Do Measurements Made On Quantum States Have Random Outcomes?

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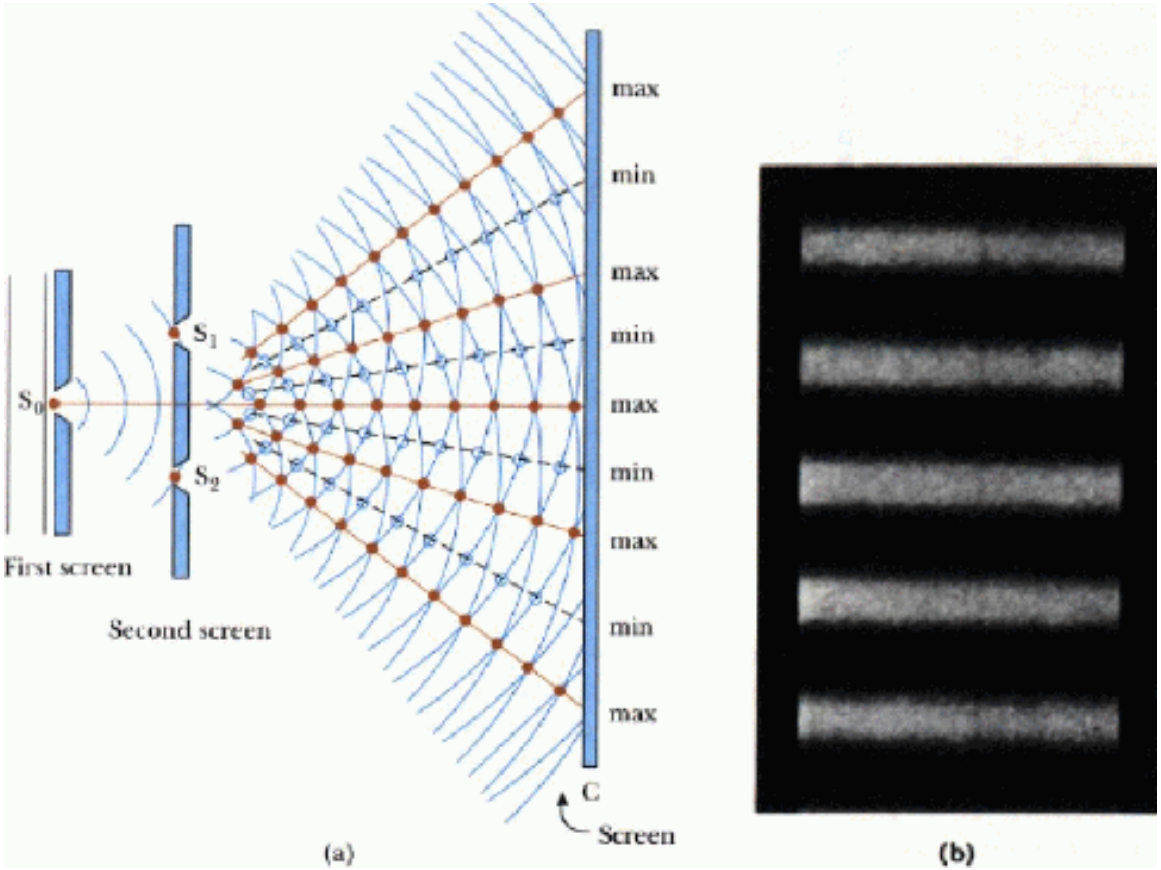
Quantum Information Theory

- Quantum information theory is a huge inter-disciplinary field applying computer science to get new results in quantum mechanics.
- Today we shall apply computability theory produce a fundamental result in quantum mechanics!

A Quick Guide to Quantum Mechanics

- A quantum state can be a superposition of two different values.
- A superposition is like a wave (where two parts of a wave can be in two different places).
- When the wave is measured, it behaves like a particle – the wave appears to be in only one of two or more positions – like a particle.
- “Wave-particle duality”



Young's Slit Experiment

Particles sent through the two slits behave like a wave (because an interference pattern is observed). However they are observed to only go through one slit (like a particle).

Quantum Measurements

- Today we are interested in the **randomness** of measurements.
- An photon can be in a superposition of two different positions.
- When the position of the photon is measured, its position is **randomly** chosen to be one of the two positions.
- According to physics, quantum measurements are the only **randomness** in nature.
- The Copenhagen Interpretation “appears to be confirmed” Adrian Kent, quant-ph 0905.0624

Today's Question

- Is the outcome of a quantum measurement random?
- When I measure a quantum state, is the outcome of the measurement truly random or is there some hidden deterministic but seemingly random process (e.g. the weather in London) which determines the result?

Information (Kolmogorov) Complexity

- Define randomness of an object to be the length of the shortest computable description of that object.
- An object is random if it has no short computable description.
- The digits of π are not at all random (short description).
- Is there some way of predicting the outcome of a quantum measurement?

Quick Proof that Nothing Can Be Proved To Be Random

- The Halting Problem (it's impossible to determine whether a general computer program halts).
- An object is random if it has no short computable description.
- To prove that an object is random, need to show that there is no short program which halts and outputs the object.
- Therefore it is uncomputable to say whether an object is random.

Application to Quantum Mechanics

- One cannot prove that there is no deterministic algorithm that decides the outcome of a quantum measurement.
- The postulates of quantum mechanics are very strange (waves which act as particles when you measure them).
- Are there hidden variables?

Hidden Variables

- Famous question in quantum mechanics.
- Can quantum mechanics be explained by classical mechanics and hidden variables?
- One cannot prove that there is no deterministic algorithm that controls quantum mechanical systems so today we have seen that one cannot prove that hidden variables do not exist!

Conclusions

- A very simple result applied to quantum mechanics.
- Fundamental but simple result in the foundation of quantum mechanics.