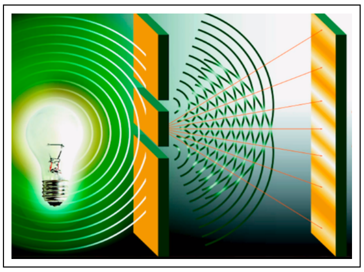
Philosophy of Physics 1b – Lecture 7

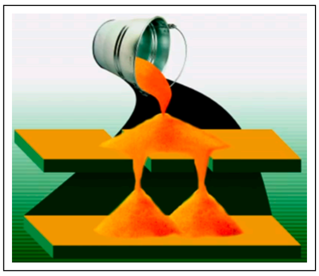
1 Review

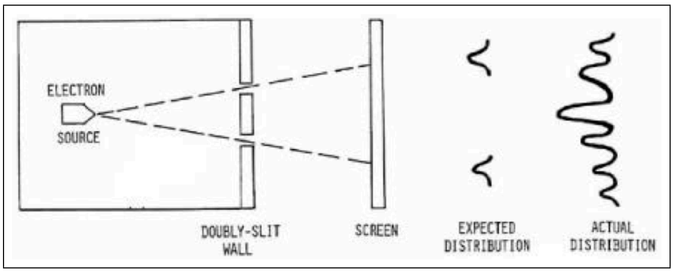
- **Two ways in which the quantum state evolves (changes) over time:** (1) For **isolated** systems, the quantum state evolves in a 'smooth', 'continuous', deterministic (predictable) way, in accordance with Schrödinger's Equation. (2) When a **measurement** is made, the quantum state changes ('collapses') 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?
- **Last week:** Problems against the complete description view, especially the **Measurement Problem** and the **EPR argument**.
- **This week:** Arguments against the **incomplete description** view

2 The two slit experiment

- **Question:** What happens if we fire small particles towards a screen containing two small slits? Where do particles which go through the holes end up?
- **Answer:** In two clusters, one from the left hand slit, and one from the right hand slit. Note that we could get the same pattern by doing the experiment first with one slit open, and then with the other open. The two-slit pattern is just the sum of the two individual one-slit patterns.
- **Question:** What happens if we do the same thing with waves – e.g. ripples on a water surface, or light.
- **Answer:** Having two slits makes a real difference, because the waves going through one slit 'interfere' (i.e. enhance or cancel out) those going through the other. So the pattern in the two-slit case is not just the sum of the patterns in the one-slit cases individually.
- **Quantum interference:** According to QM, microscopic particles (e.g. electrons) 'behave like waves', in the sense that they produce interference effects in two-slit experiments. In the following diagram, the lines on the right (above 'Expected distribution' and 'Actual distribution') represent graphs showing the number of electrons detected at the corresponding place on the screen.

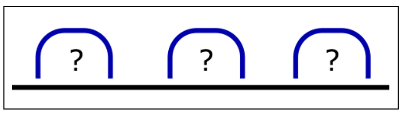






- Why is this a problem for the (Einstein) view that QM gives an incomplete description? Einstein wants to say that each electron really goes through one slit or other, even if the quantum description doesn't tell us which. But if that were so, wouldn't we expect the 'Expected distribution' above, which is just the sum of the two individual one-slit distributions – i.e. the distributions we get with just one slit open? Explanation of the interference pattern seems to require that in some sense the electron 'goes through both slits'.
- But what happens if we 'look to see' where the electron is going? We find it going through just one slit, but observing its position in this way destroys the interference effect! In the early days of QM, Einstein's opponents (e.g., Bohr, Heisenberg), interpreted this to mean that the electron doesn't have a precisely defined position, expect when we measure its position – so reality is 'fuzzy', and becomes 'sharp' when we make a measurement.

3 No hidden variable theorems



- If QM is an incomplete description of a physical system, then there are aspects or properties that it doesn't describe – "hidden variables".
- Various mathematical results – "no hidden variable theorems" – seem to show that no "hidden variable theory" could have the consequences predicted by QM. The following toy example gives a flavour of these arguments.
- **The shell game example:** Suppose we are allowed to turn over any two shells – any two, but no more than two. We can repeat the experiment (with a new presentation of three shells) as often as we like. Suppose that after many trials, we have always found the following result: a **single red stone** under one of the chosen shells, and a **single green stone**, under the other. How could this be explained?
- **It can't be**, if what happens when turn over a shell is simply that we reveal a pre-existing (but previously "hidden") state of affairs (which isn't influenced by our choice of shells). [Why not? Think about it!]

- In a similar way, various mathematical results show that no straightforward "chicken sexing" model – in which quantum measurement is thought of as revealing pre-existing properties, which not somehow **produced** by the measurement – can reproduce the results predicted by QM.
- There are various loopholes, but in one way or another, they all involve the idea that the reality revealed by the measurement depends on the nature of the measurement (e.g. on what else is measured at the same time – as in '**contextual**' HV theories), in a way which is not true in classical physics.

4 Bell's theorem

- Recall the EPR argument (1935) that QM is incomplete. EPR argued that in certain cases, involving two correlated particles, we could use measurements on one particle to find out about the other. Assuming **locality** – 'no action at a distance' – what we do on one particle doesn't affect the other; so what we what we would find out about particle 2 (if we did a measurement on particle 1) is 'true anyway'. This was EPR's argument that QM doesn't give 'the complete picture'.
- To avoid this conclusion, Einstein's opponents – Bohr, Heisenberg, etc – need to reject locality. And we saw that if "collapse" is a real physical process, there are other reasons for thinking that reality is non-local.
- But in 1965 John Bell showed that non-locality isn't just a problem for Bohr – Einstein's "hidden variable" team can't avoid it, either. Bell's argument relies on the same kind of case as the EPR argument: independent experiments on a pair of correlated particles. [Details on presentation in lecture.]

5 The man who proved Einstein wrong?

- In effect, Bell (a) takes Einstein's own conclusion from the EPR argument about the perfect correlations when the same measurement are made on both particles – viz., that there must be some "hidden" "element of reality" responsible for the correlation in these cases; and (b) shows that this conclusion conflicts with other predictions of QM, when different measurements are made on the two particles.
- Ironically, Bell shared Einstein's instincts about QM – he too thought that it is an incomplete theory.
- Did Bell show that QM is complete? **No:** he only showed that a theory of "hidden variables" would have to be non-local **too**. So Bell "evened the score", in showing that non-locality isn't just a problem for the complete description views. But he didn't show that non-local hidden variable theories are impossible. (They are possible – e.g. the **de Broglie-Bohm** Theory – but like 'collapse' views, they are hard to reconcile with special relativity.)

6 Summary: problems with incomplete description view

- **The two-slit experiment:** hard to understand interference effects unless it is "objectively indeterminate" which slit a particle goes through (so that in some sense, it goes through both).
- **The "no hidden variable" theorems.** Show it is impossible for HV theory to reproduce predictions of QM, at least if we assume that measurement simply reveals a pre-existing property (and disallow 'contextuality').
- **Bell's theorem:** shows that a hidden variable theory can't escape non-locality.

7 Should we try to "interpret" quantum mechanics?

- **Instrumentalism** – the "shut up and calculate" view.
- General attractions of instrumentalism (i.e., the view that scientific theories are just 'instruments' for predicting the results of measurement, rather than descriptions of reality) in philosophy of science: empiricism and verificationism. QM and logical positivism – an historical coincidence.
- Problem for any instrumentalist view in science: what **exactly** should we be instrumentalist/antirealist about? Where is the "cut" between description of reality and mere instrument – or between "theory" and "observation"?
- Copenhagen followers tended to talk about a division between the "microscopic" and the "macroscopic", but how do we make this precise? Isn't this just the Measurement Problem all over again?
- Can instrumentalism ever be justified as a practical attitude in physics? It is one thing to accept that physics might reach a limit, beyond which no further progress or explanation or interpretation is possible; quite another to be justified in behaving as if physics has already reached that limit – i.e. in not trying to go any further. QM offers plenty of puzzling phenomena – e.g. "action at a distance" – which it seems natural to try to explain. We might fail, but how could we know in advance that explanation was impossible?

8 The retrocausal loophole

- Bell's Theorem assumes that in QM, as in the familiar world, a system can be affected by what happens to it in the past, but not the future. Otherwise, there's an easy way to avoid non-locality, by decomposing those 'spooky actions at a distance' into local actions via the past.
- Cure may seem worse than the disease, but why, exactly? (Philosophy needed!)