Knowing Nature: Aristotle, God, and the Quantum

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Abstract

Aristotle's theory of nature offered a number of advantages from a Christian point of view. It allowed for a profound difference between human beings and other material entities based on a distinction between rationality and sub-rationality, which fit nicely with the Biblical conception of humans as the unique bearers of the divine image in the physical world. At the same time, Aristotelianism conceived of human desires and aspirations as continuous with the striving of all natural entities to their essence-determined ends, providing an objective and scientific basis for objective norms in ethics, aesthetics, and politics. The Scientific Revolution of the last three hundred years, while clearly enabling an amazing degree of progress in our understanding of the physical basis of the world (both at the very small and very large ends of the scale), occasioned the unnecessary loss of many metaphysical insights of Aristotle and the Aristotelian tradition, insights which remain essential to the understanding of middle-sized objects-- like human beings. The quantum revolution of the last one hundred years has gradually transformed the imaginative landscape of natural science, creating new opportunities for the recovery of those same Aristotelian themes. (191)

1. Introduction

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In Aristotle's philosophy of nature, the metaphysical relationship between material wholes and their parts is a complex and varied one. In some cases, the parts are wholly prior to the whole, namely, when the whole is merely an unorganized *heap* of parts. In other cases, however, the whole is ontologically prior to its parts, in the sense that the parts derive their reality and causal agency from their participation in the life of the whole. This is true most centrally organisms (including human beings) and their functional parts.

Consequently, the Aristotelian image of nature is one in which there are metaphysically fundamental entities at multiple levels of scale. Some metaphysically fundamental things are composed of smaller things, possessing a nature that is not reducible to the natures and spatial relationships of their parts. In contrast, the modern image of nature, dominant from the time of Galileo and Bacon until the quantum revolution, and most fully developed in the theories of Newton and Maxwell, is one in which all fundamental material entities are simple and microscopic in scale. On the quintessentially "modern" view, every composite thing is a mere heap (in Aristotelian terms), wholly reducible to the autonomous natures and pairwise interactions of their ultimate constituents.

In this modern revolution, the ascendancy of the microscopic was combined with a rejection of two of the four *causes* or modes of explanation in Aristotle's philosophy: namely, the *formal* and the *final*. The Aristotelian scheme of understanding action or causation in terms of the exercise of causal powers and dispositions of things, anchored in the enduring natures of those things, was replaced by exclusive reliance on mathematical *laws* of motion, with very careful attention paid to the spatial arrangements and relative motions of the microscopic parts of things.

The quantum revolution of the last 100 years has transformed the image of physical and chemical nature in profound ways that are not yet fully understand by philosophers or physical scientists. The new image of nature has in fact revived

Aristotelian modes of understanding across a wide swath of scientific disciplines, a transformation that has occurred spontaneously and almost without being noticed. As the neo-Aristotelian framework begins to take shape and rise to the level of common knowledge, thereby influencing our metaphysical imagination, our understanding of our shared human nature and our place in the cosmos will improve in ways that are quite concordant with classical Christian humanism.

In section 2, I will lay out the principal elements of Aristotle's image of nature, with its multi-leveled world that included real agency at the biological and personal levels. I will then briefly describe in section 3 the anti-Aristotelian revolution of the seventeenth century and its metaphysical consequences, including the immediate movement toward some form of mind/matter dualism and the subsequent shrinking of the domain of the soul to a vanishing point. The ultimate result of this revolution is the dominance within philosophy of *micro-physicalism*, the thesis that all of material reality is exhausted by the autonomous natures of fundamental particles (or waves) and their spatial and temporal inter-relations.

In section 4, I point out the ways in which the quantum revolution has reversed the advantages enjoyed by micro-physicalism under the Newton-Maxwell regime. Quantum theory reveals a world in which wholes are typically prior to their parts--that is, a world in which either the causal powers or the spatial locations (or both) of micro-particles depend upon the irreducibly holistic features of the systems to which they belong. This is the well-known fact of the non-separability of quantum properties.

The so-called *measurement problem* in quantum mechanics has created a situation in which it is now quite unclear how the familiar "classical" properties (like spatial position) of the macroscopic objects that we can observe relate to the quantum states of their ultimate constituents. Quantum mechanics is thus open to multiple, empirically equivalent *interpretations*, some of which simply deny that macroscopic objects are wholly derivative, obtaining their macroscopic properties by a mere summation of the properties of their parts. I will describe a neo-Aristotelian interpretation of quantum mechanics: Nancy Cartwright's *dappled world* model.

Finally, in section 5, I will conclude with a call for philosophers, theologians, and scientists to collaborate in a new philosophy of nature.

2. Aristotle's image of nature

In Aristotle's philosophy of nature, as developed in his *Physics* and *Metaphysics*, all material things have two metaphysical factors or grounds: their *matter* and their *form*. The matter of a thing consists of its parts or components: the matter of a mixture is the elements that compose it, and the matter of an organism is made up of its discrete parts. There is really no such thing as *matter* as such (except as a kind of useful fiction or limiting-case idealization, so-called "prime" matter). Instead, *matter* is a relative term: the many parts and components are (collectively) *the matter of* the whole they compose.

There are, correspondingly, two fundamental kinds of explanation or causation: formal and material. Material explanation is bottom-up: we explain the characteristics of a whole in terms of the way in which the characteristics of its parts and their relations to each other constrain how the whole must be. We can explain the flammability of a book in terms of the flammability of its pages, and we can explain the shape of one of the Great Pyramids in terms of the spatial relations among its constituent blocks of stone.

Formal causation, in contrast, is top-down. To give the formal cause of a thing is to elucidate its essence, the what-it-is-to-be a thing of its kind. The essence of a composite thing constrains and partially determines the natures and mutual relations of its parts. The essence of each part depends (to some degree, at least) on the essence of the whole in which it participates. For example, to be a heart is to be an organ that plays a certain role in an organism's circulatory system. To be *flesh* is to be organic material that participates actively in the organic functions of an animal. To be *a gene* is to be part of a DNA molecule that codes for the production of certain proteins in the natural cellular activity of the cell. And so on.

Once we have the formal and material causes of complete material things (which Aristotle called ουσιαι or *substances*), we can predict and explain how they will interact. That is, we will have an account of the active and passive causal powers of things: what changes they can cause in others and what changes they can undergo themselves. This way of accounting for change—namely, change as the result of the exercise of causal powers, rooted in the forms or essences of the agent and patient involved—is called *efficient* causation. The Aristotelian model of efficient causation does not simply seek to describe the changes as conforming to some abstract laws of nature or of motion (as is the case in much modern philosophy, following the lead of Hume) but rather attempts to understand the changes as expressions of the formal and material causes of the entities involved in the interaction. In part, this is because Aristotle conceives of time as the product of change, and not vice versa. It is essences (the formal causes) of things that propel time forward by inducing change and initiating activities. Unlike early modern philosophers, Aristotle did not think of change as the by-product of the inexorable forward movement of time and the guidance of abstract and global laws of nature.[2]

The Aristotelian conception of efficient causation through causal powers allows for the existence of exceptional situations: situations in which the causal power of one substance is frustrated or distorted by the action of another substance, or by the absence of one of its natural preconditions. It is natural in an Aristotelian

[2] See Cartwright (1983) and (1994) for a defense of the Aristotelian model of efficient causation, in light of modern experimental science.

framework to speak of the *malfunctioning* of a substance when its causal powers are blocked or disabled. In addition, a complex substance can become more or less denatured, losing (perhaps permanently) some of the causal powers that define its natural kind. This loss of characteristic powers can be identified with the phenomenon of being *damaged*. We can further distinguish between a substance's normal and abnormal environment by identifying which external conditions do or do not damage or disable it.

Final causation or teleology—the universal directedness of things to their natural "ends"—readily follows from this Aristotelian foundation. The active and passive causal powers of a thing have an inherent and ineliminable reference to an ideal future: how things *would* proceed if those powers *were* able to express themselves fully and without interference. As Thomas Aquinas puts it in the *Summa Theologiae* (Part I, Q44, A4): "Every agent acts for an end: otherwise one thing would not follow more than another from the action of the agent, unless it were by chance." This applies even to inanimate agents. David Armstrong referred to this as the "proto-intentionality" of causal powers (Armstrong 1999, 138-40), and George Molnar spoke in such cases of "physical intentionality" (Molnar 2003, 60-66). Thus, the intentionality of human desires and aspirations (their being about some possible, ideal future) is perfectly continuous with the proto-intentionality of all Aristotelian substances, whether animate or inanimate, conscious or non-conscious, rational or sub-rational.

In particular, as Aristotle notes (*Parts of Animals* I, i, 640b-641b), the heterogeneous parts of animals require explanation in terms of their end (τελοσ). Teleology in biology is simply the application to living things of Aristotle's general scheme of explanation. If organisms truly exist as genuine substances (ουσιαι), then they must have forms that supply them and their parts with genuine, irreducibly biological causal powers. As we have seen, to bear causal powers is ipso facto to be ordered to certain kinds of ideal futures. Thus, there is an unbreakable connection between the substantial reality of organisms and the genuineness of biological teleology.

As Georg Toepfer has put it in a recent essay:

> "…teleology is closely connected to the concept of the organism and therefore has its most fundamental role in the very definition of biology as a particular science of natural objects…. The identity conditions of biological systems are given by functional analysis, not by chemical or physical descriptions…. This means that, beyond the functional perspective, which consists in specifying the system by fixing the roles of its parts, the organism does not even exist as a definite entity." (Toepfer 2012, at 113, 115, 118)

Consequently, in the Aristotelian image of nature, *substances* (metaphysically fundamental things) exist at many levels of scale and composition. For this reason, we cannot give a complete description of the material world by simply aggregating a large number of microscopic descriptions. Exclusive attention to the microscopic scale will necessarily leave out many crucial facts about the natures of macroscopic substances and the causal powers that derive from these macroscopic natures.

Aristotelians can thus acknowledge real and irreducible agency at many different levels of scale: chemical, thermodynamical, biological, and socio-political, as well as micro-physical. In particular, the rational agency of human beings is not threatened by their complete materiality. The macroscopic behavior of the whole human being is not merely a by-product or *epiphenomenon* of the interactions of his microscopic parts and those of his environment. The human being as such, including a rational sensitivity to the true value of things, makes a real contribution to the flow of events in the material world, without requiring any interaction between the body and some separate, wholly immaterial soul. For Aristotelians, the human soul is the form of the living human body.

This does not mean that human beings cannot survive death. Thomas Aquinas argued convincingly that the human form (as conceived by Aristotle) could survive the death of the body, since the life of human beings includes a purely intellectual set of activities (namely, understanding and contemplating universal truths) that do not depend on any corporeal organ (not even the brain). Thus, the human form or soul can exist by enabling and sustaining these purely intellectual activities, even after it has ceased to inform and structure the organic processes of the body. With God's help at the moment of resurrection, the human soul can resume its natural function as the form of a living, human body.[3] While we are embodied, our souls are **not** separate entities that interact causally with the microscopic parts of our body. Instead, the embodied soul is the form that inherently structures the powers and inter-relations of those parts, grounding all of their own causal powers (from the "inside", so to speak).

As Edward Feser (2010) and many others have pointed out, Aristotle's scheme of universal natural teleology fits beautifully with a form of the argument from design, as exemplified by Thomas Aquinas's Fifth Way (in the *Summa Theologiae* Part I, Q2 A3). Since God is the uncaused First Cause of all of nature, He must be the ultimate source of all of nature's inherent teleology. Thus, the proto-teleology of the inanimate and sub-rational world is wholly grounded in the wisdom and foresight of God.

3. The anti-Aristotelian revolution

From the late Middle Ages (after the death of Thomas Aquinas) through the Scientific Revolution and the birth of modern philosophy in the seventeenth

[3] See Brian Leftow's clear exposition of the Thomistic understanding of the soul in Leftow (2001) and (2010).

century, Western Europeans abandoned three key elements of the Aristotelian system. First, beginning with Duns Scotus, they replaced Aristotle's matter-form relation with the early modern conception of *matter as such*, as something with an inherent nature of its own. Second, they replaced Aristotle's model of interlocking causal powers (active and passive) and time as the measure of change with a model of abstract laws of motion and a fixed and independent temporal dimension. Third, and consequent to the first two, they abandoned Aristotle's formal and final causation, limiting teleology to the relation between conscious agents and their felt desires and impulses.

3.1 The introduction of matter as such

As described by Richard Cross (Cross 1998, 74-77), the scholastic philosopher Duns Scotus replaced Aristotle's relational conception of matter (*x* is the matter of *y*, or the *x*'s are collectively the matter of *y*) with a substantive conception of matter, in which matter *as such* has its own determinate nature and causal dispositions. For Aristotle, the relation of matter to form was a relation of potentiality to its actualization: to say that the *x*'s are collectively the matter of *y* is to say that the *x*'s have the joint potential to compose something of *y*'s nature. Thus, if there were such a thing as pure or prime matter, matter as such, it would be a thing of pure potentiality, with no positive nature of its own.

In contrast, Scotus (and the scholastic philosophers who followed him, including William of Ockham) thought of matter as a kind of thing or stuff, with it own intelligible nature.

3.2 Abstract laws of motion

Early modern science and philosophy in the sixteenth century inherited this late-medieval conception of matter as a kind of stuff. The essence of matter was quantitative: all matter takes up a definite volume (by filling a region of space). By taking into account the relative density of matter in its various locations, we can assign to each chunk of matter a certain absolute quantity, which corresponds to something like weight and, eventually, mass.

What about the inherent causal dispositions of this matter? In this simplest picture (embraced by Descartes), matter has the disposition to move in a constant velocity (by inertia, or conservation of momentum), unless deflected from this movement by a collision with other material bodies. The discovery of gravity and, eventually, of electromagnetic forces spoiled the simplicity of this late-scholastic/early-modern model and in effect re-introduced at the microphysical level instances of something very much like Aristotelian forms (the form of the electron as negatively charged, for example).

This partial recovery of Aristotelian metaphysics was obscured by the simultaneous replacement (in thinkers like Malebranche and Hume) of causal powers by laws of motion. Instead of thinking about bodies as having (by virtue of gravitational mass or electric charge) the *power* of moving and moving other bodies, scientists and philosophers were instead content to describe the regular relationships between inputs and outputs as described by abstract laws of motion, conceived of as "laws of nature".

This shift from hypothesizing natures and their powers to the use of mathematical equations and functions to describe possible motions reflected the earlier pragmatism of Descartes and Francis Bacon. Descartes and Bacon expressed their lack of interest in a deep understanding of why things acted the way they did. They argued that modern science should instead focus simply on predicting and controlling the behavior of things.

> "It is possible to attain knowledge which is very useful in life, and, instead of that speculative philosophy which is taught in the schools, we may find a practical philosophy by means of which, knowing the force and action of fire, water, air, the stars, heavens and all other bodies that environ us,… [We can] employ them all in uses to which they are adapted, and thus render ourselves the masters and possessors of nature." (Descartes, *Discourse on Method*, Volume I, 119. See also Bacon, *The Advancement of Learning*, p. 96.)

3.3 Rejection of formal and final causation

Once modern philosophers and scientists had replaced talk of causal powers and interactions with abstract laws of motion, quite naturally the concepts of formal and final causation fell into disuse. Laws of motion were supposed to be universal and exceptionless, leaving no room for malfunction or damage.

The pragmatism of philosophers like Descartes and Bacon contributed to the removal of teleology from natural science. Understanding the natural end of something contributed nothing to our control over it. Control required merely a detailed knowledge of the internal disposition of its matter, in such a way that laws of motion could be used to predict and control its behavior. Attention to natures, causal powers, and inherent directedness were merely distractions from this urgently needed project:

> "But this misplacing hath caused a deficience, or at least a great improficience in the sciences themselves. For the handling of final causes, mixed with the rest in physical inquiries, hath intercepted the severe and diligent inquiry of all real and physical causes, and given men the occasion to stay upon these satisfactory and specious causes, to the great arrest and prejudice of farther discovery." (Francis Bacon, *The Advancement of Learning*, p. 987)

The French biologist Claude Bernard (1813-1878) clearly expressed the modern attitude in saying, "The final cause does not intervene as an actual and efficacious law of nature." (Bernard 1966, p. 336) Bernard cannot conceive of any causation except that expressed by abstract laws. He drew the logical consequence: "Vital properties are in reality only the physicochemical properties of organized matter." (Bernard 1966, pp. 22-23) (Quoted by Gilson and translated by John Lyon, 1984, pp. 35-6)

3.4 The dualism of modernity: A fractured world

If the natural world consists entirely of a (more or less) uniform "matter", and if this matter simply obeys universal, exceptionless "laws", what place is left for human thought and human agency? Beginning with scholastic philosophers like Duns Scotus, European thinkers began moving away from the Aristotelian hylomorphism of Thomas Aquinas toward some form of mind-body dualism. Scotus and Ockham, followed by Bacon and Descartes, explicitly limited the scope of teleology and purpose to the conscious desires of human egos, egos that are now radically divorced from the world of matter.

3.5 The Soul of the Gaps: The abolition of human agency and teleology

However, this dualism of the late scholastic and early modern world did not constitute a stable position but quickly collapsed into an austere form of materialism. Dualism introduced a kind of "soul of the gaps": mental entities as an extraneous, adventitious addition to the scientific worldview, introduced simply to explain those features of human life and experience that science has not (yet) explained in terms of the motions of matter. As we gained a more and more complete understanding of the operations of the brain, of the nerve cells that make up the brain, and of the organic molecules that make up those cells, there seemed to be less and less room for the intervention of immaterial souls of the Cartesian kind. Eventually, a more austere and monistic form of materialism took hold, pioneered by Thomas Hobbes, by French thinkers like d'Holbach, and by the German materialists of the 19th century.

This materialism ultimately takes the form *of micro-physicalism*, the thesis that every truth (causal and otherwise) about any macroscopic substance is wholly grounded in and explained by the microphysical facts, including both the intrinsic properties of the micro-particles and binary spatial relations among their positions and velocities in a uniform and rigid background of absolute space. Moreover, this grounding of macroscopic truths in microscopic facts licenses an ontological *reduction* of macroscopic things to their microphysical parts and their spatial relations: the former are *nothing over and above* the latter.

This micro-physicalism, common to both ancient materialists like Democritus and Lucretius and modern physicalists like Quine or David Lewis, has always stood in some tension with our common-sense understanding of ourselves as *rational agents*. For example, in the *Phaedo*, Plato puts into Socrates' mouth an argument against metaphysical microphysicalism (98c-99b).

> "And it seemed to me it was very much as if one should say that Socrates does with intelligence whatever he does, and then, in trying to give the causes of the particular thing I do, should say first that I am now sitting here because my body is composed of bones and sinews, and the bones are hard and have joints which divide them and the sinews can be contracted and relaxed and, with the flesh and the skin which contains them all, are laid about the bones; and so, as the bones are hung loose in their ligaments, the sinews, by relaxing and contracting, make me able to bend my limbs now, and that is the cause of my sitting here with my legs bent… and should fail to mention the *real causes*, which are, that the Athenians decided that it was

> best to condemn me, and therefore I have decided that it was best for me to sit here and that it is right for me to stay and undergo whatever penalty they order."

Microphysicalists have essentially three options in response to this argument: (i) they can deny the existence of real or objective values altogether (the goodness of Socrates' remaining in Athens), (ii) they can assert that our intentions or decisions are never really sensitive to these objective values (Socrates' rational appreciation of this value), or (iii) they can claim that objective values and our sensitivity to them are somehow wholly grounded in the microphysical facts. None of these three seems promising. Jonathan Dancy (2003), Christina Korsgaard (1986) and many others in recent years have created powerful objections to a Humean subjectivism about value. And, in any case, it seems that subjective values must ultimately be grounded in objective value, if reason is to have any normative force at all. Even if one supposes that particular things are good for an agent only because he or she desires them, one must still suppose that desires are the sort of thing that (other things being equal) ought to be satisfied—that there is something objectively worthy about seeking to satisfy them. Finally, as J. L. Mackie and others have recognized (Mackie 1977), it is hard to believe that the objective value or to-be-sought-ness of certain states or actions could be wholly grounded in the sort of facts described by micro-physics. Micro-physics provides no room for the rational teleology of human values.

3.6 The triumph of micro-physicalism

Why do so many philosophers find physicalism—the thesis that the only fundamental facts are physical facts—so attractive? All of the juice, the inherent plausibility, of physicalism comes from our attraction to *microscopism*: the thesis that only the ultimately microscopic facts are fundamental. Without the microscopist presumption, there is no reason to privilege physics over other sciences. There are many non-physical science—chemistry, thermodynamics, biology, even cognitive psychology—that have been successful in identifying real causal mechanisms in our world, and there has been absolutely no sense in which these other sciences have been progressively replaced by pure physics as science advances. What gives physics its privileged position is the fact that it studies the smallest things, the things of which the objects of other sciences are composed, together with the microscopist presumption.

But what accounts for the attractiveness of microscopism? One motivation has been that of maintaining a unified picture of nature and of our scientific knowledge of nature: the unity of nature ideal or the unity of science ideal. This does give us some reason to minimize the number of fundamental forces that we posit and to resist accepting any violations of the fundamental conservation laws. These reasons, in turn, justify at least to some extent a reluctance to embrace mind-body dualism, with its need for mind-body interaction.

However, the unity of nature ideal doesn't give us reason to embrace anything as extreme as microscopism much less microphysicalism. There is no obvious reason why large, composite objects, fully located within the one world of nature, couldn't possess and exercise fundamental causal powers, even in the absence of new fundamental forces or violations of energy conservation.

The real core of the appeal of microscopism has to do with a sense that modern science has vindicated a kind of Democritean ontological reductionism. The thought is that we simply don't *need* to posit any fundamental agency except at the level of the smallest particles or units of matter. We could, in principle, explain everything in terms of the powers and interactions of the micro-particles, in the sense that everything at higher or larger scales is wholly grounded in the goings-on at the microphysical level.

Modern science provides a framework for a kind of bottom-up reductionist narrative: political and social phenomena reduce to individual psychology, individual psychology to biology (including neuroscience), biology to thermodynamics, thermodynamics to chemistry, chemistry to atomic physics, atomic physics to particle physics. As progress in science over the decades and centuries increases the strength of every link of this chain, anti-reductionists seem to be always on "the wrong side of history," forced into an increasingly extreme form of obscurantism.

Microphysicalism, therefore, depends on a Democritean starting point:

(1) Facts about microscopic atoms and the void are, metaphysically speaking, *fundamental* or ungrounded facts.

(2) This ungrounded foundation consists of microscopic entities with certain intrinsic characteristics (shape and size for Democritus, but this can be extended to include things like charge, mass, spin, and so on), and certain instantaneous spatial relations.

(3) All spatial relations can be ultimately grounded in a large number of simple binary or ternary relations among the microscopic entities (such as distance).

In other words, "atoms and the void" (as Democritus put it) constitute the uniquely fundamental level of reality, and everything else completely *depends on* and *is determined by* them—that, everything is *wholly grounded* by them.

Aristotle's hylomorphic model denied the fundamentality or ungroundedness of the microscopic realm. For Aristotelians, the intrinsic characters of and mutual relations (including spatial relations) among the microscopic entities are typically or at least often grounded in the natures of the macroscopic entities of which they are parts.

4. The quantum counter-revolution

4.1 The revenge 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 in terms of the conservation of energy (the analytic or Hamiltonian method). In the latter case, the structure of the model imposes certain constraints on the possible evolution of the system, and the dynamical laws pick out the actual evolution on the basis of some minimization (or maximization) principle, like the principle of *least action*. (See Yourgrau and Mandelstam 1979, pp. 19-23, 164-167; Lindsay and Morgenaw 1957, pp. 133-6; Lanczos 1986, pp. xxvii, 345-6.)

The Newtonian model is Democritean, but the Hamiltonian is Aristotelian, in being both essentially holistic and teleological. The total energy of a closed system is an irreducibly holistic or non-separable property of the system: it cannot be reduced to the intrinsic properties of the system's constituents, taken individually. More importantly, variational principles like the least action principle treat the holistic character of an entire trajectory as fundamental, rather than the set of instantaneous facts about the composition of forces that constitutes the fundamental facts for the Newtonian model. The least-action principle is a form of teleological explanation, as Leibniz already recognized (McDonough 2008, 2009).

In classical mechanics, either model can be used, and they are provably equivalent. Hence, classical mechanics leaves the metaphysical question of micro-physicalism vs. hylomorphism unresolved. However, with the quantum revolution, the Hamiltonian picture becomes mandatory, since the fundamental entities 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 1936, pp. 119-126; Planck 1960; Dusek 2001; Thalos 2013, pp. 84-86.) In addition, *the total energy and action of a closed system are essentially holistic or non-separable properties of that composite system*, which stands in contradiction to the demands of micro-physicalism.

Furthermore, by forcing reliance on the Hamiltonian model, quantum mechanics brings into sharper relief the holistic character of causal interaction. As noted by Tiehen and Kronz (2002), the Hamiltonian model for complex quantum systems is non-separable: "In that case, the time evolution of the density operator that is associated with a part of a composite system cannot in general be characterized in a way that is independent of the time evolution of the whole." (Kronz and Tiehen 2002, pp. 343-4) The causal power responsible for the evolution of the system is an irreducibly joint power, not supervening on the binary causal powers of the component particles.

Aristotelian philosophy of nature requires processes as the natural results of the exercise of causal powers. These Aristotelian processes (κινησεσ) have intrinsic direction and pacing.[4] Aristotle did not, as his late medieval and early modern critics supposed, anthromorphize nature by attributing vague "urges" or "drives"; rather, he developed a framework within which animal and human drives could be seen as

[4] Schulman (1989) draws out a fascinating parallel between Aristotle's account of motion as 'potential' and 'indeterminate' in *Physics* III and *Metaphysics* III and Richard Feynman's sum over possible histories approach to quantum mechanics. Aristotle denies that the location of a moving body is fully *actual* except at the beginning and end of a continuous process of locomotion. Feynman's sum-over-histories approach is a way of fleshing this out: the moving body takes every possible trajectory between the two points, with mutual interference explaining why the paths with least action predominate.

special cases of the intrinsic directedness of holistic processes. The system as a whole consequently acquires its own intrinsic teleology (or, better, *entelechy*).

4.2 Non-separable states

The most obvious blow that quantum mechanics strikes to micro-physicalism comes from the undeniable *non-separability* of the quantum properties of entangled systems. As noted by Teller (1986), Healey (1991), Silberstein and McGeever (1999, pp. 186-90), Kronz and Tiehen (2002, pp. 325-330), along with many others, the quantum state of a pair of entangled particles (particles in the singlet state, as in the Einstein-Podolsky-Rosen thought experiment) is irreducibly a state of the pair as such: it is not even determined by the intrinsic properties of the particles (considered individually) or the spatial distance or relative velocity between them. In these cases, the whole is literally more than the sum of its parts.

For a long time, philosophers assumed that this sort of quantum weirdness could be limited somehow to the microscopic domain, being almost completely swamped at the phenomenological level by phenomena that completely conform to the requirements of microphysicalism. However, it turns out that this kind of quantum holism is very much the rule rather than the exception, producing measurable results at the phenomenological level nearly all the time (Primas 1980, p. 41).

4.3 The measurement problem

The so-called "Copenhagen" interpretation (the interpretation given to the quantum theory devised by Niels Bohr and Werner Heisenberg) gives us reason to doubt all three of these premises. In the Copenhagen interpretation, the microphysical facts consist merely in the attribution to microscopic entities of certain potentialities, and these potentialities essentially include causal relations to macroscopic systems. A quantum doesn't typically have any position or momentum at all (not even a vague or fuzzy one): it has merely the potential to interact with macroscopic systems as if it had some definite position or momentum (or other observable feature) at the moment of the interaction. Thus, the quantum world (so understood) can be neither metaphysically fundamental nor 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 metaphysically fundamental and complete basis for the macroscopic world?

Hylomorphism offers a ready answer to this puzzle. The microscopic constituents of macroscopic objects have (at the level of actuality) only an indirect relation to space and time: they are located (roughly) somewhere at a time only *qua* constituents of some fundamental, macro- or mesoscopic substance (in the Aristotelian sense). Such microscopic objects are not metaphysically fundamental in their entirety, and their metaphysically fundamental features do not provide a complete basis for the features of the substantial wholes they compose. This is a welcome result, since it makes physical theory compatible with the *Phaedo* argument.

The Copenhagen interpretation is not the only way to make sense of quantum mechanics. Recent years have seen the emergence of the many-worlds (Everett) interpretation, Bohm's mechanics, and various objective collapse theories. The very fact that we face now a plethora of competing interpretations of quantum mechanics puts the relationship between physics and metaphysics on a very different footing from the one they had under the classical paradigm. Micro-physicalism was the only plausible interpretation of classical physics. In contrast, some interpretations of quantum mechanics are extremely friendly to hylomorphism. I will sketch one of these, which I will call 'Pluralistic Quantum Hylomorphism'.

Pluralistic Quantum Hylomorphism is an interpretation inspired by some remarks of Heisenberg (1958), and defended by Wolfgang Smith (2005), Nancy Cartwright (1999) and Stanley Grove (2008). On this view, the world consists of a variety of domains, each at a different level of scale. Most of these domains are fully classical, consisting of entities with mutually compatible or commutative properties. At most one domain is accurately described by quantum mechanics. Since location does not (for quantum objects) "commute" with other observables, like momentum, the quantum objects are only intermittently located in ordinary, three-dimensional space, although they always retain a probability of interacting with classical objects at a definite location. Interaction between quantum properties and classical properties (including those of experimenters and their instruments) precipitates an objective collapse of the quantum object's wavefunction, as a result of the joint exercise of the relevant causal powers of the object and the instruments, and not because of the involvement of human consciousness and choice.

Paul Feyerabend offered a helpful tripartite distinction of philosophies of science: the positivist, the realist, and the structural (Feyerabend 1983). The positivist is the anti-realist, who denies that reality has any structure that is independent of our interests and assumptions, the "realist" believes that there is a single, unified structure of reality, realized at a single scale, and the structuralist takes reality to comprise a plurality of relatively autonomous structures. The realist or monist perspective contributed to the rise and development of modern science, but the quantum revolution has seen a return to the pluralism of Aristotle:

> "Einstein and especially Bohr introduced the idea that [scientific] theories may be context-dependent, different theories being valid in different domains. Combining these ideas with abstract mathematics such as various algebras, lattice theory, and logics then led to a powerful revival of the structural approach. Thus the search for a generalized quantum theory is exactly in Aristotle's spirit: we do not take it for granted that the quantum

> theories we have are the best way of dealing with everything, looking either for new interpretations or suitable approximation methods to solve hairy cases; we rather try to identify domains and theories suited for them and then look for ways of relating these theories to each other." (Feyerabend 1983, vii)

Here is how Nancy Cartwright describes this pluralist view:

> "…quantum realists should take the quantum state seriously as a genuine feature of reality and not take it as an instrumentalist would, as a convenient way of summarising information about other kinds of properties. Nor should they insist that other descriptions cannot be assigned besides quantum descriptions. For that is to suppose not only that the theory is true but that it provides a complete description of everything of interest in reality." (Cartwright 1999, p. 232)

Thus, the hylomorphic interpretation combines features of both the old Copenhagen and newer objective collapse interpretations. It is a fully realist view about the microscopic, unlike Bohr's version of the Copenhagen interpretation, and it is ontologically pluralistic, in contrast to other objective collapse theories. It admits a plurality of objective domains, and it doesn't treat wave collapse as a phenomenon explainable within the pure quantum domain, by some as-yet-unknown microphysical interaction.

Unlike the Copenhagen view, the PQHM interpretation fully embraces the reality of quantum objects and quantum states. In addition, the Copenhagen view suffers from being two narrowly dualistic, distinguishing the classical world from the quantum world. In contrast, the hylomorphic interpretation embraces a salutary kind of ontological pluralism, recognizing that the non-quantum or supra-quantum world is itself a “dappled” world (as Nancy Cartwright puts it), dividing naturally into multiple domains at multiple scales.

Pluralistic Quantum Hylomorphism shares two crucial advantages with the Copenhagen view. First, it embraces realism about classical objects and classical states, and so it can make sense of our experimental practices in a straightforward way. Second, it fits the actual practice of scientists well, who are in practice ontological pluralists (as Nancy Cartwright has documented).

5. Conclusion: Back to the Aristotelian future

The holistic and teleological character of quantum mechanics does not by itself vindicate the reality of teleology and agency at the biological or personal levels. However, it does dramatically change the imaginative landscape of modern science, making the supposition of top-down, formal causation in the realms of chemistry, thermodynamics, biology, and psychology plausible. In fact, the trend of science in the last fifty years has been toward greater differentiation, not unity. Taking these scientific results at their face value means accepting causal agency (understood in Aristotelian terms) at many levels, including the macroscopic level of complete organisms. The idea that there could be a natural and fundamental teleology governing human choices is once again fully credible, and God as the ultimate source and ground of teleology is once again an attractive path for natural theology.

Bibliography

Armstrong, David M. (1999), *The Mind-Body Problem* (Boulder, Colorado: Westview Press).

Bacon, Francis (1915), *The Advancement of Learning* (London: Dent).

Bernard, Claude (1966), *Lecons sur les phenomenes de la vie commune aux animaux et aux vegetaux* (Paris: Libraire Philosophique J. Vrin).

Cartwright, Nancy (1983), *How the Laws of Physics Lie* (Oxford: Clarendon Press).

Cartwright, Nancy (1994), *Nature's Capacities and their Measuremen*t (Oxford: Clarendon Press).

Cartwright, Nancy (1999), *The Dappled World: A Study of the Boundaries of Science*, Cambridge: Cambridge University Press.

Cross, Richard (1998), *The Physics of Duns Scotus: The Scientific Context of a Theological Vision* (Oxford: Clarendon Press).

Cross, Richard (1999), *Duns Scotus* (Oxford: Oxford University Press).

Dancy, Jonathan (2003), *Practical Reality* (Oxford: Oxford University Press).

Descartes, Rene (1973), *Discourse on the Method of Rightly Conducting the Reason*, trans. Elizabeth Haldane and G. R. T. Ross, *The Philosophical Works of Descartes*, Volume I (Cambridge: Cambridge University Press).

Dusek, Val (2001), "Aristotle's Four Causes and Contemporary 'Newtonian' Dynamics," in *Aristotle and Contemporary Science*, vol. 2, D. Sfendoni-Mentzou, J. Harriangadi and D. M. Johnson (eds.), New York: Peter Lang, pp. 81-93.

Feser, Edward (2010), "Teleology: A Shopper's Guide," *Philosophia Christi* 12(1); reprinted in Edward Feser, *Neo-Scholastic Essays* (South Bend, Indiana: St. Augustine's Press, 2015), pp. 49-58.

Feyerabend, Paul (1983), "Foreword," in Primas (1983), pp. i-xii.

Gilson, Etienne (1984), *From Aristotle to Darwin and Back Again: A Journey in Final Causation, Species, and Evolution,* trans. John Lyon (University of Notre Dame Press).

Grove, Stanley F. (2008), *Quantum Theory and Aquinas's Doctrine on Matter*, Ph.D. dissertation, Catholic University of America.

Heisenberg, Werner (1958), *Physics and Philosophy: The Revolution in Modern Science*, London: George Allen and Unwin.

Healey, Richard (1991), "Holism and nonseparability," *Journal of Philosophy* 88:393-421.

Healey, Richard (2011), "Reduction and Emergence in Bose-Einstein Condensates," *Foundations of Physics* 41: 1007-1030.

Koons, Robert C. (2000), *Realism Regained: An Exact Theory of Causation, Teleology, and the Mind* (Oxford: Oxford University Press).

Koons, Robert C. (2014), “Staunch vs. Faint-hearted Hylomorphism: Toward an Aristotelian Account of Composition,” *Res Philosophica* 91:1-27.

Korsgard, C. M. (1986), “Scepticism about Practical Reason,” Journal of Philosophy 83:5-25.

Kronz, Frederick and Justin Tiehen (2002), “Emergence and quantum mechanics.” *Philosophy of Science* 69:324-347.

Lanczos, Cornelius (1986), *The Variational Principles of Mechanics*, 4th edition, New York: Dover Publications.

Leftow, Brian (2001), "Souls Dipped in Dust: Aquinas on Soul and Body," in Kevin Corcoran, ed., *Body, Soul and Survival* (Ithaca, N.Y.: Cornell University Press), 120-38.

Leftow, Brian (2010), "Soul, Mind and Brain," in George Bealer & Robert Koons, eds., *The Waning of Materialism* (Oxford: OUP), 395-416.

Lindsay, Robert Bruce and Henry Morgenaw (1957), *Foundations of Physics*, New York: Dover Publications.

Mackie, J. L. (1977), *Ethics: Inventing Right and Wrong* (Harmondsworth: Penguin).

McDonough, Jeffrey K. (2008), “Leibniz's Two Realms Revisited,” *Nôus* 42: 673-696

McDonough, Jeffrey K. (2009), “Leibniz on Natural Teleology and the Laws of Optics,” *Philosophy and Phenomenological Research* 78: 505-544.

Molnar, George (2003), *Powers: A Study in Metaphysics* (Oxford: Oxford University Press).

Planck, Max (1960), “The Principle of Least Action,” In *A Survey of Physical Theory*, R. Jones and D. H. Williams (trans.), New York: Dover Publications, pp. 69-81.

Primas, Hans (1980), “Foundations of Theoretical Chemistry,” In *Quantum Dynamics for Molecules: The New Experimental Challenge to Theorists*, R G. Woolley (ed.), New York: Plenum Press, pp. 39-114.

Primas, Hans (1983), *Chemistry, Quantum Mechanics, and Reductionism: Perspectives in Theoretical Chemistry*, Berlin: Springer-Verlag.

Schulman, Adam L. (1989), “Quantum and Aristotelian Physics,” Ph.D. dissertation, Harvard University.

Smith, Wolfgang (2005), *The Quantum Enigma: Finding the Hidden Key*, 3rd edition, San Rafael, Calif.: Angelico Press.

Thalos, Mariam (2013). *Without Hierarchy: The Scale Freedom of the Universe*, Oxford: Oxford University Press.

Toepfer, Georg (2012), “Teleology and its constitutive role for biology as the science of organized systems in nature,” *Studies in History and Philosophy of Science Part C: Studies in History and Philosophy of Biological and Biomedical Sciences* 43: 113-119.