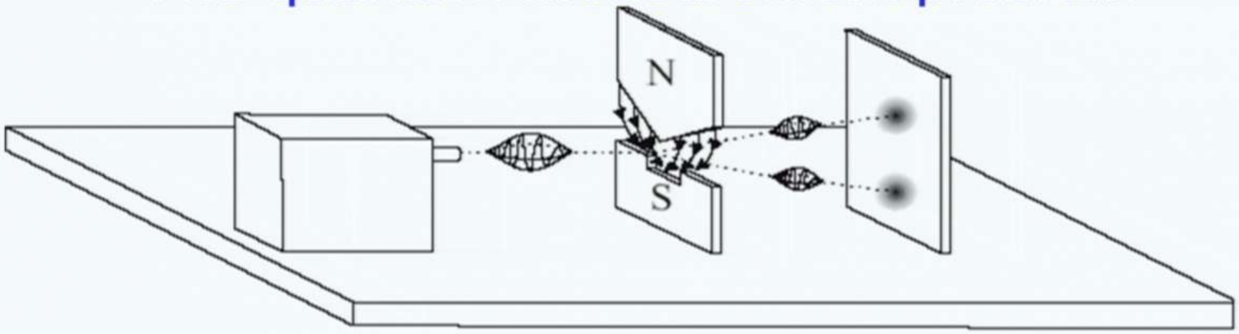

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U is a linear operator $U(a|\psi\rangle + b|\phi\rangle) = aU|\psi\rangle + bU|\phi\rangle$

$$S_{\hat{z}} = (+1)|\uparrow\rangle\langle\uparrow| + (-1)|\downarrow\rangle\langle\downarrow|$$

$$(S_{\hat{z}} \otimes I)(a|\uparrow\rangle \otimes |\text{“up”}\rangle + b|\downarrow\rangle \otimes |\text{“down”}\rangle)$$

$$a(S_{\hat{z}}|\uparrow\rangle) \otimes |\text{“up”}\rangle + b(S_{\hat{z}}|\downarrow\rangle) \otimes |\text{“down”}\rangle$$

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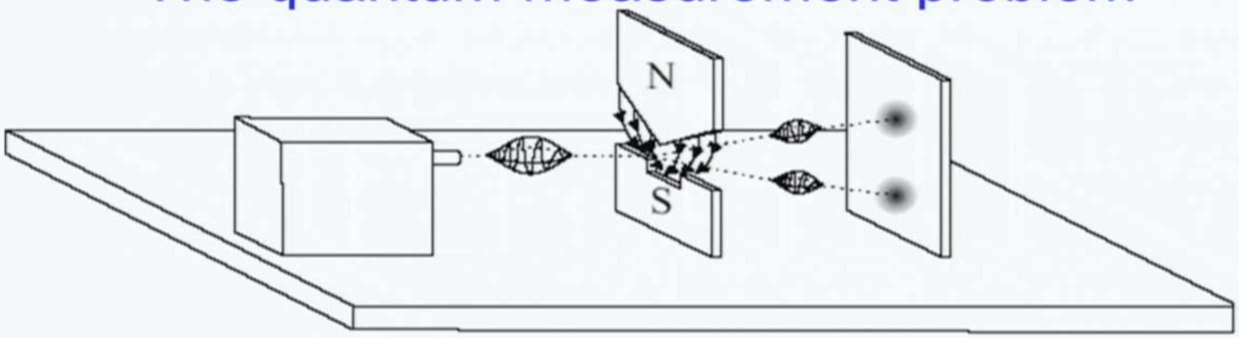
$$a(S_{\hat{z}}|\uparrow\rangle) \otimes |\text{``up''}\rangle + b(S_{\hat{z}}|\downarrow\rangle) \otimes |\text{``down''}\rangle$$

$$= (+1)a|\uparrow\rangle \otimes |\text{``up''}\rangle + (-1)b|\downarrow\rangle \otimes |\text{``down''}\rangle$$

$$\neq \lambda(a|\uparrow\rangle \otimes |\text{``up''}\rangle + b|\downarrow\rangle \otimes |\text{``down''}\rangle)$$

The quantum measurement problem



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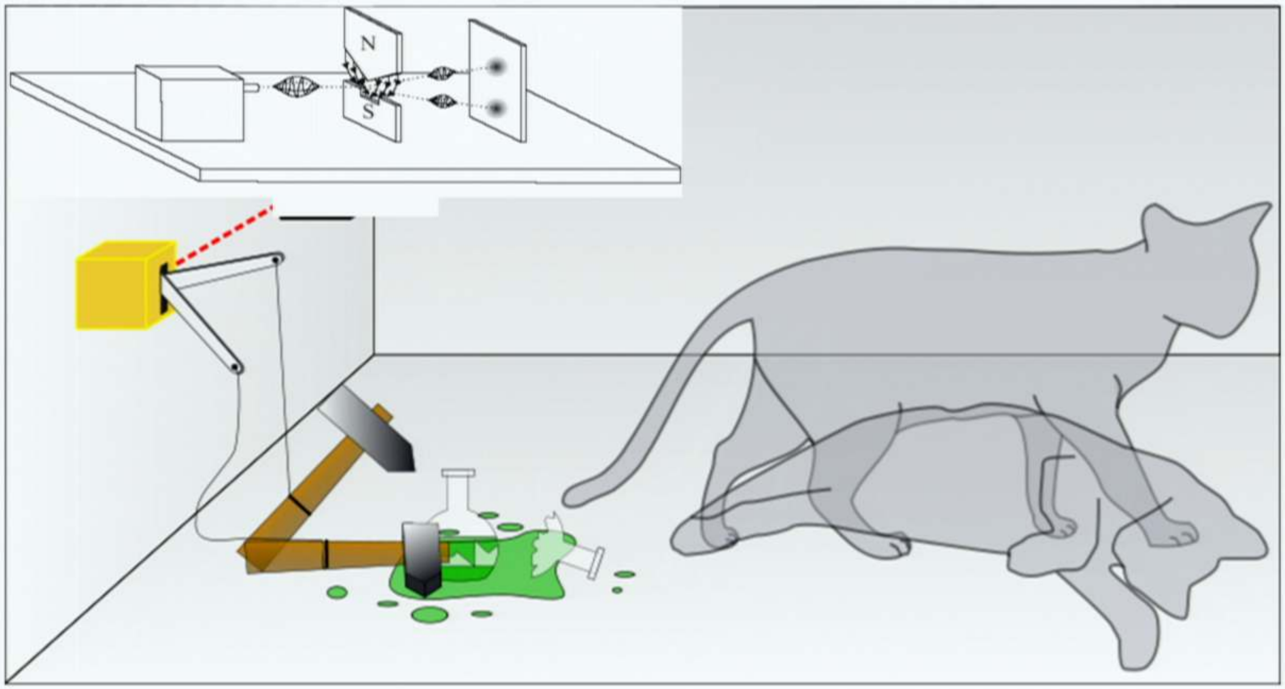
$$(a|\uparrow\rangle + b|\downarrow\rangle) \otimes |\text{"ready"}\rangle \rightarrow U[a|\uparrow\rangle \otimes |\text{"ready"}\rangle + b|\downarrow\rangle \otimes |\text{"ready"}\rangle]$$
$$= a|\uparrow\rangle \otimes |\text{"up"}\rangle + b|\downarrow\rangle \otimes |\text{"down"}\rangle$$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False starts on the measurement problem

- Interpret the reduced density operator as a proper mixture

$$a|\uparrow\rangle \otimes |\text{“up”}\rangle + b|\downarrow\rangle \otimes |\text{“down”}\rangle$$

$$\rho = |a|^2 |\text{“up”}\rangle\langle\text{“up”}| + |b|^2 |\text{“down”}\rangle\langle\text{“down”}|$$

Either contradicts original assignment of entangled state
Or is a denial of the representational completeness of ψ

False starts on the measurement problem

Responses to the measurement problem

1. Deny universality of quantum dynamics
   - Quantum-classical hybrid models
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    - ψ-epistemic hidden variable models

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