The Quantum Revolution and the Reconciliation of Science and Humanism

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Quantum mechanics is one of the most successful theories in the history of science. In some form, it is here to stay. The quantum discoveries of the 20th century transformed our understanding of the natural world. In fact, the quantum revolution is a theologically wholesome development, reconciling our scientific view with the possibility of human agency and knowledge.

The Greek philosopher Aristotle (382-322 BC) had a theory of nature that offered a number of advantages from the Christian viewpoint. While Aristotle recognized a profound difference between human beings and other “substances” (i.e., fundamental entities), based on our unique rationality, he avoided dualism, and he conceived of human aspirations as continuous with the striving of all natural things to their essential ends (i.e., teleology), providing an objective basis for norms in ethics, aesthetics, and politics.

The perennial philosophy understood nature in terms of form and matter. Substances contain a principle known as ‘substantial form’, which plays the following three roles:

1. Substantial form determines the *natural kind* of a substance by fixing its essential causal powers.
2. Substantial form is the ultimate principle of unity which secures the existence of composite and transitory entities (including organisms) as substances.
3. Substantial form undergirds the possible possession of the secondary qualities which we rely upon to identify entities, affirming the reliability of our sensory knowledge.

The postulation of substantial forms gives rise to Aristotle’s four “causes”. The form of a substance is its formal cause. The substances material components are its material cause. Aristotle accepts both top-down (formal) and bottom-up (material) explanations. The form supports the existence of a set of causal powers for each substance. These causal powers orient the substance toward acting in a particular way in the world (final causation), and they enable substances to effect change in one another (efficient causation).

1. The Quantum Revolution

In the modern revolt against Aristotle, dominant from the time of Galileo until the quantum revolution, all fundamental material entities are simple and microscopic in scale. No composite thing (like you and me) is a true substance. Instead, we are mere heaps, wholly reducible to the natures and interactions of our ultimate constituents.

The quantum revolution of the last 100 years has transformed the image of nature in profound ways, reviving Aristotelian modes of understanding. Physicists first discovered in the early 20th century that the energy of isolated systems cannot vary continuously but must jump from one discrete level (quantum) to another. This apparently modest discovery has profound implications for all of science. It actually constituted a kind of “Scientific Counter-Revolution,” reviving the Aristotelian conception of nature in at least three ways: rehabilitating teleology, unseating the microscopic world from its privileged position, and securing the ontological autonomy of chemistry and thermodynamics (and potentially also the autonomy of biology and psychology) from mere physics.

* 1. The Revival of Teleology

Classical mechanics can be formulated in either of two ways: in terms of differential equations, based on Newton’s laws of motion, or in terms of integral equations, relying on the conservation of energy (the Hamiltonian method). The Newtonian model is completely bottom-up, but the Hamiltonian is Aristotelian, being both holistic and teleological. The total energy of a closed system is a holistic property: it cannot be reduced to the properties of the system’s constituents, taken individually. More importantly, the Hamiltonian method relies on so-called “variational principles,” like the least action principle. Use of the least-action principle is a form of *teleological* explanation, as Leibniz recognized (McDonough 2008, 2009).

In classical mechanics, either model can be used, and they are provably equivalent in that setting. However, with the quantum revolution, the Hamiltonian picture becomes mandatory, since the particles can no longer be imagined to be moving in response to the composition of forces exerted at each moment from determinate distances. Teleology reigns supreme over mechanical forces, as Max Planck noted. (See Planck 1960, pp. 119-126; Dusek 2001; Thalos 2013, pp. 84-86.)

* 1. Unseating the Micro-Physical: The Measurement Problem

A quantum particle doesn’t typically have any position or momentum at all: it has merely the *potential* to interact with macroscopic systems in various locations. Thus, the quantum world cannot be a complete basis for the macroscopic world.

Of course, this situation gives rise immediately to a puzzle: what, then, is the relationship between the macroscopic and quantum worlds? Presumably, macroscopic physical objects are wholly composed of quanta. How, then, can the quanta fail to be a complete basis for them?

Aristotle offers a ready answer to this puzzle. The microscopic constituents of macroscopic objects exist only as potentialities for interaction. They are only virtually present, except when they are activated.

Quantum mechanics has given rise to a dizzying variety of “interpretations,” each offering their own solution to the measurement problem. Some involve monstrously exotic hypotheses. The many worlds interpretation posits the existence of an unimaginably large number of parallel universes, each splitting off from a common history at every moment. David Bohm’s model supposes that the entire cosmos is instantaneously involved in guiding the movement of each particle, making it impossible to isolate any interaction from remote and uncontrollable factors. Objective collapse theory postulates new and so-far undetected mechanisms for producing mostly determinate results at the macroscopic scale. The transactional supposes that the future can influence the past, and the Copenhagen interpretation supposes that phenomena are real only when we observe them. Only the Aristotelian interpretation preserves our common-sense knowledge without speculative add-ons. And the very existence of multiple interpretations reflects the fact that quantum mechanics, unlike “classical” mechanics, no longer provides unambiguous support to materialism.

* 1. Thermal Substances: The Irreducibility of Quantum Chemistry

I have developed and defended a theory of thermal substances in some recent work (Koons 2018a, 2020, 2021), building on the pioneering work on quantum chemistry by the theoretical chemist Hans Primas (1980, 1981). William Simpson ably lays out the case for the existence of such substances in his doctoral thesis (Simpson 2019), building on the work of cosmologist George Ellis and physicist Barbara Drossel (Drossel 2015, Ellis and Drossel 2018).

On this theory, the world consists of thermal-chemical *substances* (typically macroscopic in scale) and their virtual microscopic *parts*. Each thermal substance has a full complement of “classical” properties, such as temperature, entropy, and chemical composition. In contrast, the class of *quantal* properties are typically found in apparently contradictory states called “superpositions.” The neo-Aristotelian theory thus avoids the paradox of Schrödinger’s cat, which is supposed to be simultaneously dead and alive. As an Aristotelian substance, the cat and its biological and chemical properties never enter into such contradictory conditions.

Quantum chemistry and thermodynamics are demonstrably irreducible to quantum micro-physics, in contrast to the situation in pre-quantum science, which favored a bottom-up determination of everything by physics. This can be seen in two ways. First, as we have just seen, the quantum world is incomplete, a realm of mere potentiality, in contrast to the fully actual and determinate character of thermal and chemical properties. Second, pure quantum physics cannot explain *spontaneous symmetry breaking* (Woolley 1988, Ruetsche 2011), which is needed to explain chemical structure and phase transitions (like melting or evaporating). The Stone-von Neumann theorem demonstrates that no finite quantum system can have multiple, “unitarily inequivalent” states, which are needed for symmetry breaking (Sewell 2002). Quantum theorist overcome this result by using the “continuum limit”, treating quantum systems as composed of an infinite number of virtual parts. The fact that we must use such an “unrealistic” procedure rules out in principle the possibility of an exhaustive, bottom-up explanation of chemical and thermodynamic facts in terms of quantum particles and their states. The inequivalent states (or *superselection* sectors) of quantum chemistry and thermodynamics correspond to irreducibly chemical and thermodynamic properties.

1. Prima Facie Problems
	1. Violations of the Law of Non-Contradiction or Excluded Middle

In the classic two-slit experiment, individual electrons seem to take multiple, incompatible paths between the source and the screen, going simultaneously through both the right and left slit of the barrier. It is only when the electron is detected at the screen that the wave-function “collapses” into one definite path. The theorem of John S. Bell (Bell 1987) demonstrated that, if quantum theory is correct, we cannot suppose that individual particles take definite paths before detection—that is, we cannot assume that quantum probabilities merely reflect our ignorance of which path is already actual. Some take quantum theory to require a revision of classical logic: either supposing that the electron *both is and is not* passing through the left slit (violating the law of non-contradiction), or that the electron *neither is nor is not* passing through that slit (violating the law of excluded middle).

However, from the perennial philosophy, these erroneous conclusions result from failing to distinguish between actuality and *potentiality* (or *act* and potency, to use the traditional terms). The electron is not a substance—it is rather a potential *action* of the substantial source that generates the electrons. This source has the potential of affecting either the left and right slit. However, when actualized, the electron will always be detected in exactly one place.

Werner Heisenberg first noted (Heisenberg 1958) that quantum mechanics had simply revived Aristotle’s notion of potentiality. In pre-quantum physics, we did not need to refer to potentialities at all. We could simply describe and predict the actual trajectories of particles using deterministic laws of motion. In quantum theory, as in Aristotle’s philosophy of nature, a complete description of nature requires us to include also the merely potential states and locations of things.

* 1. Violations of the Causal Principle: Natural Ex Nihilo?

All quantum theory incorporates an element of indeterminism. We could never predict with certainty where and when a quantum effect will be detected by our instruments, even if we were to know all of the physical facts with perfect precision, and even if we were able to perform all necessary calculations instantaneously. The world’s evolution is irreducibly *probable* in nature.

But being undetermined should not be confused with being *uncaused*, as Elizabeth Anscombe pointed out in her inaugural Cambridge lecture (Anscombe 1981). Aristotle’s philosophy of nature always recognized that rational agents are undetermined. Quantum mechanics has simply revealed that natural agents are more like rational agents than Aristotle had supposed.

Here is an extreme case of this indeterminism: the spontaneous appearance of virtual particles in the quantum vacuum. At first glance, this seems a violation of the ancient principle Ex Nihilo Nihil Fit (nothing comes from nothing). However, appearances are deceiving.

Remember, quantum particles, including virtual particles, are not substances. They are only *potential actions* of substances. When a virtual particle is produced in the so-called “vacuum,” the particle is generated by a quantum field, which represents the potential action of one or more macroscopic substances in the environment. When a virtual particle is detected, the detector helps to actualize some active power of these substances. The causal principle is fully respected at all times.

* 1. Non-Local Spookiness

As John Bell’s theorem demonstrated, quantum mechanics requires a certain kind of instantaneous influence at unlimited distances. This is illustrated by the Einstein-Podolsky-Rosen (EPR) thought experiment, in which a decision about what property to measure at one point in space can have an instantaneous effect on the probabilities of results at a distant measurement site. This is a serious problem for mechanistic forms of materialism, which is why it worried Einstein so much, but it poses no difficulty at all for Aristotelians. Aristotle believed in instantaneous influence a distance: he thought, for example, that a light source illuminates an extended body of air instantaneously. Aristotle was wrong about the propagation of light, but he was right in thinking that one substance can influence a distant substance instantaneously. The power of a substance to act propagates outward at a velocity no greater than the speed of light, but the actualization of a power at one point in space can affect instantaneously the way in which that same power manifests itself at a distant point, as the EPR experiment illustrates.

1. Back to Aristotle’s Philosophy of Nature

Quantum mechanics re-affirms what Aristotelians have known all along: that the world’s ultimate constituents are not the extremely small and simple particles of physics, but much larger, composite bodies with irreducibly holistic and teleological properties and powers. This puts us firmly on the path toward recognizing that even more complex bodies--namely persons and other living organisms--can also be metaphysically fundamental entities, with irreducibly biological and psychological properties and powers. Once we have accepted top-down determination of parts by wholes in chemistry, it is not at all hard to accept what common sense teaches about the top-down determination of my body’s behavior by me. The indeterminism of quantum mechanics leaves plenty of room for human free will to make a real difference in the natural world, without violating any laws of nature or requiring any special elan vital or mental force.

Moreover, Aristotelianism provides the best foundation for science, since it is the only philosophy of nature that fully secures the reliability and accuracy of our senses, something that is absolutely needed if experimental science is to be a source of knowledge. The so-called secondary qualities of color, smell, and solidity are real and irreducible features of reality, properties of thermal substances. Our sense of vision, hearing, and smell are all simply adaptations of real chromatic, acoustic, and osmotic interactions between non-living thermal substances. They are not, as modern scientists like Galileo and Descartes supposed, mere appearances in the mind. The natural world is not fundamentally colorless, soundless, smell-free, and intangible, but a world rich in qualities as well as quantities.

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