PHYS-453

4-THE STATISTICAL INTERPRETATION

…and the nature of measurement
in quantum mechanics

Probabilities in classical physics

- In classical physics the probabilities are a result of *incomplete knowledge*.
- For example the prediction of the outcome when we toss a coin is prevented because we do not know the parameters of the problem: the initial conditions for position and velocity, the air pressure fluctuations etc.
- If we knew all them and insert them in a supercomputer then we would know the outcome.

The statistical interpretation

- Statistical interpretation introduces a kind of **indeterminacy** into quantum mechanics. It seems that all quantum mechanics has to offer is *statistical* information about the *possible* results.
- Is this indeterminacy a fact of nature or a defect of theory?
- Suppose we *do* measure the position of a particle and I found it at point C. Where was the particle *before* I made the measurement?
- There three schools of thought regarding the quantum indeterminacy:

The realist position

- The particle *was* at C (Einstein and others).
- Then quantum mechanics is an *incomplete* theory. It cannot tell us where the particle was.
- The realist say that this is not a fact of nature but a reflection of our ignorance.
- “The position of the particle was never indeterminate, but was merely unknown to the experimenter” (d’ Espagnat)
- Some additional information (known as **hidden variable**) is needed to provide a complete description of the particle.

The orthodox position

- *The particle wasn't really anywhere.* (Bohr, Heisenberg and others).
- It was the act of measurement that forced the particle to "take a stand".
- "Observations not only *disturb* what is to be measured, they *produce* it..". This is the so-called **Copenhagen interpretation.**
- It is the most widely accepted position among physicists.

The agnostic position

- *Refuse to answer.*
- What we know is the outcome of a measurement. We do not know anything before the measurement so it is meaningless to ask what was going on before.

The Bell's inequalities

- In 1964 John Bell showed that it makes an *observable* difference whether the particle had a precise (though unknown) position prior to the measurement, or not.
- Bell's discovery eliminated agnosticism as a viable option and made it an experimental question whether the realist or the orthodox interpretation is the correct choice.
- Bell's discovery had a great impact on quantum mechanics. It pointed the importance of **quantum entanglement**, which although known it had been disregarded.

The nature of measurement

- What if we made a *second* measurement *immediately* after the first?
- On this everyone is in agreement: A repeated measurement (on the same particle) must return the same value.
- The measurement rapidly alters the wave-function which is now sharply peaked about C. This is the so-called **collapse of wave function**.

The non-local nature of measurement

- Imagine a wavefunction spread in our galaxy! Assume we measure its position and we find it in our class! What "physical" mechanism is responsible for such a huge "shrinkage" of the wavefunction?
- If we consider that a detector measures the position in a small time interval then the "withdrawal" of the wavefunction from the remote edges of our space would require "speeds" higher than that of light.
- Measurement in quantum mechanics has a extremely **non-local** character.

The meaning of average value

- If a measurement collapses the wave function then what is the meaning of the average value of a physical quantity?
- It is the average of measurements on an **ensemble** of particles *all prepared in the same state* Ψ.