

# The Theory of Observation in Quantum Mechanics

Fritz London & Edmond Bauer (1939)

Bea Fatima  
The Quantum World

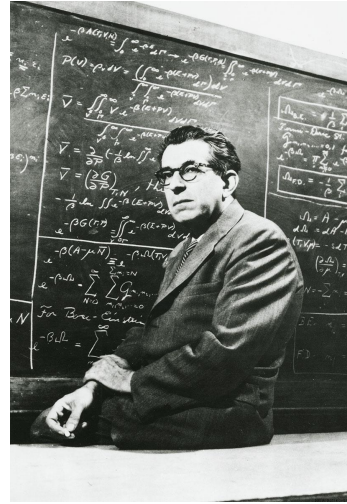
# Why is This Paper Important?

## Quantum Mechanics in 1939:

- Schrödinger equation
  - Deterministic
- Born rule
  - Probabilities come from the wavefunction and correspond to experimental results
- Copenhagen interpretation
  - Wavefunction collapses during measurement
- Measurement problem is an open question

## Key question:

If everything obeys Schrödinger evolution, WHY do measurements have definite outcomes?



Fritz London and Edmond Bauer

# What is a Wavefunction?

Schrödinger evolution is deterministic, but QM predicts probabilities

**How can something deterministic contain probabilities?**

**Option 1:  $\psi$  represents incomplete knowledge/classical ignorance**

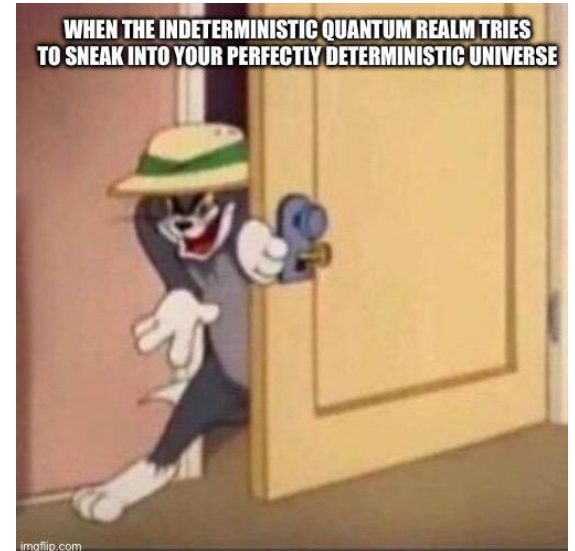
- Probabilities = ignorance
  - Ex: 70% chance of rain (describes knowledge of object, not object itself)
- Similar to Brownian motion, we can update our knowledge for a better tuned model

Measurement reveals what was already true (reality is definite)

**Option 2 (London and Bauer's view):  $\psi$  is a complete description**

- Probabilities are not ignorance
- $\psi$  represents maximal knowledge
- Measurement creates a problem: **If the wave function is already complete, why does measurement appear to give us new information?**

$$i\hbar \frac{\partial}{\partial t} |\Psi\rangle = \hat{H} |\Psi\rangle$$



# A Strange Quantum Feature...

## Pure State

- Represents maximal knowledge
- Described by a single wavefunction
- Not classical ignorance

## Mixed State

- Statistical mixture of possible states
- Represents incomplete knowledge
- Similar to classical probabilities
- No single wavefunction describes the system

***"This distinction becomes important when we couple systems together. Surprisingly, the total system can remain in a pure state even though its individual parts appear mixed."***

London & Bauer were describing a key feature of entanglement.

# A Strange Quantum Feature...

- Classical: know whole  $\Rightarrow$  know parts
  - a. “...the *maximal knowledge of a composite system implies a maximal knowledge of all its parts*”
- Quantum: know whole  $\nRightarrow$  know parts
  - a. Information lives in correlations between systems
- This becomes the basis of the measurement problem
  - a. Complete knowledge of the total system (pure state) does not imply a definite outcome for the apparatus (mixed state)

# London and Bauer's Solution

Object

$$\Psi(x) = \sum_k c_k u_k(x)$$

Before observation

- Object: mixed
- Apparatus: mixed
- Observer: mixed
- Total system: pure

Object +  
Apparatus

$$\Psi(x, y) = \sum_k c_k u_k(x) v_k(y)$$

Object +  
Apparatus +  
Observer

$$\Psi(x, y, z) = \sum_k c_k u_k(x) v_k(y) w_k(z)$$

The total state still contains all branches.  
Why does the observer experience only one?

# London and Bauer's Answer

The total state still contains all branches.  
Why does the observer experience only one?

$$\Psi_k(x, y, z) = u_k(x) v_k(y) w_k(z)$$

- The object, apparatus, and observer is described by a single entangled state
- The total wavefunction still contains all possible outcomes, and no definite outcome has yet been selected
- The observer has direct access to their own experience ("faculty of introspection")
- Consciousness identifies with one branch of the superposition
  - This "act of objectification" creates a definite outcome.

After observation:

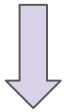
- **Object:** pure
- **Apparatus:** pure
- **Observer:** pure
- **Total system:** product state of pure states

**This is their proposed solution to the measurement problem.**

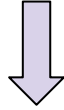
*"The observer establishes his own framework of objectivity and acquires a new piece of information about the object in question"*

# Previous Intuition

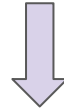
Object



Apparatus



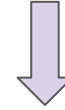
Collapse



Definite Outcome

# London and Bauer's Solution

Object + Apparatus



Entangled State



Observer becomes correlated



Conscious awareness

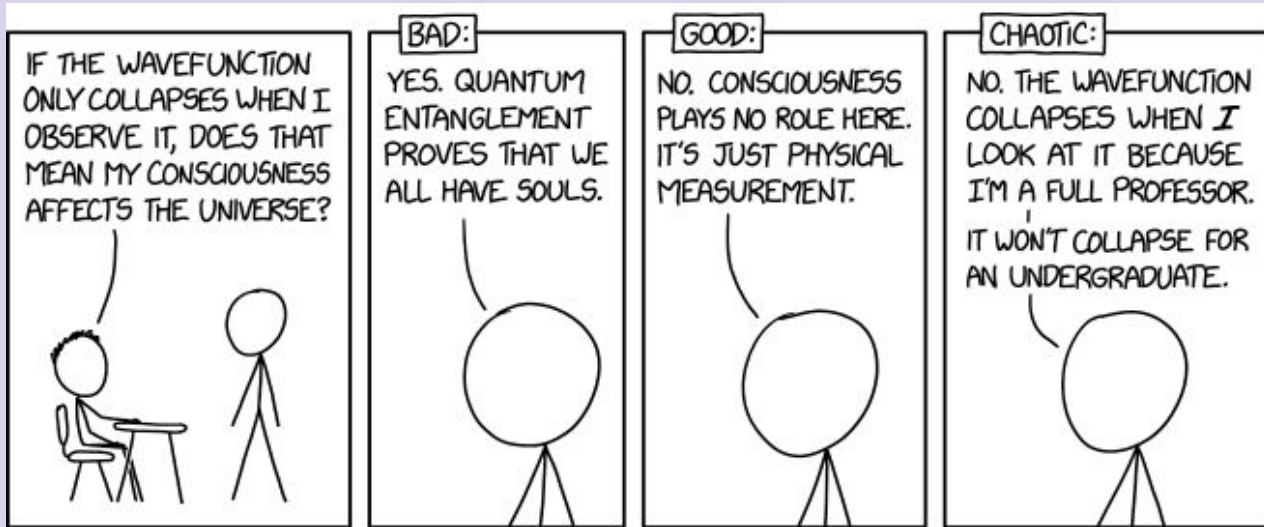


"Act of Objectification"/Collapse



Definite Outcome

# This is VERY strange...



# My View

## Strengths

- Clear statement of the measurement problem
- Recognizes that the apparatus alone does not explain outcomes
- Early description of entanglement and its features
- **Treats the observer and the apparatus as part of the quantum system**

## Weaknesses

- Consciousness is left undefined
- Why does consciousness have this property/ability?
- No clear criteria for a “conscious observer”
- The mystery seems relocated rather than solved

# Can Science Remain Objective?

**Question: If consciousness is required for a definite outcome, would that make reality subjective?**

## Classical Objectivity

- Properties exist whether observed or not
- Objects possess continuous properties
- Objectivity = observer independent world

## London & Bauer's "Quantum Objectivity"

- Different observers can examine the same apparatus
- Observers can communicate and agree on results
- Quantum mechanics correctly predicts these results
- Scientific practice remains unchanged.

**Even though consciousness is introduced, QM redefines objectivity by replacing the notion of preexisting properties with reproducible observations predicted by theory.**

# What Happened Next?

1939

London & Bauer

- Consciousness selects a branch

1961

Wigner's Friend

- Consciousness collapse idea developed further

1970s - today

Alternative solutions

- Decoherence
  - Environment suppresses interference
- Many Worlds
  - No collapse, all branches exist
- Pilot-Wave
  - Particles always have hidden positions

London & Bauer were among the first to place consciousness at the center of the measurement problem, but most modern interpretations reject this idea.

# A Modern Challenge: Quantum Information

## London & Bauer

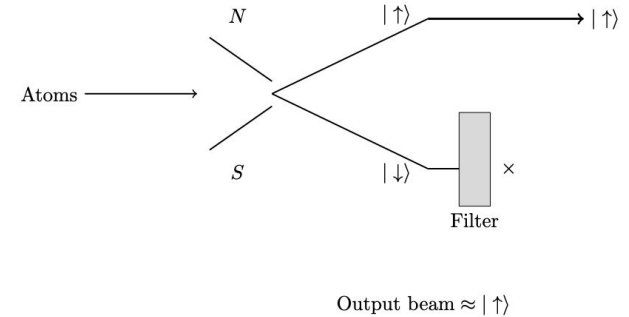
- Consider a Stern Gerlach apparatus
  - Filters can make it so the spin up beam only goes through
  - The filter never puts any individual object into a new pure state, it can only put it into a mixed state
  - You can say atoms that emerged from the slit are spin up, but you cannot say that a particular atom definitely emerged

*"The filter alone thus truly produces pure cases, but in an absolutely anonymous form."*

## Modern QIT

- Single-photon sources can prepare individual photons in well-defined quantum states (e.g. polarization)
- Quantum gates manipulate individual qubits through controlled unitary evolution
- State preparation is regarded as a physical process
- No appeal to consciousness is needed

**Question:** Is London and Bauer's distinction between an "anonymous" pure state and an individual quantum system still necessary?



### Example of State Preparation:

- Prepare a qubit in  $|0\rangle$
  - Apply a Hadamard gate
- $$H|0\rangle \longrightarrow \frac{1}{\sqrt{2}}(|0\rangle + |1\rangle)$$
- Measure the qubit

Individual quantum systems are routinely prepared, manipulated, and measured.

# Discussion Questions

- Why should consciousness have this special power?
  - Is the "act of objectification" a physical process or a philosophical one?
  - Is observation fundamentally different from any other physical interaction?
- What distinguishes a conscious observer from a sufficiently complex physical system?
  - If the apparatus is not the reason behind the collapse of the wave function because it is part of the system, why should the same argument not apply, for example, to the observer's brain?
- To what extent is objectivity truly preserved?
- Could a measurement occur in a universe with no conscious observers?

# Citations

Fritz London and Edmond Bauer, 'The Theory of Observation in Quantum Mechanics',  
<https://www3.nd.edu/~dhoward1/The%20Theory%20of%20Observation%20in%20Quantum%20Mechanics.pdf>

