Quantum Physics & Reality

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"Anyone who is not shocked by quantum theory has not understood it."

- Niels Bohr

Overview/objectives

"Quantum phenomena challenge our primitive understanding of reality; they force us to re-examine what the concept of existence means. These things are important, because our belief about what is *must affect how we see our place within it, and our belief about what we are. In turn, what we believe ultimately affects what we actually are and, therefore, how we behave."* – Euan Squires

- Conceptual focus - Bring to the surface some elements of our basic picture of reality, so we can see if our common-sense beliefs are consistent with what we know from experiments in quantum physics
- Analogies to provide some intuition about pictures of reality that might be consistent with these experiments

Tonight's Core Question

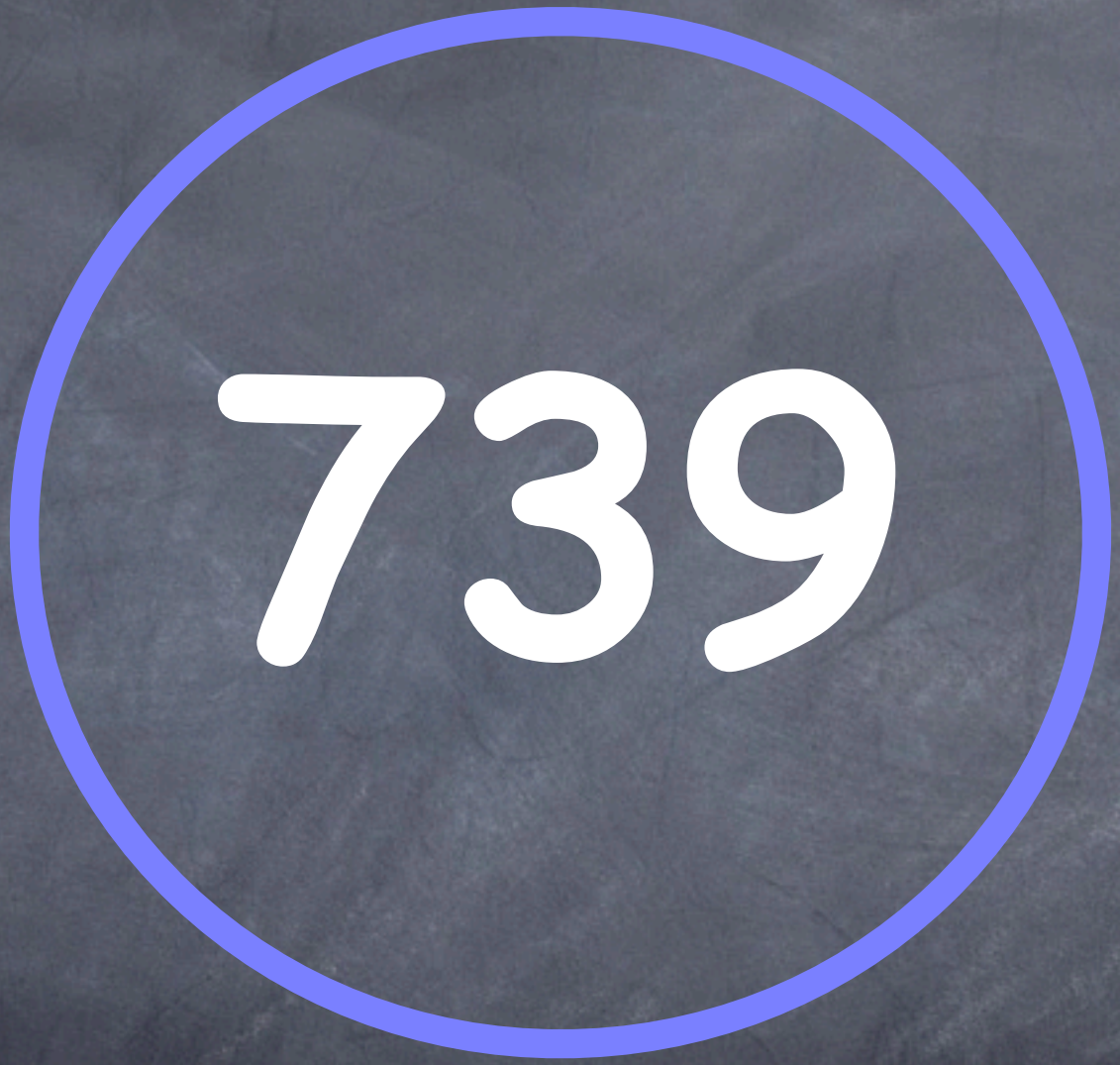
Prompted by experiments in quantum physics, but with implications that extend far beyond…

Do physical properties always have definite values, which they possess all the time, independently of any observation (measurement) of them?

As Einstein once expressed it more poignantly and with great frustration over the implications of quantum theory, "Is the moon there when nobody looks?"

Gaining a concrete sense of what it means for a property of the world to have well-defined, independent reality…

I've chosen a number between 1 and 10,000. I'd like you to make a guess in your mind and hold it there so you know what your guess is (also think about how confident you feel that your number is the one I've picked)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Realism

Standard notion of reality we carry around with us, which Einstein and many others shared: there is a completely well-defined reality "out there" which we can discover with our observations, but which has well-defined properties independently of our interaction with it

Experiments in quantum mechanics cast serious doubt on this picture as an accurate way to understand fundamental reality…

(This was the aspect of quantum physics that most bothered Einstein and led him to resist the theory as incomplete at best)

20 Questions – Quantum vs. Classical (summarizes different views of reality)

"No elementary phenomenon is a phenomenon until it is registered ('observed')." – John Wheeler

Classical Version: One person thinks of a specific object (a pink elephant, for example) and holds it firmly in mind while others ask her yes/no questions in order to pin down what the object is. (Is it bigger than a person? - Yes ; etc.). The key feature of this classical version of the game is that reality is well-defined all along. The answer is always a pink elephant, and the questions serve only to allow participants to learn this already-defined fact

Quantum Version: The person does not start by thinking of a definite object. Instead, she simply answers each question as it is asked, not restricted by the necessity of making the answers match with the properties of a specific, real object. She only has to make sure that all the answers are consistent with one another. There is still a great deal of structure and many restrictions in the quantum version of the game. But there is a freedom also that is different from the classical version - answers given from one round to the next in the game can have a more flexible relationship to one another than is possible in the classical version.

Summary:
Conceptual Highlights of Quantum Physics

- Questions about nature are "answered" only when they are specifically "asked".
- Interference of possibilities - what we observe when there are 2 (or more) possible ways for something to happen is not just the sum of what we get by considering each of the 2 possibilities separately.
- Fundamental uncertainty - Quantum theory gives as its final answer only a prediction of probabilities for what we will find when we observe something.
- Entanglement - parts of a system don't always have isolated identities with independently defined properties.

Entanglement

The possibility of correlations between observable properties, even when neither property is well-defined before it's observed, introduces the bizarre phenomenon of quantum entanglement

Imagine 2 of us agree to go off to opposite sides of the city, and at 9 pm start making a list of 100 numbers, recording 1 every 5 seconds. What would be your reaction if we later met to compare lists, and found that they were identical?

Key developments in the case against "naive realism"

- EPR Paradox (Einstein, Podolsky, & Rosen 1935)
- Bell's Theorem/Bell's Inequality (John Bell, 1964)
- Aspect Experiments (1980's)

David Mermin, Physics Today, April 1985, provides an excellent summary

"It is wrong to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature."

– Niels Bohr