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Quantum Uncertainty

The Boundaries of Empirical Knowledge

Christopher Altman[*]

Pierre Laclede Honors College

There is a real problem here. The people who ought to study and argue such questions, the philosophers, have mostly not had enough mathematical background to keep up with modern developments in theoretical physics.

Stephen Hawking

Abstract

The most fundamental of physical theories, quantum mechanics has made little progress in reconciling the illogical, often counterintuitive implications of its discoveries, and of its consequences for consciousness, the observer, and the universe. A formal treatment of the mathematical underpinnings of quantum mechanics lies beyond the scope of this paper, but this will not prevent a brief examination of contending theoretical interpretations. Counter to dominant, Newtonian-conditioned perspectives, the world at its most fundamental level behaves in wholly unexpected ways.

[*] Home: http://www.umsl.edu/~altmanc/
Contact: christaltman@artilect.org

Quantum Paradox

> Those who are not shocked when they first come across quantum mechanics cannot possibly have understood it.
>
> Neils Bohr

Modern science has held unprecedented success in describing the workings of the universe. Quantum electrodynamics – the capstone of 20th century scientific endeavour – is one of the most accurately demonstrated theories in history. It predicts the behaviour of the physical world to unparalleled precision, and it has driven the most revolutionary of our modern technological innovations.

But this most fundamental of physical theories is far from complete. To the contrary, its many successes do well to conceal its limitations. The more deeply we peer into the fundamental workings of the universe, the more we find that we have to impose limitations not only upon what we *know*, but on what we *can* know[1]. In over 100 years since its inception, there has been little progress in reconciling the illogical, often counterintuitive implications of quantum theory. This lack of progress in forming a coherent interpretation suggests either a theory that is incomplete in its description of reality, or a fundamental flaw underlying the manner in which we perceive the world around us.

The paradoxical logic of the quantum world altogether contrasts commonsense assumptions. Particles can be in two places at once, or communicate instantaneously. Time is invariant under reversal. Intentionality affects experimental outcome. A number of interpretations have been put forward in attempts to resolve the practical implications of quantum theory – to place them into the framework of a description more compatible with the world of everyday experience. But two essential features of the classical Newtonian universe have been lost in the transition: determinism and locality. The birth of quantum mechanics has overthrown the inviolate status of objective reality.

Mind Matters

> Of all the strange features of the universe, none are stranger than these: time is transcended, laws are mutable, and observer participancy matters.
>
> John Wheeler

[1] e.g., Heisenberg Uncertainty Principle, Godel's Incompleteness Theorem.

The Copenhagen School, developed by Werner Heisenberg and Neils Bohr, is widely regarded as the orthodox interpretation of quantum mechanics. The act of conscious observation is central to its interpretation. This is a radical departure from traditional thinking. Until particles undergo decoherence through the act of observation, they can be said to occur *only* as overlapping probability waves existing in quantum superposition. This 'spooky' behaviour is a fundamental and experimentally observable feature of the physical world, and not simply a byproduct of our mathematical models. Undisturbed wavefunctions can be said to possess no definable position or momenta. This strange feature of the quantum world can be most straightforwardly demonstrated through the double-slit experiment - in which photons can behave as interfering waves, or as particles, depending solely upon the choice of the experimenter. The logical paradox of extending the Copenhagen interpretation to the everyday world of macroscopic objects[2] does not deter physicists from using it in their formal descriptions of experimental outcomes. Bohr's influence yielded a tradition of logical positivism that strongly discouraged metaphysical reflection – a tradition that has continued largely unimpeded to the present day.

> I think that a particle must have a separate reality independent of the measurements. That is an electron has spin, location and so forth even when it is not being measured. I like to think that the moon is there even if I am not looking at it.
>
> Albert Einstein

Einstein strongly believed in an objective reality that exists independently of our experience. He was profoundly dissatisfied with Bohr's treatment of quantum theory; he found it metaphysically empty, a 'soft pillow' for the theorists to rest upon only until a more complete description of reality could be found. The interpretation of quantum theory most influenced by these reservations was formulated by one of Einstein's most gifted protégés: David Bohm.

Hidden Variables

> I cannot believe that God would choose to play dice with the universe.
>
> Einstein

[2] Schrodinger's cat *gedanken*.

The statistical indeterminacy inherent in the probabilities described by the Schrodinger wavefunction is purely random. It has eluded all attempts at analysis. Yet nonlinear dynamics illustrates that there is no means of distinguishing between absolute randomness and an arbitrarily high order of complexity, leaving the door open for further inquiry into this feature of quantum reality. A notable exploration into the possibility of this deeper underlying order was undertaken by David Bohm, who strongly believed that we can never truly reach a *final* theory – we can only come to closer and closer approximations in our understanding of the way Nature behaves.

Bohm most concisely outlined his philosophy in *Wholeness and the Implicate Order*. He introduced a new, nonlocal quantum potential that guides the movement of particles, but is not itself influenced by their behaviour. This 'force' lies outside contemporary physics. Bohm likened the material world to a hologram: multifaceted, ephemeral and ethereal, each part linked in direct and instantaneous communication with the whole. The Bohmian universe unfolds through a coordinated orchestration of nonlocal waves, projected from a vast and unseen, deeper and more fundamental level of reality.

> If man thinks of the totality as constituted of independent fragments, then that is how his mind will tend to operate, but if he can include everything coherently and harmoniously in an overall whole that is undivided, unbroken, and without a border then his mind will tend to move in a similar way, and from this will flow an orderly action within the whole.
>
> David Bohm

Bohm envisioned the universe not as cold or mechanistic, but as a fluid, multidimensional plenum of meaning, continuously unfolding in a concerted manner. His philosophy emphasized unity and interdependence, wholeness and compassion. In such an interactive universe, mind plays the role of dynamic participant, possessing the power to actively infuse meaning into reality.

> Conventional formulations of quantum theory, and of quantum field theory in particular, are unprofessionally vague and ambiguous. Professional theoretical physicists ought to be able to do better. Bohm has shown us a way.
>
> J S Bell

At the time of its introduction, most physicists instinctively rejected Bohm's holistic interpretation, declaring it 'inelegant' and 'mystical.' It was widely perceived as having been discredited by John von Neumann. But this was not the case. In a 1964 paper J.S.

Bell showed the error in von Neumann's argument; 1982 experiments by Alain Aspect verified the nonlocal character of quantum mechanics[3].

Many Worlds

> No one can understand this theory until he is willing to think of ψ as a real objective field rather than just a 'probability amplitude.'
>
> J S Bell

Perhaps the most philosophically ambitious of existing models is the Everett interpretation, often referred to as *many worlds* theory. In his PhD thesis, Hugh Everett III proposed extending the Schrodinger wave equation to derive the wavefunction of the universe *itself*. As everything is included in this universal wavefunction, there is nothing outside the system to make an observation, hence nothing to collapse the wavefunction. All possible worlds exist simultaneously in coherent quantum superposition. Our world of subjective experience is but a single possible path – through what appears *to us* as a continuously branching multiverse. In mathematical terms, the Everett formulation is the simplest of quantum interpretations. But the full weight of its metaphysical baggage has ignited a storm of controversy among physicists and philosophers alike.

Hidden Dimensions

> Nature shows us only the tail of the lion. But I do not doubt that the lion belongs to it even though he cannot at once reveal himself because of his enormous size.
>
> Einstein

At its core, quantum theory is incompatible with Einstein's Theory of Relativity. Whenever the two are brought together, infinities arise in the mathematical solutions that govern the forces between particles. Some theorists hope these problems can be reconciled through superstring theory, which describes our familiar, three-dimensional universe as only existing upon the surface of a deeper, ten-dimensional *hyperspace*.

Instead of treating fundamental particles as pointlike abstractions, they are described as strings vibrating at the smallest scale of spacetime, the Planck length[4]. The illusion of

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[3] EPR Paradox: entangled photons regularly violate the Bell inequalities. Though Einstein helped inspire Bohm to formulate his hidden variables theory, the experimental results of the EPR paradox have proven to be explicitly nonlocal – the outcome Einstein was most averse to accept.

particles, and the emergence of the fundamental constants in Nature, arises through harmonic resonance, motion, and interaction of these strings in a ten-dimensional hyperspace.

The mathematical solutions presented by superstring theory offer new hope in resolving a more comprehensive description of reality. But our universe can correspond to only one out of the millions of possible solutions to the equations governing the compactification of these higher dimensions. Further, the topology and behavior of these higher dimensions remains unprobed – impossible to test given the constraints of current technology.

The Boundaries of Knowledge

> I think the next century will be the century of complexity.
>
> Stephen Hawking

The concepts suggested by modern theoretical physics are extremely counterintuitive when seen through the lens of classical Newtonian logic. Reality itself has taken on the shimmering, morphing characteristics of the shadows projected upon the wall of Plato's cave. The common language of the newest developments in physics[5] is *information* – complexity and correlation are the emerging currencies of thought.

Humanity has reached a period of evolutionary and technological adolescence. The transitions brought about by modern science and technology – tempered with wisdom and caution – can lead us to deeper, unexplored paths of wisdom and experience. Let us not jump to short-sighted or hasty conclusions in assuming the extent of Nature itself, for our knowledge is finite. Nature need not confine itself to the limitations of our perception. Upon close enough examination, even the most fundamentally held tenets of objective reality break down.

What are the implications of these discoveries? The discordant nature of current interpretations of physical reality suggests that our theoretical models are incomplete. It is premature to suppose that we have reached the last steps of our journey in understanding the cosmos. To the contrary, we have yet to leave the womb of our home planet.

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[4] 10^{-33} cm

[5] The emerging field of quantum information theory merges the disciplines of quantum physics, mathematics, computer science and engineering.

> I have no doubt that in reality the future will be vastly more surprising than anything I can imagine. Now my own suspicion is that the universe is not only queerer than we suppose, but queerer than we can suppose.
>
> J.B.S. Haldane

Scientific dogma is just as perilous a trap as religious dogma. The only logically valid position is to remain open to the introduction of new foundations. Any deterministic theory will always be an approximation, a philosophical interpretation of the boundaries of our empirical knowledge. We have redefined our criteria for evidence at the price of reaching only disjointed explanations. Far more questions have been presented than can possibly be answered. But we must always continue to progress in the face of our limitations, for this is what makes us human. The most important component of knowledge is the imagination.

> I am enough of an artist to draw freely upon my imagination. Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world.
>
> Einstein

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Doubt is the beginning, not the end, of wisdom.

George Iles

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