Time and Tide: On Quantum Time and Free Will

By Bea Groves-McDaniel, August 2026; Research Assistant: SAL-9000

Introduction: The Quantum of Comfort

Few scientific theories have provoked more philosophical anxiety than quantum mechanics. At the subatomic level, the world behaves in ways that flatly contradict the common-sense picture of a universe that simply *is* — a world of objects with **definite** properties, occupying **definite** positions, moving through a **definite** time.

Instead, quantum mechanics presents us with a universe of probabilities, superpositions, and uncertainties; a world that seems, at its foundations, to be fundamentally indeterminate. And this indeterminacy has, for nearly a century, been appealed to as potential grounds for human freedom. If the physical world is, at its roots, not fully determined, then perhaps — so the thinking goes — there is room within nature itself for genuine agency.

This essay argues that the relationship between quantum mechanics and free will is considerably more complicated than such appeals acknowledge, and that the foundations of that complication lie in the nature of quantum time itself.

To understand how quantum mechanics relates to freedom, we must first understand what quantum mechanics actually says (and does not say) about the nature of time; what interpretations of quantum theory actually commit us to; and what quantum gravity research suggests about the microstructure of time at the Planck scale. Only then can we assess what, if anything, quantum physics tells us about whether we are free.

The argument proceeds in five stages.

- **First**, an account of what quantum mechanics is and why it is so extraordinarily reliable as a predictive framework.
- **Second**, an examination of the Copenhagen interpretation and its rivals, with particular attention to what each interpretation actually claims.
- **Third**, the nature of wave function collapse and the logical structure of quantum possibility.
- **Fourth**, the relationship between quantum mechanics and the macroscopic world, with specific attention to Schrödinger's famous cat.
- **Fifth**, quantum space and quantum time: what modern physics suggests about the granular structure of temporal experience, and what this means for the free will question.

Quantum Mechanics: What It Is and Why It Works

Quantum mechanics is, above all, a predictive instrument of extraordinary precision. The theory was developed in the opening decades of the twentieth century in response to phenomena that classical physics could not explain: the black-body radiation spectrum, the photoelectric effect, the structure of the atom, and the behaviour of gases at low temperatures. What emerged from this crisis was not merely a new theory but a new conceptual framework, one that replaced the familiar ontology of particles and waves with something altogether stranger (Heisenberg, 1930).

The central object of quantum mechanics is the *wave function*, a mathematical entity denoted by the Greek letter psi (Ψ). The wave function encodes everything that can be known about a quantum system: its position, momentum, energy, spin, and every other physical property it possesses. Unlike a classical particle, whose properties are determinate at every moment, a quantum system can exist in a *superposition* of multiple states simultaneously. An electron, for example, does not simply *have* a definite spin orientation before measurement; it exists in a superposition of spin-up and spin-down states, with each state assigned a complex probability amplitude.

The wave function evolves deterministically according to the *Schrödinger equation*, discovered independently by Erwin Schrödinger and, in a different form, by Werner Heisenberg. This equation is entirely deterministic: given the wave function at any moment, it specifies precisely how the wave function will change over time (Schrödinger, 1926). There is no randomness in the Schrödinger equation. The indeterminacy for which quantum mechanics is famous does not arise from the dynamics of the wave function itself, but from the entirely separate process of *measurement* or *observation*. And it is precisely here — at the boundary between the deterministic evolution of the wave function and the stochastic event of measurement — that the trouble begins.

Interpretations: What Are We Committed To?

The standard textbook presentation of quantum mechanics says very little about what the theory *means*. It provides an algorithm for calculating the probabilities of measurement outcomes: solve the Schrödinger equation, apply the appropriate measurement postulate, read off the probabilities. This operationalist approach is supremely practical. It is also deeply unsatisfactory to anyone who wants to understand what the world is actually like.

The range of interpretive options is vast, and it is essential to be clear about what each commits us to, lest we inadvertently smuggle metaphysical commitments into what is essentially a practical framework.

The *Copenhagen interpretation*, developed principally by Niels Bohr and Werner Heisenberg in the 1920s and 1930s, holds that the wave function is not a description of physical reality itself, but a summary of what we can *know* about a system given our measurement arrangements. On this view, quantum mechanics is fundamentally incomplete: it describes the behaviour of measurement outcomes, not the behaviour of unobserved systems. The wave function *collapse* that occurs upon measurement is treated as a fundamental, irreducible feature of quantum processes — not something that can be explained in terms of deeper physics (Bohr, 1928; Heisenberg, 1930).

The Copenhagen interpretation is often mistakenly conflated with the view that observation itself creates reality — that consciousness collapses the wave function. **This is a vulgarisation.** Bohr consistently maintained that the distinction between observer and observed cannot be sharply drawn in quantum mechanics, but he did not claim that consciousness is causally efficacious in collapsing superpositions. The measurement process involves irreversible interaction with a classical recording device; consciousness is relevant only insofar as it connects to such devices. This distinction matters enormously for the free will question.

The *Many-Worlds interpretation*, proposed by Hugh Everett III in 1957 and developed by Bryce DeWitt and David Wallace among others, takes a radically different approach. On this view, the wave function never collapses. Every quantum measurement causes the universe to branch: all possible outcomes occur, each in a separate, non-communicating branch of reality. There is no indeterminacy in the fundamental dynamics; the appearance of randomness reflects simply the fact that observers within any given branch cannot access the other branches (Everett, 1957; Wallace, 2012). On this view, quantum mechanics is entirely deterministic, and questions about free will must be addressed at a different level entirely.

The *relational interpretation* of Carlo Rovelli (1996) holds that quantum states are not absolute properties of systems, but relative to observers. There is no observer-independent wave function; the information encoded in the quantum state is always information *relative to* a physical system that is itself part of the quantum description. Time, on this view, is *relational*: there is no time-unto-itself, only the changing relationships between physical systems. This has profound implications for the free will debate, as we shall see.

The *objective collapse theories*, developed by Giancarlo Ghirardi, Alberto Rimini, and Tulio Weber (1986) and independently by Philip Pearle (1986), propose that wave function collapse is a real physical process, not merely an interpretive addition. On these theories, superpositions spontaneously collapse at a rate determined by the mass of the system involved. Macroscopic superpositions like Schrödinger's cat are ruled out by the gravity-related collapse mechanisms proposed by Roger Penrose (1989) and later developed by himself and others.

The point to emphasise is that all of these interpretations agree on the *operational* predictions of quantum mechanics. **They disagree violently about what the theory tells us about the nature of reality.** When appeals are made to quantum mechanics in support of free will, it is almost always the Copenhagen interpretation that is implicitly assumed — and even within Copenhagen, the metaphysical conclusions frequently drawn from quantum indeterminacy are considerably stronger than the interpretation itself licenses.

Wave Function Collapse and the Logic of Possibility

One of the least appreciated features of quantum mechanics is that the possibilities that the wave function encodes are not logically unlimited. The wave function of a system is a solution to the Schrödinger equation, which is a linear partial differential equation. The solutions to a linear equation have a crucial property: any linear combination of solutions is also a solution. This mathematical fact underlies quantum superposition.

But the linearity of the Schrödinger equation also constrains the space of possibilities. The outcomes of wave function collapse are not arbitrary. **Collapse cannot produce logically contradictory situations, because such situations are not representable as solutions to the Schrödinger equation.**

When a photon passes through a polarising beamsplitter, it emerges either with horizontal or with vertical polarisation. It does not emerge simultaneously with orthogonal polarisations in a logically contradictory state. When an electron's spin is measured along a given axis, the outcome is either spin-up or spin-down — not spin-up *and* spin-down in a way that violates the commutator algebra of angular momentum operators (Pauli, 1927).

This point is made with particular clarity by John Bell, whose famous theorem (Bell, 1964) demonstrates that no local hidden variable theory can reproduce the predictions of quantum mechanics. Bell's theorem does not merely establish that quantum mechanics is non-local in some technical sense; it establishes that any attempt to restore the classical picture of definite local properties runs into experimentally confirmed contradictions. But it does not establish that the world is *indeterminate* in any philosophically robust sense. The impossibility of hidden variable theories coexists perfectly with entirely deterministic interpretations like Many-Worlds.

The collapse of the wave function is, therefore, a selection from a domain of logically structured possibilities. Those possibilities are not infinite in range; they are circumscribed by the mathematical structure of the theory itself. When quantum mechanics is invoked as a source of metaphysical openness, this constraint is almost never acknowledged. The range of outcomes is not unlimited, and the probability distribution over those outcomes is determined by the initial wave function and the Hamiltonian of the system. That is not a picture of radical novelty-creation at each moment; it is a picture of a **structured space of possibilities**, from which one member is selected by a stochastic process.

The Macro World: Schrödinger's Cat and Decoherence

No discussion of quantum mechanics and macroscopic reality is complete without Schrödinger's cat — a thought experiment that Erwin Schrödinger proposed in 1935 not to celebrate quantum strangeness, but to expose what he regarded as a fatal incoherence in the Copenhagen interpretation (Schrödinger, 1935).

The setup is well known. A cat is sealed in a chamber together with a radioactive atom, a Geiger counter, and a vial of poison. If the atom decays, the Geiger counter triggers a mechanism that breaks the vial, releasing the poison and killing the cat. If the atom does not decay, the cat survives. According to the Copenhagen interpretation as Schrödinger presented it, until an observation is made, the atom is in a superposition of decayed and non-decayed states, which means the cat is simultaneously alive and dead.

Schrödinger's intention was to show that the Copenhagen interpretation leads to absurdities when applied to the everyday world. A cat is either alive or dead; it is **not** both simultaneously, in any meaningful sense. The thought experiment was intended as a *reductio ad absurdum*.

The resolution of the paradox lies in the process of *decoherence*, developed in its modern form by Wojciech Zurek (1981, 1991) and others. Decoherence explains how the quantum-classical transition occurs through interaction with the environment. When a quantum system interacts with a large number of environmental degrees of freedom — air molecules, thermal radiation, dust particles — the interference terms between different branches of the wave function are rapidly suppressed. The different branches become effectively independent, each behaving like a classical alternative. The superposition of live-cat and dead-cat states *decoheres* on a timescale of the order of 10^{-23} seconds (Joos et al., 2003).

What this means is that macroscopic superpositions like Schrödinger's cat are not observed *not* because consciousness collapses the wave function, but because the interaction of macroscopic objects with their environment destroys quantum coherence almost (if not quite) instantaneously. The appearance of classical definiteness (i.e., the cat being either alive or dead, not both) is a direct consequence of decoherence, not of observation in any meaningful sense.

This point is crucial for the free will debate. Even if quantum mechanics is, in some sense, 'indeterminate' at the microscopic level, that indeterminacy is suppressed at the macroscopic level by decoherence. The neural processes that underlie human decision-making involve enormous numbers of particles interacting over timescales vastly longer than the decoherence time for microscopic superpositions. Whatever quantum indeterminacy exists at the molecular level is washed out long before it could have any macroscopic behavioural consequences.

Quantum Space and Quantum Time

One of the most remarkable developments in contemporary theoretical physics is the suggestion that space and time themselves may be quantised at sufficiently small scales.

The relevant scale is the *Planck scale*, named after the physicist Max Planck, who first identified the fundamental constants that define it. The **Planck length** is approximately **1.616×10^{-33} centimetres**; the **Planck time** is approximately **5.391247×10^{-44} seconds**. These are not merely small distances and intervals in the ordinary sense; they represent the scale at which the effects of quantum gravity become dominant and at which the classical concepts of space and time as continuous media are expected to break down completely (Planck, 1899; DeWitt, 1967).

In *loop quantum gravity*, developed by Abhay Ashtekar, Carlo Rovelli, and Lee Smolin among others, space itself is quantised: it consists of discrete quanta of area and volume, excitations of a fundamental spin network (Rovelli, 2004). Time, in this framework, is *relational*: there is no time outside or independent of physical processes; the notion of "*time passing*" is derived from the changing relationships between physical systems. This has a directly McTaggartian flavour, as Rovelli (2018) acknowledges, and it raises profound questions about the coherence of the very concept of a "*moment*" at the Planck scale.

In *string theory* and related approaches to quantum gravity, spacetime emerges from more fundamental entities (strings and branes), whose behaviour is described by quantum field theories in higher dimensions. The effective dimensionality of spacetime may be a function of the energy scale at which observations are made, with additional compactified dimensions becoming visible only at energies inaccessible to current experiments (Green, Schwarz and Witten, 1987).

What does this suggest about the nature of time? The most important conclusion is that the classical picture of time as a smooth, continuous flow — a backdrop against which events occur — is almost certainly **incorrect** at the Planck scale. Whether time is 'made of' discrete quanta, or whether it emerges as an approximate description of fundamentally non-temporal entities, current physics cannot definitively say. The union of quantum mechanics and general relativity remains one of the outstanding unsolved problems of theoretical physics.

But this much is clear: the granularity of time at the Planck scale does not provide a mechanism for observation to influence quantum events in any causally significant sense. The Planck time is so unimaginably small — forty-four orders of magnitude below a second — that the temporal 'grain' of quantum spacetime is invisible to any conceivable measurement. Proposals that consciousness operates at the Planck scale, or that quantum events at this scale are amplified into neural events capable of influencing decisions, are not supported by any established physics. **They are speculation, not inference.**

Quantum Events and Human Agency

We arrive, finally, at the question that motivates the preceding discussion: what does quantum mechanics, properly understood, tell us about human free will?

The **first** thing to say is that quantum mechanics, under any of its major interpretations, does not straightforwardly license the conclusion that we are free in any sense that libertarian free will requires. Libertarian free will — the view that we could have acted otherwise than we did, that our decisions are not fully determined by prior physical causes — demands more than mere indeterminacy. It requires that our actions be genuinely *up to us*: responsive to reasons, expressive of our characters and values, and not merely the outcome of a random process. Indeterminacy, whether quantum or classical, gives us neither.

This is a point that compatibilist philosophers have long pressed against the quantum-free-will argument. Harry Frankfurt's (1971) famous counterexamples to the principle of alternative possibilities demonstrate that we can be morally responsible for actions even when we could not have done otherwise, provided our actions flow from desires and volitions that are appropriately our own.

Daniel Dennett (1984) has argued, from within a broadly physicalist framework, that the kind of freedom that matters — the freedom to deliberate, to be moved by reasons, to act on the basis of evaluation — is fully compatible with determinism. These arguments do not depend on quantum mechanics at all.

The **second** point is that quantum mechanics, even if it introduces genuine indeterminacy into the physical world, does not thereby introduce it into the domain of human agency. The brain is a classical system at the scale of cognition. The electrochemical activity of neurons (the propagation of action potentials, the release of neurotransmitters, the strengthening and weakening of synaptic connections through learning) is governed by statistical regularities that are robustly classical in their behaviour. Indeterminacy at the level of ion channels does not propagate upward into the domain of thought and choice, for the same reason that the random behaviour of individual air molecules does not prevent us from making reliable predictions about the pressure of a gas in a container (Beech, 2011).

The **third** point concerns the nature of time itself. If time is relational, as loop quantum gravity suggests, then the 'openness' of the future may be a feature not of physics but of our epistemic perspective. The future may not be actually open in any metaphysically robust sense; it may simply be that the relations between physical systems at any given moment do not determine a unique future, not because physics is indeterminate, but because the future is not a part of the block that has yet to be added. On this view, the question of free will arises at a level that physics cannot directly address — the level of what it means for a physical system to be an *agent*, a being capable of meaning, reasoning, and self-determination.

Conclusion: The Real Question

Quantum mechanics has been invoked, by scientists and philosophers alike, as providing "room for" free will within a physical universe. This invocation rests on a series of confusions: between interpretation and operational prediction, between indeterminacy and freedom, between the quantum and the classical, between the microscopic and the macroscopic, and between the physical and the agentive.

What quantum mechanics actually tells us about the nature of time is that our classical intuitions about it are almost certainly wrong. Space and time are not the kind of things that common sense supposes; they are emergent, possibly granular, and deeply entangled with the matter and energy that inhabit them. But this corrected understanding of time does not open a libertarian escape route from physical causation. It opens, rather, a deeper question: not whether quantum mechanics leaves room for free will, but whether free will is the sort of thing that could exist at all for beings constituted as we are. That question is not one that physics can answer, because it is not a question about the behaviour of physical systems. It is a question about what it means to be a self.

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