Philosophy of Quantum Mechanics: Week 8

Unitary Quantum Mechanics

We have seen that unitary quantum mechanics commits us to macroscopic superposition states, such as

$$|\psi\rangle = \alpha\,|\mathrm{alive}\rangle + \beta\,|\mathrm{dead}\rangle\,. \tag{1}$$

This is supposed to be problematic (indeed, as we have discussed, it's one possible way of putting the measurement problem)—for it seems that *we never observe such macroscopically indefinite states*. It was as a result that Bell posed the following dichotomy:

1. Either unitary quantum mechanics *is not everything*, or...
2. unitary quantum mechanics *is not right*.

Modern Everettians contend that this is a false dichotomy; as Wallace writes: (*The Everett Interpretation*, p. 4)

> We have indeed seen that states like $|\psi\rangle$—a superposition of states representing macroscopically different objects—are generic in unitary quantum mechanics, but it is actually a *non sequitur* to go from this to the claim that macroscopic objects are in indefinite states.

By rejecting the idea that states such as $|\psi\rangle$ represent indefinite states, Everettians can reject Bell's dichotomy. They seek to *endow the formalism of unitary quantum mechanics with a realist interpretation, without modification or supplementation*.

The Everett Interpretation

The Everett interpretation can be taken in two parts:

(A) A postulate that the state of the universe is faithfully represented by a unitarily evolving quantum state.

(B) A claim that (in certain conditions—namely in the presence of decoherence), the quantum state must be understood as describing a multiplicity of approximately classical, approximately non-interacting regions which look very much like 'classical worlds'.

Some, such as Kent (1990), resist (B):

> [O]ne can perhaps intuitively view the corresponding components [of the wave-function] as describing a pair of independent worlds. But this intuitive interpretation goes beyond what the axioms justify: the axioms say nothing about the existence of multiple physical worlds corresponding to wave function components.

Emergent Entities

How is an Everettian supposed to respond to criticisms such as that of Kent? Typically, they do so by appeal to notions of *emergence*. As Wallace writes, (*Emergent Multiverse*, p. 47):

> It is simply untrue that any entity not directly represented in the basic axioms of our theory is an illusion. Rather, science is replete with perfectly respectable entities which are nowhere to be found in the underlying microphysics.

Hofstadter and Dennett (1981) put the point as follows:

> Our world is filled with things that are neither mysterious and ghostly not simply constructed out of the building blocks of physics. Do you believe in voices? How

> about haircuts? Are there such things? What are they? What, in the language of a physicist, is a hole—not an exotic black hole, but just a hole in a piece of cheese, for instance? Is it a physical thing? What is a symphony? Where in space and time does 'The Star-Spangled Banner' exist? Is it nothing but some ink trails in the Library of Congress? Destroy the paper and the anthem would still exist. Latin still *exists* but it is no longer a living language. The language of the cavepeople of France no longer exists at at all. The game of bridge is less than a hundred years old. What sort of thing is it? It is not animal, vegetable, or mineral.

The philosophy of science term for such entities is *emergent*: they are not directly definable in the language of microphysics—but that does not mean that they are somehow *independent* of the underlying microphysics.

Everettians claim that what goes through for such entities goes through *mutatis mutandis* for the worlds of the Everett interpretation: (Wallace, *Emergent Multiverse*, p. 48)

> [W]orlds, in the Everett interpretation, are likewise emergent entities ... [T]his is actually a rather mundane claim ... it puts Everettian worlds on a par with all manner of unmysterious, scientifically respectable entities.

Emergence

It's worth spelling out in more detail why Everettians take their worlds—i.e. their decohered wavefunction branches—to be emergent entities. Typically, they do so by appeal to *Dennett's criterion*: (see Wallace, *Emergent Multiverse*, p. 50)

> **Dennett's criterion:** A macro-object is a pattern, and the existence of a pattern as a real thing depends on the usefulness—in particular, the explanatory power and predictive reliability—of theories which admit that pattern in their ontology.

Examples:

- Tigers.
- Phonons in solid-state physics.

Wallace: (*Emergent Multiverse*, p. 58)

> Science is interested with interesting structural properties of systems, and does not hesitate at all in studying those properties just because they are instantiated 'in the wrong way'.

Quantum Mechanics

Now let's return to quantum mechanics. How, exactly, is the above story regarding emergence meant to be deployed for Everettian ends? Wallace writes: (*Emergent Multiverse*, p. 60)

> [I]f we apply the same principles to quantum mechanics as we apply in general through science to identify higher-level ontology, we find that, since both the histories [$|\mathrm{alive}\rangle$] and [$|\mathrm{dead}\rangle$] represent a state of affairs where the system in question is *structured* like a cat, they represent a state of affairs where the system in question *is* a cat. We recover, then, what we would expect to recover: that macroscopically definite quantum states represent classical states of affairs in just the way that they are usually taken to.

Now let's focus on a state such as (1). What, if anything, does this represent? Here is the crucial Everettian observation:

1. $|\mathrm{dead}\rangle$ instantiates a structure which represents a dad cat, and so—by the general functionalist principle used in science—that state itself represents a system containing a dead cat.
2. Similarly, $|\mathrm{alive}\rangle$ instantiates structure which represents a live cat, and so—by the general functionalist principle used in science—that state itself represents a system containing a live cat.

3. The superposed state (1) instantiates all of the structure by virtue of which $|\mathrm{dead}\rangle$ instantiates a dead cat, *and* all of the structure by virtue of which $|\mathrm{alive}\rangle$ instantiates a live cat.

4. So applying, again, the same general principles of functionalism, the state (1) represents a system containing both a dead cat, and a live cat. Superposition has become multiplicity at the level of structure: (1) instantiates two independent lots of macroscopic structure, and so represents two distinct macroscopic systems at once.

Decoherence

The live-cat and dead-cat states can be understood to constitute autonomous *worlds*, because of *decoherence*: (Wallace, *Emergent Multiverse*, p. 62)

> In general ... there is no inference between the live-cat and dead-cat states, and so both lots of structure continue to be present. The reason we can be confident of this is because of decoherence, which in general prevents the macroscopic degrees of freedom of quantum systems from interfering, and so guarantees that structures instantiated by the macroscopic degrees of freedom of quantum systems are not erased when those systems are in superpositions of macroscopically definite states.

On the notion of *worlds*, Wallace continues: (*Emergent Multiverse*, p. 63)

> And of course, in reality, no cat-containing box can be isolated from its surroundings. The room in which the box sits will get entangled with the box—and then there will be two rooms, and soon after that, two planets, and soon after that, two solar systems. And so unitary quantum mechanics, interpreted realistically, is a many-worlds theory—not because the 'worlds' are present in some microphysically fundamental sense but because the quantum state instantiates many different macroscopic systems.

Branch Counting

Modern Everettians are often asked the question: *how many branches?* There is no well-defined answer to this question, for the number of (decohered) branches depends upon the level of *coarse-graining* deployed. (See Wallace, *Emergent Multiverse*, p. 101).

Probability

The Everettian universe is deterministic, so how is an advocate of this interpretation supposed to account for the probabilities we actually observe when performing quantum mechanical experiments (e.g. in Stern-Gerlach experiments)? This is a huge topic—which we will explore in week 10.