

Philosophy of Physics 1b – Lecture 6

1 Review

- **Two ways in which the quantum state evolves (changes) over time:**
 1. For **isolated** systems, the quantum state evolves in a ‘smooth’, ‘continuous’, deterministic (predictable) way, in accordance with Schrödinger’s Equation.
 2. When a **measurement** is made, the quantum state changes (‘collapses’) in an abrupt, discontinuous and (in general) indeterministic way, in accordance with the **measurement postulate**.
- **The big issue:** Does the quantum state provide a **complete description** of physical reality, or are there ‘hidden’ aspects of reality that it doesn’t describe? Is Heisenberg’s Uncertainty Principle a restriction on the sharpness of **reality itself**, or only of **what we can know** about reality.
- **This week’s topic:** Arguments **AGAINST** the complete description view

2 Schrödinger’s Cat

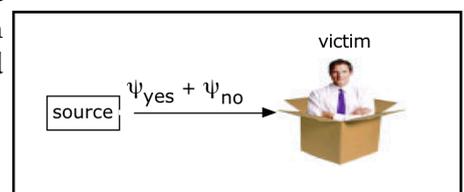
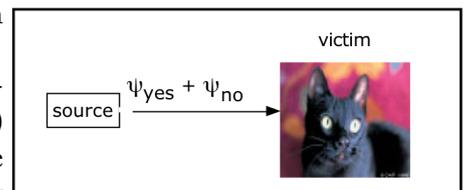
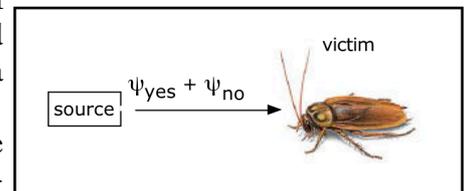
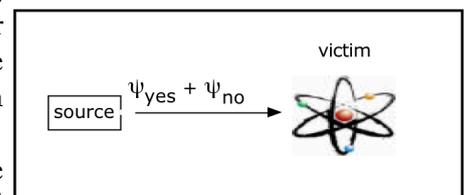
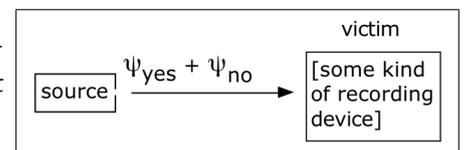
- Schrödinger’s argument against the “fuzzy reality” view:

“One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following diabolical device ... In a Geiger counter there is a tiny bit of radioactive substance, so small that perhaps in the course of one hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid.

If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The first atomic decay would have poisoned it. The ψ function for the entire system would express this by having in it the living and the dead cat (pardon the expression) mixed or smeared out in equal parts.

It is typical of these cases that an indeterminacy originally restricted to the atomic domain becomes transformed into macroscopic indeterminacy, which can then be resolved by direct observation. That prevents us from so naively accepting as valid a ‘blurred model’ for representing reality. In itself it would not embody anything unclear or contradictory. There is a difference between a shaky or out-of-focus photograph and a snapshot of clouds and fog banks.” (Schrödinger, 1935)

- **Schrödinger’s point:** If we say that microscopic things such as atoms are not determinately “decayed” or “not decayed”, until a measurement is made, then we have to say the same about large (“macroscopic”) objects such as cats, in cases in which the state of the cat depends on the state of the atom. In other words, if the process of “collapse” which gives us definite outcomes is a change in reality, rather than a change in our knowledge of reality, then big objects as well as little objects must exist in strange “uncollapsed” states (“superpositions”, e.g. of a live and a dead cat).
- **Common reply to Schrödinger:** Why can’t the cat perform the measurement which produces a definite outcome? Why should reality have to wait for us to open the box?
- **Response:** There’s nothing special about cats. In the generic experiment, the “victim” is a device with two possible states (e.g. “yes” and “no”, or “alive” and “dead”), capable of recording the two possible outcomes of the experiment. The issue when “collapse” takes place is the issue as to when the victim acquires a determinate state (e.g. “alive” or “dead”).
- The response to Schrödinger’s point was that if the victim is a cat, then the victim “makes the measurement” and “collapses the state”, before an external observer opens the box. Let’s replace the cat with a range of simpler and more complicated “victims”, ranging from an atom (at the simple end) to a person (at the complex end).
- In which cases does a measurement take place before we open the box? The first case (when the recording device is an atom) is an isolated quantum system is anything is, so in this case we should have no “collapse”, only smooth change in accordance with Schrödinger’s Equation (type 1 evolution).
- By the time we reach the case of the cat, the orthodox view says that a measurement is taking place (i.e. type 2 evolution – “collapse” – is happening) before we open the box. But we can put as many intermediate cases as we like between the atom case and the cat case. In this gradation of cases, what determines the crucial borderline, between cases (like the atom) in which **collapse doesn’t happen**, and cases (like the cat, according to the standard view), in which **collapse does happen**?
- This issue is the infamous **Measurement Problem**.



3 The Measurement Problem

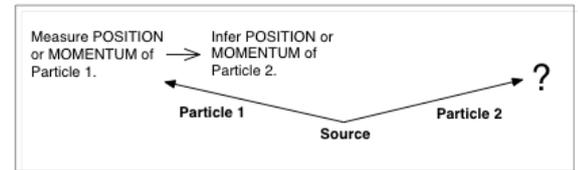
- This issue – where does real measurement happen? – is widely seen as the biggest single problem facing **complete description** views of QM.
- It's important to be clear why it isn't a problem for **incomplete description** views of QM. For an incomplete description view, measurement is just a matter of **acquisition of information** (like finding out that a chicken is male) – it doesn't involve a **physical change** in the system being measured. So no need to answer a question like this: Under what circumstances, **precisely**, does measurement-induced change (“collapse”) happen?
- The point of the Not-Just-Cats experiment was to show that this question is very hard to answer.

4 Does consciousness solve the Measurement Problem?

- Digression about “Wigner’s friend”.
- Does consciousness collapse the state function?
- Is this a plausible response to the Not-Just-Cats experiment?

5 The Einstein-Podolsky-Rosen (EPR) argument

- A second major objection to the complete description view proposed by Einstein and his Princeton colleagues Podolsky and Rosen in 1935.
- Recall one of our formulations of the **big issue**: Is Heisenberg’s Uncertainty Principle a restriction on the “sharpness” of **reality itself**, or only of **what we can know about reality**?
- Interpreted as a restriction on the “sharpness” of reality itself, one version of Heisenberg’s Uncertainty Principle says that a particle cannot have both a precise **position** and a precise **momentum**, at the same time. EPR argue that in some cases, this is possible – there are extra “hidden variables” not described by quantum mechanics.
- The EPR argument relies on two crucial assumptions:
 1. **Locality**: no action at a distance; change at one place doesn’t instantaneously affect things a long way away.
 2. **Criterion of Reality**: If we can predict with certainty what the result of a measurement **would be**, then there exists an “element of reality” responsible for that result (even if the measurement is not actually made).
- With these assumptions, the argument goes like this:
 - (a) If we **were to** measure position of Particle 1, we **could** predict with certainty the position of Particle 2; so (by **Criterion of Reality**) Particle 2 **would have** a definite position in this case.
 - (b) By the assumption of **Locality**, whether we **actually** measure position of Particle 1 has no effect on the real properties of Particle 2; so
 - (c) Particle 2 has **definite position**, even if we don’t measure the position of Particle 1. (The combination of Locality and the Criterion of Reality implies that it is enough that we could measure the position of Particle 1, and that Particle 2 would have a definite position in that case.)
 - (d) Repeating same argument for momentum, Particle 2 also has a **definite momentum**.
 - (e) Hence the QM description is **incomplete** (Heisenberg’s Uncertainty Principle is a restriction on our **knowledge**, not a restriction on **reality itself**).



6 Why does locality matter?

- (i) Old objections to the idea of action-at-a-distance. (Recall Newton and gravity.) (ii) New objections, based on Einstein’s Special Theory of Relativity, which holds that instantaneous action-at-a-distance is a physically meaningless (or at least highly problematic) notion, **because simultaneity is not well defined at a distance**.
- The EPR argument highlights the fact that if “collapse” is a physically real process, it threatens to conflict with Special Relativity. This is true even of a simple position measurement on a single particle, which changes the state from something spread out over space (corresponding to non-zero chance of finding the particle anywhere in a large region), to something very localised. This requires an instantaneous change over a wide region of space – something very hard to reconcile with Special Relativity.
- In fact the problems associated with reconciling objective “collapse” with Special Relativity are even worse than this. According to Special Relativity, the time-ordering of distant events can be different for different observers. Combined with instantaneous collapse-at-a-distance, this implies that the history of an individual particle can be different for different observers.
- “I cannot seriously believe in [QM] because the theory cannot be reconciled with the idea that physics should represent a reality in time and space, **free from spooky actions at a distance**.” – Einstein to Max Born, 1947

7 One more problem – “collapse” is time-asymmetric

- The state of a quantum system depends on the last measurement (in the past), but not on the next measurement (in the future). Why this is a problem: because in other respects, the fundamental laws of physics don’t care about the difference between past and future. But again, this is not puzzling if “collapse” is just a **change in our information**, not a **change in the world**.