PHY202 Quantum Mechanics

Topic 11

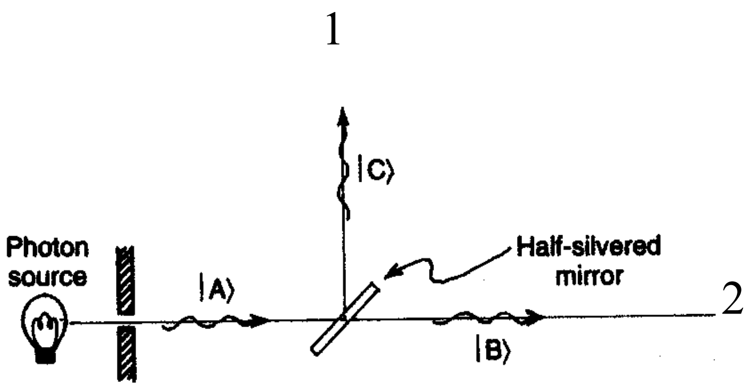
Puzzles and Paradoxes in Quantum Mechanics

Outline of Topic 11

1. A Photon Interferometer

2. Schrödinger's cat paradox

Photon Interferometer



A ray of light incident on a half-silvered mirror will split into two rays, where each ray is half the intensity of the original ray.

The quantum mechanical description of a single photon is that at the mirror the photon wavefunction ψ_A splits into two components:

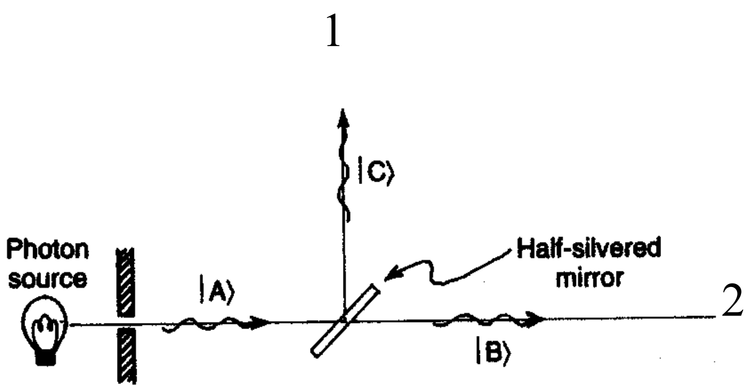
$$\psi_A \rightarrow \sqrt{\frac{1}{2}}(\psi_B + i\psi_C)$$

This is a *linear superposition* of photon states.

The factor of i arises for the reflected component, because there is a one-quarter wavelength shift upon reflection. (It is this which causes interference.)

This superposition seems to imply that the photon goes in both directions simultaneously.

However, if we *measure* what happens to a single photon incident on the mirror by placing detectors at 1 or 2 we would find that it went in one specific direction.



Quantum mechanically this is because the measurement has caused ψ_A to collapse into one of its components, namely ψ_B or ψ_C.

This puzzle raises the question:

What is a measurement?

Until a measurement is made, the wavefunction evolves in a completely deterministic way.

Indeterminism only enters when a measurement is made.

These issues are brought to the fore by Schrödinger’s famous cat paradox.

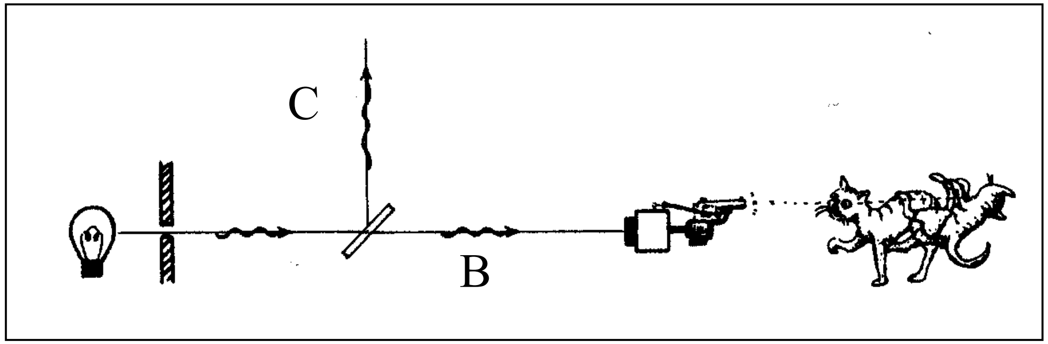
A Schrödinger Cat Paradox

The concepts of a photon (or electron) splitting into two appears odd.

But because a photon is a microscopic object most people feel able to “accept” it.

But what about macroscopic objects, like cats?

Schrödinger introduced his paradox in 1935 to illustrate what he felt was the incompleteness of quantum mechanics.



Let us suppose that we have a half-silvered mirror again so that the photon wave-function splits, as before:

$$\psi_A \rightarrow \sqrt{\frac{1}{2}}\left(\psi_B + i\psi_C\right)$$

The photon along path B triggers a gun that kills the cat ($\psi_B \rightarrow \psi_{dead}$), whereas the photon along path C does not ($\psi_C \rightarrow \psi_{alive}$).

When Does the Measurement" Happen?

We assume that the mirror, cat and gun are in an opaque box – and thus cannot be observed.

We also assume that the cat is not a "measuring device", so that the wavefunction does not initially collapse.

Thus,

$$\psi_A \rightarrow \sqrt{\frac{1}{2}}\left(\psi_{dead} + i\psi_{alive}\right)$$

The cat is in a superposition of dead and alive states.

In principle, there are measurable interference effects associated with this superposition of dead and alive states.

The wavefunction collapses when a measurement is made.

What does this mean?

Is the cat conscious of itself?

Does the cat become dead or alive when an “observer” looks into the box?

Does this imply a special role for conscious beings?

Note the Schrödinger’s cat paradox is more than just a statement about our lack of knowledge of the cat’s state.

Few people would claim that the cat is really in a superposition of these states.

So, when does the wavefunction collapse actually occur?

These issues have not been resolved to the satisfaction of all physicists.

Some claim that incoherence effects in macroscopic objects destroy interference phenomena, so the issue is “not relevant”.

More esoteric explanations include the many worlds hypothesis (Everett), the role of quantum gravity in wavefunction collapse (Penrose), or non-linear terms in the Schrödinger equation.

The apparent role of the conscious observer also attracts the interest of philosophers.

Many physicists (*e.g.* Einstein, “God does not play dice.”) regard the lack of objective reality in quantum mechanics as deeply disturbing, and therefore regard it as a “provisional” theory to be eventually replaced by a more complete “correct” theory.

Lack of determinism in quantum mechanics also leaves room for free will.

In the absence of this complete theory (if it exists), it is probably sensible to regard quantum mechanics as an operational procedure to predict experimental outcomes, because:

No prediction of quantum mechanics has ever been disproved.

In particular, the results of experiments designed to test for “incompleteness” in quantum mechanics agree with quantum mechanical predictions (and not with deterministic “hidden variable” theories).

MERRY CHRISTMAS

AND

A HAPPY NEW YEAR!