2 Essential Thermochemical and Biological Powers

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1. Introduction

There are three great options in the philosophy of nature: materialism, cosmic monism, and plural holism. These correspond to the metaphysical priority of, respectively, the very small, the very large, and the intermediate. Human beings and other organisms fall into the intermediate category. I will argue in Section 2 that a philosophy of nature that gives pride of place to thought and responsible, intentional action, while avoiding Cartesian dualism and idealism, must embrace the Aristotelian option of plural holism (Inman 2018).

Before turning to the details of contemporary quantum science, I will sketch the basic requirements of an Aristotelian pluralism in Section 3. Aristotelian philosophy of nature maintains a unique balance between top-down (formal) and bottom-up (material) modes of explanation. This balance requires the use of a repertoire of basic Aristotelian concepts, including proximate and prime matter, substantial form, quantitative accidents, and integral and virtual parts.

The greatest challenge to the viability of Aristotelian natural philosophy comes from the apparent atomism of modern science since the Scientific Revolution. I will argue in Section 4 that the discovery of the quantum world in the early twentieth century effected a kind of Aristotelian counter-revolution, displacing the ostensible atomism of the Newton-Maxwell model with an irreducible holism, a holism that is most apparent in quantum chemistry and thermodynamics. Consequently, I will argue in Section 5 that the world according to a neo-Aristotelian framework should consist of living organisms and what I shall call 'thermal substances' (along with remnants of these). In that section I will develop the theory of thermal (inorganic) substances in some detail, addressing the questions of their origin and individuation.

With the theory of thermal substances in place, I will be able to turn to an account of the world of organisms in Section 6. We will see there that thermal substances serve as virtual parts and as proximate matter for living organisms. This opens up the possibility of a formal mode of

DOI: 10.4324/9781003125860-4

causation by the souls or substantial forms of living organisms, avoiding some of the difficulties of Cartesian interactionism. In Section 7, I discuss how an Aristotelian philosophy of nature will enable us to rehabilitate what Wilfred Sellars called *the manifest image of the world* (Sellars 1962), undergirding the veridicality and reliability of human observation and experimentation.

2. The Three Options in the Philosophy of Nature

Aristotle's metaphysics clearly assigns the status of fundamental to living organisms, despite their intermediate size. Organisms are neither mere heaps of atoms nor mere fragments of the whole cosmos. They are instead among the *primary beings* of the world – the things that have unity and exist in the strictest, most central sense.

Since the Scientific Revolution of the seventeenth century, a kind of philosophical atomism has tended to dominate our understanding of nature. On this view, the power and nature of any composite material entity depends on the powers, natures, and mutual arrangements and motions of the smallest bits of matter. This would seem to leave no room for genuine human agency, as Plato recognized in the *Phaedo* (98c–99b). The agency of the particles leaves nothing for reason or free will to do, except in a subordinate and derived way. The atomistic materialist cannot find a place in the world for genuine rational powers, a kind of fundamental responsiveness of the human mind to reasons and evidence.[1]

In response, many theists have embraced a kind interactionist dualism or some form of idealism or cosmic holism (e.g., Rowan Williams – see Pickstock 2015), trying to carve out real space for the domain of reason. However, there are severe theological and apologetic costs to these dualist and idealist stratagems. Both dualists and idealists must posit a problematic explanatory gap between natural phenomena and our internal sensations or "phenomenal qualia" (Levine 2000). The prospects for any simple, law-like relationship between microphysical properties and sensory qualia are extremely dim, as noted by Robert Adams (1987). Instead, we are left with massively gerrymandered and anomalous correlations between physical conditions and experiential qualities, correlations that can never be illuminated by causal mechanisms. Dualists and idealists also face difficult questions about how spiritual realities can interact with physical processes without violating physical symmetries and conservation laws. Dualists and idealists seem to be stuck with a fruitless quest for some elusive vital force (*élan vital*) by which the mind can move fundamental particles (see Lowe 1992). Ethically, dualists and idealists run the risk of downplaying the importance of bodily integrity, since they make the human body wholly extrinsic to the human person as such (see, for example, Lee and George 2009).

If we set aside dualism and idealism as problematic and implausible, then we are forced to choose between the three remaining options: atomism, monism, and pluralism. Atomists hold that only extremely small entities, like subatomic particles or point-intensities of fields, can be metaphysically fundamental, while monists (like Jonathan Schaffer) take that there is only one fundamental entity, the entire cosmos (Schaffer 2010). Pluralists assume that we can find fundamental entities at many different scales of size, including intermediate-sized entities like living organisms. From a traditional theistic point of view, there are at least three reasons for favoring pluralism: preserving human agency, securing our knowledge of necessary and normative truths, and buttressing the teleological argument for God's existence.

First, both physical monism and atomism threaten human agency. If reason is to have any power, the human being must be capable (*sans* reason) to arrive at more than one conclusion (whether theoretical or practical). And which alternative conclusion we do reach must be explainable in terms of our reasons and acts of will – it cannot be exhaustively explained at either the atomic or the cosmic level without introducing an implausible coincidence of overdetermination, that is, an ad hoc, pre-established harmony between the material and the rational (of the sort proposed by Gottfried Leibniz).

Second, for the same reason, monism and atomism threaten human epistemology. Our non-empirical knowledge of necessary facts requires that those facts have some direct impact on our faculty of intuition. The intuitions we form must not be explainable in terms of processes at the atomic or cosmic level, processes with no real, constitutive connection to the relevant necessary facts. This is especially problematic for our knowledge of purely normative facts, since normative facts seem to play no role in determining the nature or movements of either material atoms or the physical cosmos as a whole. Any morality with an intellectual component (anything, that is, beyond the most voluntarist of divine command or social-convention theories) requires both real human agency and real knowledge of normative reasons (see Koons 2017, 2019b).

Third, Aristotelian pluralism provides strong grounds for inferring the existence of a transcendent Creator, as exemplified by Thomas Aquinas's Fifth Way (see Feser 2008, 110–119). To be viable, pluralism must reject Humean doubts about causation, embracing a robust realism about causal powers. As pluralists, Aristotelians attribute such robust causal powers to composite material substances, including living organisms. Causal powers correspond to teleological structures, since each causal power is intrinsically ordered to a particular result. If there are fundamental causal powers possessed by living organisms, then those powers define a distinctively biological teleology.

These causal powers must themselves be explained in terms of the natures or essences of these composite substances. These natures must somehow be imposed upon appropriate material parts or components. Hence, there must be compatibility between the material requirements of the biological essences and the attributes of inorganic material things. Otherwise, it would be impossible for living things to grow, develop, or reproduce. For example, there must be a compatibility between inorganic substances (like water, O_2, CO_2, or various mineral salts) and the substance of living organisms like plants, a compatibility that enables the latter to absorb and integrate the former. Moreover, there must be an adequate causal explanation of why these particular biological essences are actually imposed upon parts of the natural world. Even if, as Aristotle supposed, all of the species of organisms had been exemplified from eternity past, we would still need an explanation for the imposition of these specific essences on those particular streams of material substrate. We would still need to know the ground for the existence of any living things at all. Given, as we now know, that life is a relatively late arrival, the need for an adequate cause of its emergence becomes especially acute.

Darwinian natural selection, even if correct as an explanation of the generation of new species, falls short of providing a metaphysically sufficient explanation of this fact (see Stephen Boulter's chapter in this volume). Evolution can describe how the life-engendering powers of the natural world came to be exercised and in what order they were exercised, but it cannot explain why those powers are there in the first place. Given the metaphysical fundamentality of organisms, we cannot hope to explain the origin or development of life simply by describing possible trajectories of the constituent particles. Even if matter fell by chance into optimal spatial arrangements and mutual motions, it wouldn't thereby constitute an Aristotelian substance. And given the non-eternity of species, possible future species must exist in the mind of something like a Craftsman, in the way that the form of a house is present in the mind of an architect.

3. Building a Pluralist Philosophy of Nature

Building a pluralist philosophy of nature is not a trivial task. Pluralists must make room in the world for both top-down explanation (explaining parts in terms of wholes) and bottom-up explanation (explaining wholes in terms of parts), while atomists and monists need only one or the other mode. For pluralists, the world consists of substances, fragments of substances, and heaps of substances. For atomists, the world consists only of substances and heaps, while for the monist it consists only of a single substance and its fragments.

Moreover, it is clear that many substances (like organisms) interact with their environment *through their parts*. Hence, the powers of the whole substance must in some way be dependent on the disposition of those parts. In addition, the very survival of a substance depends on the appropriate cooperation of its parts. At the same time, there must be something that *unifies* those parts (and just those parts) into a single substance. For Aristotelians, this something is known as a *substantial form*. Each substance has a single substantial form that makes it what it is and that unifies its parts, both at a time and through time.[2] The substantial form of a substance does not simply consist in the nature of its parts and their mutual arrangement in space – it is that which ultimately *grounds and explains* those natures and that arrangement.

For composite, material substances, substantial form cannot be the whole story. There must also be that on which the substantial form operates. This is the substance's *matter*. The primary metaphysical role of matter is that of *individuation*. Chunks of matter individuate a substance and its parts from substances and parts of the same natural kind. They ground the mutual distinctness of things that are specifically the same (the same in kind). This individuating role is what gives the Aristotelian a unique and attractive account of natural sameness (see Brower 2017; Koons 2018b). If we consider matter in its pure function as a bare individuator, we arrive at the concept of *prime matter*. A chunk of prime matter has no positive nature, quality, or quantity of its own. It simply individuates its substance or part of a substance from others of the same kind.[3]

However, prime matter is never wholly on its own and so never actually bare. It is always of necessity informed by a substantial form, and this informing results in various layers of what is called *proximate matter*. The human being, for example, is obviously composed of various kinds of tissue, such as bone, muscle, skin, and blood. Each chunk of tissue corresponds to a chunk of prime matter, but a chunk that has been natured and qualified by the human being's one substantial form. Each piece of proximate matter is composed of parts of more elementary, less proximate kinds of matter. Such intermediate forms of matter in a living organism include proteins, lipids, and carbohydrates, which in turn are composed of still less proximate matter, like carbon, hydrogen, and oxygen, with the most elemental forms of matter (protons, neutrons, electrons) constituting a layer just "above" that of prime matter. It is the one substantial form of the human being (the human soul) that is responsible for the character of each of these layers of matter above the level of prime matter, but each level has an important role to play in explaining the persistence and varying powers of the whole substance. The explanatory role that these layers play is called *material causation*. The substantial form plays the complementary role of *formal causation*.

Given the critical role that substantial form must play in the Aristotelian framework, it is impossible for one substance to contain another or even to overlap another substance. Substances in the Aristotelian scheme satisfy what Jonathan Schaffer calls the *tiling constraint* (Schaffer 2010). The material universe consists entirely of non-overlapping substances (and remnants of these). Parts of substances, therefore, cannot be actual substances themselves. Their natures or identities (or both) are inextricably tied to the whole substance of which they are a part.

Given the tiling constraint, all parts of substances must be either integral parts or virtual parts. An *integral part* of a substance is a part whose whole nature and individual identity is tied to that substance. My hand, for example, is essentially a hand, so essentially a part of a human being. Integral substances can sometimes exist independently of their "host" substance, but they persist only as remnants of that substance and never as substances in their own right. Their natures are such that it is metaphysically impossible for an integral part to exist except as a part or a remnant of a particular substance. Their individual identities are irrevocably tied to the organism from which they originated.

In contrast, *virtual parts* of a substance have intrinsic natures that are independent of the whole. This does not violate the unicity of substantial form, since the virtual parts have only potential existence within the whole substance. Moreover, the fact that this inorganic substance can exist as a virtual part of the organism is grounded in the organism's own substantial form.

For any virtual part of a substance, there are many empirically indistinguishable counterparts existing as actual substances in their own right and not as mere virtual parts. The water in my veins, for example, corresponds chemically and thermodynamically to batches of water existing in the inorganic world as actual, independent substances. In this case the tiling constraint is satisfied by stipulating that the virtual part no longer has actual existence while part of my body. It exists only *potentially*, contributing to the persistence and powers of my body but not constituting at the same time a distinct substance. For this reason, none of the water in my veins can be numerically identical to any inorganic sample of water that I ingested, since the inorganic water was a substance in its own right and not merely a virtual part of another substance. This transmutation of inorganic substances into virtual parts and vice versa is an unavoidable theoretical cost of the hylomorphic picture, but it is a cost well worth paying.

The structured parts of a substance (e.g., organs and tissues of the living body) are its integral parts, while the kinds of stuffs contained by the substance (water, lipids, proteins, nucleic acids) are or correspond to virtual parts.

Aristotelian natural philosophy includes the reification of certain features of substances – the *accidents*. These accidents are abstract particulars, corresponding to the *modes* or *tropes* of modern metaphysics. Each particular accident is simultaneously both a real entity, tied essentially to a single subject, and a feature of that subject. So, Socrates's musicality is a classic example of such an accident. It is *that by which* Socrates is musical. The accident is ontologically dependent on Socrates, and it exactly resembles other instances of the same kind, such as Plato's musicality.

These individual accidents can themselves be generated and corrupted, and they enter into other causal and explanatory relations.

The very fact that substances have parts of any kind is the responsibility of the substantial form. The substantial form is responsible both for providing its integral parts with their natures and with transmuting external inorganic substances into its virtual parts. Substantial form also imposes forms of *quantity* on batches of prime matter – so-called *quantitative accidents* of volume, mass, and relative position. These quantitative accidents stand in part-whole relations to one another. For example, the location of my left elbow is contained within the location of my left arm. These quantitative accidents are responsible for the possibility of my body's having quantitative or material parts, both integral and virtual. The identities of these quantitative accidents have a dual anchor: in the first place, to the particular substances to which they belong, in the second place, to the particular packet of prime matter that they inform. It is because the quantitative accidents are tied inextricably to the individual identity of the substance to which they belong that all integral parts of the substance are similarly so tied.

4. The Case for Thermal Substances

Integrating this Aristotelian natural philosophy with modern science faces the problem of the inorganic world. Aristotelians will always count living organisms among the world's substances. Given the tiling constraint, the sum total of substances and their remnants must together constitute the whole of the material world. It is clear that organisms alone cannot fit this bill. Much of the world is not and never has been part of any living organism. Where can we find the fundamental Aristotelian *substances* in that inorganic world, needed to complete the plural holist picture? I will argue that we can take our cues from the holistic character of quantum chemistry and thermodynamics. I have developed and defended a theory of thermal substances in some recent work (Koons 2018a, 2019a, 2021), building on the pioneering work on quantum chemistry by the theoretical chemist Hans Primas (1980, 1981), and William M. R. Simpson very ably lays out the case for the existence of such substances in the preceding chapter and in his doctoral thesis (Simpson 2019), building on the recent proposal of contextual wave function collapse by the cosmologist George Ellis and the physicist Barbara Drossel (Drossel 2015; Ellis and Drossel 2018).

On this picture, none of the entities described in so-called fundamental physics are in fact fundamental; that is, none of them are Aristotelian substances. Instead, quarks, electrons, photons, and the rest have merely *virtual* presence in true material substances.

Quantum theory provides a fertile field for the theory of Aristotelian accidents. However, we cannot identify particles with accidents in a one-to-one fashion. Rather, it is *pluralities* of indistinguishable particles (which I will call *congeries*) that are to be identified with Aristotelian accidents. In standard interpretations of quantum theory (in fact, all the interpretations except the Bohmian one),[4] particles lack determinate and enduring identities. Both Dirac-Fermi and Einstein-Bose statistics treat elementary particles as mere figures in an accounting book, like dollars in the bank, rather than as enduring nodes of possibility, reidentifiable as particular individuals at different times and in varying possible scenarios (see the chapters in Part I in Castellani 1998, and Redhead and Teller 1991). In nearly all situations, particles lack location and many intrinsic properties (like momentum or spin). In fact, the location of a particle (when not actually measured) cannot be considered to be determinately restricted to any finite region of space (Clifton and Halvorson 2001). And the actual number of particles in a system is not an absolute fact but depends on one's frame of reference (Fraser 2008).

Each *congeries* of indistinguishable particles is, nonetheless, a real entity, but an entity that is ontologically dependent on the thermal substance that contains it. Such congeries of particles correspond with the thermal substance's *power* of affecting and being affected by other thermal substances at the quantum level. An individual particle is fully actualized when such an interaction occurs. At that moment, the individual particle exists as a distinct individual – an individual accident in the category of *action* or *passion*.

A congeries of indistinguishable particles is a virtual quantitative part of a thermal substance, corresponding to a quantitative accident. In traditional Aristotelianism, a solid bronze sphere has a top half that corresponds with a certain hemispheric accident of quantity. So, a congeries of indistinguishable particles, as a quantitative accident of the thermal substance, corresponds to a *virtual quantitative part* of that thermal substance. Such congeries are analogous to the quantities of elements (earth, water, air, fire) that existed virtually in Aristotle's theory of mixtures (in *On Generation and Corruption*, Book 1). A congeries of particles is ontologically dependent on the thermal substance and not an actual substance in its own right. It doesn't exist in full actuality but only in virtue of the power of the substance to act and be acted on in certain ways. In its virtual presence in the substance, a congeries of quantum particles counts as a virtual part of the *proximate matter* of that substance – again, analogous to the way that elemental quantities counted in Aristotle's chemistry.

The substantial form of the whole thermal substance is responsible for the existence, nature, and mutual combination of the quantal entities that make up its proximate matter. At the same time, the resulting proximate quantum-level matter must satisfy certain conditions for the whole substance to persist and to have the contingent powers that it does have. Hence, there is a legitimate place for bottom-up material explanation in the Aristotelian scheme. We can partly explain the persistence of a substance and its actions upon and reactions to its environment in terms of the powers and potentialities corresponding to its quantum constituents. There are two complementary modes of explanation: material and formal, and both are prior to the usual explanation in terms of *efficient* causation, which is invoked in explaining the production of changes.

This theory of thermal substances and their quantum accidents agrees with Niels Bohr's Copenhagen interpretation of quantum mechanics on two points: the incompleteness of the quantum-level description of the world and the existence of definite states within the complementary "classical" world. I differ with Bohr, however, in refusing to separate reality into two disjoint domains (quantal and classical). Instead, the world consists of thermal *substances* and their virtual quantal *parts*. Each thermal substance has both classical and quantal properties. The classical properties form a non-trivial core or *center* of mutually commutable observables, defining super-selection sectors (Primas 1980, 1981). These classical properties never enter into quantum superpositions. In contrast, the disjoint class of *quantal* properties are typically found in *superposed* states, with non-trivial probabilities assigned to the constituents of orthogonal bases of observables. Two quantal properties do not typically commute, since they belong to the same super-selection sector.

The theory of thermal substances denies the completeness of the microphysical. One important aspect of the scientific revolution of the seventeenth and eighteenth centuries was its emphasis on what Aristotelians would label material causation and explanation through hypothetical necessity. If large systems are to behave as they are observed to do, they must be composed of parts with intrinsic natures and mutual arrangements in space that are capable of sustaining the observed collective behavior. From an Aristotelian point of view, this analytic approach is perfectly legitimate. It is illuminating to learn that water is composed (virtually) of H_2O molecules, and that cells contain (virtually) double helices of DNA.

Where microphysicalism went wrong was in insisting that macroscopic phenomena can be *exhaustively* explained in terms of microphysical facts. Microphysicalists assume that all facts supervene on the microphysical entities and their arrangements in space. This is true both of atomists of various kinds and those who believe that matter is infinitely divisible, like Empedocles or Descartes. The motions of large bodies depend on their composition and the motions of those components, and not vice versa. On this view, all true explanation on this view is bottom-up, from the very small to the large, and never top-down. This means that for the microphysicalist, there can be no room for substantial form – with one possible exception. If there are fundamental, indivisible particles, they and they alone could have substantial forms. Anti-atomists like Descartes or Empedocles must reject substantial forms altogether, since on their view there are no true unities in nature, merely various uniform and infinitely divisible continua.

In any case, on this view, neither people nor organisms more generally nor any of the many things that we can perceive have substantial forms at all. Consequently, microphysicalists must deny the reality of all the so-called secondary qualities, such as color, smell, or taste, since these, if they existed, would be accidents of macroscopic substances.

Long before the quantum revolution, this anti-realism about the "manifest image" of the world (to use Wilfred Sellars's phrase) threatened to undermine the scientific enterprise itself, since all of our observations and experimental results presuppose the real existence of, well, observations and experiments, neither of which can easily be accommodated within a microphysicalist image of the world. Experiments require experimental conditions or setups, and these are definable only in macroscopic terms. If the macroscopic world is merely a world of misleading appearances, how are experiments possible?

So, there were always grounds for suspicion about the microphysicalist picture, but the success for so long of what is now called "classical physics," the physics of Newton and Maxwell, and even of the theories of relativity, suggested that such a picture *must* be true, whatever its philosophical and epistemological conundrums, and that we just need sufficient imagination to see how. This presumption of ultimate coherence changes dramatically with the quantum revolution. The revolution has not perhaps made microphysicalism *completely* untenable, but it has clearly put it on the defensive and opened up the *live* possibility of resurrecting substantial forms at macroscopic scales, including the scale of human beings and other organisms.

Any quantum theory of chemistry and thermodynamics must come to grips with the Stone-von Neumann theorem, proved by Marshall Stone and John von Neumann in 1931 (von Neumann 1931). The theorem states that any two "irreducible representations" of the canonical commutation relations of quantum theory are *unitarily equivalent*, whenever the system contains only *finitely* many degrees of freedom. Any two *n*-parameter systems are, therefore, unitarily equivalent. Unitary equivalence is taken, in quantum theory, to represent macroscopic indistinguishability. When using finite quantum representations, there could be no difference at the macroscopic scale in chemical composition, or phase state of matter (solid, liquid, gas), or entropy. This would seem to make chemistry and thermodynamics impossible.

Practicing quantum theorists avoid this negative result by taking their models to the *thermodynamic limit* (Liu 1999; Bangu 2009; Sewell 2002). Such models represent the macrophysical state of a substance as consisting of an infinite number of infinitesimal particles. In this way, they can escape the constraints of the Stone-von-Neumann theorem, which applies only to finite systems. It is only at the thermodynamic limit, also known as the 'continuum limit' (Compagner 1989), that the models have enough internal structure to distinguish different chemical compounds and different phases of matter. And only at that limit can we give rigorous definitions of central notions in the physics of complex systems like temperature and entropy.

There are three reasons for taking models to unrealistic limits. The first two are purely fictional: namely, using an unrealistic model because it makes calculations simpler, or because doing so enables us to ignore relatively insignificant factors (like friction or gravity). The continuum limit of quantum thermodynamics exemplifies a third reason: because only the unrealistic model contains the sort of mathematical structure needed to represent the phenomena faithfully.

When we use an unrealistic model for the third reason, the model captures some truth that a more "realistic" model of the same kind could not in principle capture. This is exactly what we should expect in the presence of substantial form. The substantial form imposes a structure on the whole system that cannot in principle be explained by the system's parts and their arrangement, given a system with only a finite number of fundamental particles. The need for an infinite model reflects a gap in the bottom-up explanation of the phenomenon in question. Only the presence of a top-down *explanans* (that is, the form) can account for the inadequacy of the finite models.

The use of infinite models in quantum statistical mechanics exactly realizes a hylomorphic model of explanation, with its inclusion of two complementary modes of explanation, namely, *formal* and *material*. The fact that the models are derived by taking finite models of the quantum components of the system to the infinite limit represents the role of *material* causation. In modeling the behavior of a body of water, we begin with a finite model of water molecules (with the appropriate numbers of protons, neutrons, and electrons). The fact that we must take these models to an "unrealistic" limit (with an infinite number of infinitesimal molecules) represents the role of *formal c*ausation. Material causation cannot fully account for the system's thermodynamic properties.

Substantial form is also responsible for the chemical composition of substances. The geometrical structure of molecules cannot be captured by quantum mechanics in the absence of the method of taking models to the thermodynamic/continuum limit. It is true that, once we have the geometrical structure (as revealed by experiment), we can use finite quantum models to explain the stability of that structure. This is just what hylomorphists would expect. Finite quantum models provide the material mode of explanation – they explain how stable chemical forms are possible. However, quantum theory in that simple form cannot give us the formal explanation of the molecular structure. Finite quantum models, unlike the corresponding models of classical mechanics, cannot explain spontaneous symmetry breaking. Such breaking of symmetries occurs only in the "unrealistic" models at the thermodynamic limit (Woolley 1988; Strocchi 1985, 117–118; Ruetsche 2006; Earman 2004). Therefore, all asymmetric chemical structure, like the left-handedness of organic amino acids, must be imposed from above, by substantial form (Woolley 1988; Hendry 2010).

At the level of microphysics, there is no true *irreversibility* or *direction* to time. Any purely quantum transition can be reversed in time, so long as we reserve electric charge and parity (left- and right-handedness) at the same time. There is, therefore, no microphysical process that is intrinsically directed toward the future. If, however, we accept thermodynamics as a fundamental science applying to thermal substances (Prigogine 1997), then the Second Law of Thermodynamics (the monotonic increase in entropy) gives us an objective, fundamental, and intrinsic direction in time associated with every actual motion. And this gives us natural teleology, as systems naturally seek their equilibrium state. The sum total of quantum-level facts does not fix the direction of time, but the substantial forms of thermal substances do.

Thus, quantum thermodynamics and chemistry provide us with examples in which the macroscopic features of the system do not *supervene on* and therefore cannot be exhaustively *explained by* the microphysical facts. That is, we could have two situations that are microphysically indistinguishable and yet chemically and thermodynamically different. Consequently, these chemical differences cannot in principle be explained exhaustively at the microphysical level. An adequate science of matter needs to combine bottom-up (material) and top-down (formal) modes of explanation. The result is not a radical form of theoretical pluralism or the disunity of science, since, as quantum thermodynamics demonstrates, we can combine both modes in a single model.

In fact, even apart from these considerations about quantum chemistry and thermodynamics, pure quantum theory itself (in the form of Schrödinger or matrix dynamics) indicates the incompleteness of the quantum domain, as recognized by Niels Bohr. The predictions of quantum dynamics all take the form of probabilities, but probabilities of *what*? The standard answer (following Bohr) is: the probability of *measurement results*. But what are measurements, and how do they have definite results? This leads to what is known as the *measurement problem* or *measurement paradox*.

A quantum measurement consists in an interaction between a human experimenter, various experimental materials (instruments, laboratory setups, and the like), and a source of quantum particles. But macroscopic entities (like experimenters and their instruments) are themselves entirely composed of quantum particles, and so quantum dynamics should apply to them as well. This leads to an infinite regress: probabilities of probabilities of probabilities, ad infinitum.

The famous thought experiment of Schrödinger's cat illustrates the first step of the paradox. If the cat is poised to observe some quantum measurement, and if we treat the cat itself as a quantum system, then the interaction between the cat and the quantum phenomenon (say, an electron that could go either up or down) will yield no definite result. Instead, the electron will begin in a superposed Up/Down state, and the cat will come to be in a superposed Observe-up/Observe-down state, until we open the box and observe what the cat has actually observed. But the observer of the cat could be treated as yet another quantum system, resulting in an infinite regress.

Aristotelian pluralists deny that macroscopic entities like human experimenters and their instruments can be represented adequately by finite quantum models. Thermal substances have classical, mutually commuting properties, like chemical composition, temperature, and phase of matter, properties that never enter into quantum superpositions. When a quantum power interacts with a thermal substance and produces a change in classical properties, a "measurement" has occurred with a definite result.

I can illustrate the hylomorphic solution to the measurement paradox by introducing the thought experiment of *Schrödinger's ice cube*. We put an ice cube in a box, and attach it to a system that responds to some quantum-level event, an event in a 50/50 superposed state. If the system results in an Up event, the ice cube melted, and if it results in Down event, the ice cube remains frozen. Now the ice cube is entirely composed of protons, neutrons, and electrons, and so it is subject to quantum modeling. However, the ice cube is a thermal substance, and so it has a substantial form that imposes a phase of matter (namely, *solidity*) upon those particles. The distinction between two phases of matter occurs only at the level of *form* – it is not determined by the quantum state of the constituent particles. Consequently, it is impossible for a cube to be in a Frozen/Unfrozen superposed state. Such a state simply does not exist. So, we can define a measurement event to be an event involving non-quantal properties (accidents) of substances. Whenever a quantum system produces such an event, a "measurement" occurs, regardless of whether the substance is an organism or merely a thermal substance (like an ice cube). Consciousness need not be involved, and so we escape idealism. This account, I suggest, is consistent with the contextual wave function collapse model put forward by the physicists Barbara Drossel and George Ellis (Drossel 2015; Ellis and Drossel 2018), and discussed by William M. R. Simpson in Chapter 1.

For the hylomorphist, thermal substances and organisms have definite positions in space at each moment in time, even if none of their quantum components do. Each quantum particle is, except for the moment in which its position is measured, located vaguely everywhere, with a certain, finite probability (Clifton and Halvorson 2001). Thermal substances and organisms, in contrast, have a definite, actual location at each moment.

Individual quantum particles are really just momentary accidents of substances, and so the locations of the particles do not fix the location of the substance. When not actualized by measurement, individual quantum particles are merely *powers* of interaction, typically non-localized powers. Congeries of such particles (in which the particles lack individual identities) are virtual parts of the substance.

Bohr was right in thinking that quantum mechanics indicates the incompleteness of the quantum world. But he was wrong (at least, as he is commonly interpreted) in thinking that the two domains could be kept separate through a dualism of objects or entities. I speculate that this mistake results from unfamiliarity with the hylomorphic solution, in which congeries of quantum particles act as the virtual proximate *matter* for non-quantal *forms*. We now know that even macroscopic objects can have quantal aspects – for example, superconductors and supercooled fluids, which exemplify exotic behavior thanks to quantum coherence effects. Hylomorphists are not committed to a dichotomous quantum/classical dualism but to a system in which complementary entities (namely, substances and accidents, form and matter) coexist in mutual dependency.

Prompted by the urging of John Bell (1987), defenders of microphysicalism have sought an alternative strategy for resolving the measurement paradox. These efforts have led to revived interest in Everett's many-worlds interpretation, David Bohm's pilot-wave interpretation, and a family of objective bottom-up collapse theories, including the Ghirardi-Rimini-Weber (GRW) theory.[5] These various microphysicalist reactions to the paradox explain why we have a multiplicity of "interpretations" of quantum theory. There was no such plurality of ontological interpretations of Newton and Maxwell – those theories seemed to point clearly to the truth of microphysicalism. Quantum theory no longer does so. Saving microphysicalism requires ad hoc supplementation.

Now, no one can be forced by quantum mechanics to embrace hylomorphism. Nonetheless, the hylomorphic rejection of microphysicalism preserves the simplest and most natural interpretation of the quantum formalism. It is well supported by the use of the thermodynamic limit in chemistry and thermodynamics, as required by the Stone-von-Neumann theorem. Unlike the other interpretations, hylomorphism does not require any ad hoc modifications or unverifiable additions, and it accords best with the actual practice of scientists. Practicing quantum scientists, like everyone else, are implicit Aristotelians, as the philosopher of science Nancy Cartwright (1994, 1999) has argued since the 1990s.

5. The World of Thermal Substances

A *quantitative part* of a substance is a part in a very ordinary familiar way, as a finger or a particular pint of blood are parts of an individual organism. The substantial form and the so-called *prime matter* of the substance, as well as the accidents of a substance, in contrast, are not quantitative parts. Individual quantum particles are, somewhat surprisingly, also not quantitative *parts* of thermal substances. Instead, they are merely *potential accidents* of quantitative parts. Unlike quantitative parts, individual quantum particles have no persisting particular identities. A congeries of indistinguishable particles belonging to a single thermal substance constitutes a virtual quantitative part of that substance and so part of that substance's proximate matter. Such virtual parts may be said to have a real but derived identity as persisting, re-identifiable parts of the substance.

The tiling constraint dictates that no substance can have other actual substances as quantitative parts. To do so would fatally compromise the *per se* unity of the containing substance. The requirements of *per se* unity of the composite substance are so great that we have to think of the quantitative parts as also metaphysically dependent on the whole, and not vice versa. As a result, Aristotelians are committed to what has been called the *Homonymy Principle*: no quantitative part of a substance can exist except *as a part* of that substance.

Can either accidents or quantitative parts of substances persist beyond the demise of their substances? Accidents and quantitative parts are dependent in some way on their host substances, but does this dependence rule out the possibility of their extended survival? Thomas Aquinas wrote (*In Metaphysica*, VII, L8, 1459) that substance is the 'active principle' of accidents. It is impossible for accidents to be prior to substances 'in definition (*ratio*), time, or generation' (op. cit. L13, 1579). Accidents do not have 'perfect being (*esse perfectum*)' unless they exist in a subject (L9, 1477). Priority in time means that no accident or part can exist before its substance. Priority in definition means that the identity of the accident or part is derived from that of its subject. This non-priority of accidents in both time and definition seems compatible, however, with some accidents continuing to exist *after* their substances have been destroyed. In one case, as is well known, Aquinas explicitly affirmed the possibility of the persistence of accidents in the absence of their subjects: the accidents of the Host in the Eucharist (*Summa Theologica*, Part III, q77 a1). If my theory of thermal substances is correct, this kind of survival of accidents is actually quite common even within the natural order and does not demand any ad hoc metaphysics.

I have argued elsewhere (Koons 2020) that there are good grounds within Aristotelian philosophy for positing that accidents in the category of *action* can readily survive separation from and the demise of their substantial host. For instance, Aristotle describes the archer's accident of action surviving in the arrow throughout its flight, and presumably this would be true even if the archer died while the arrow was in flight. This is extremely relevant, since quantum particles are also accidents in the category of action. A quantum particle represents a way in which one thermal substance can act upon another.

As we've seen, both accidents and quantitative parts have a dual dependence on their substances. Every accident or part must receive its existence at some point in time from a substance. Second, each accident or part is *individuated* by its substance. No two congeries of particles of the same kind are fundamentally or primitively distinct from each other. Instead, if they have real distinctness, they derive that distinctness from the numerical distinctness of their substances (Brower 2017; Koons 2018b). This means that the individual identity of each particle or collectivity of particles is essentially tied to that of a particular substance (thermal substance or organism). Consequently, no particle or collectivity of particles can be transferred from one substance to another. Once a quantum particle has interacted with a thermal substance, its individual identity has come to an end. However, as I've argued, that does not rule out the possibility of an individual particle's continuing to exist beyond the demise of its substance.

The theory of thermal substances satisfies a version of the tiling constraint. The material world consists entirely of disjoint actual substances and remnants of such substances, along with their accidents. No two actual substances overlap, and so the plurality of actual substances (including remnants of extinct substances) constitutes a set of mutually disjoint entities that collectively exhaust the whole material universe.

Every actual entity in the world is either (i) a substance, (ii) an accident of a substance, (iii) a fragment or remnant of a substance, or (iv) a group or (v) a heap of substances and fragments.[6] The five categories can be distinguished based on their degree of unity. A substance has absolute or *per se* unity. An accident, fragment (a quantitative part), or remnant of a substance has a similar degree of unity, but one that is dependent on the unity of the whole substance. A group of substances has what Thomas Aquinas called the *unity of order*, an imperfect form of unity. A heap has the lowest degree of unity – the unity of contact or contiguity.

A group has greater unity than a mere heap, but less than that of a true substance. When substances form a group, the members gain novel causal powers, both active and passive, through membership. Like substances, facts about groups are not reducible to intrinsic facts about their members and the members' spatiotemporal relations. In addition, like a substance, a group can persist despite a changing roll of members. There are two key differences between groups and substances. First, a group does not so absorb its members in such a way that the members cannot belong simultaneously to several groups, while no material entity can belong at the same time to two distinct substances. Some *but not all* of the irreducible powers of the members are grounded by the nature of the group. Second, the team cannot undergo any intrinsic change except via change of some of its members, while substances can undergo change as a whole, with the implications of the change percolating downward to the parts.

It is clear that organisms can form groups. Human beings form a bewildering variety of social groups and institutions. Many other animals also work together in analogous social structures. I would conjecture that inorganic thermal substances can also cooperate in group-like structures. Stable patterns seen in phenomena like Rayleigh-Bénard convection cells (Drazin and Reid 2004), whirlpools (Steward 2012, 241), the water cycle (Oderberg 2006), hurricanes, stars, and certain kinds of planets may indicate such irreducible collective behavior, which nonetheless falls short of the *per se* unity of substances (see Anderson 1972; Laughlin 2005).

Since developing my account of thermal substances several years ago, I am often presented with two sorts of questions. These are questions of *origin* and questions of *individuation*.

Let's take the question of origin. How did the first thermal substances come into being in the early universe? What process combined the quarks, electrons, and photons into stable, thermal substances? And, if the first thermal substances were formed by some congealing of fundamental particles, doesn't that entail that there was either a time in which there were no substances at all or a time in which particles were substances?

This question presupposes the very bottom-up imperialism that I am taking pains to deny. The first thermal substances did *not* form by some conglomeration of fundamental particles. Rather, thermal substances were there at the very beginning. If the universe is finite in extent (a so-called closed universe), then I would expect that a single thermal substance emerged from the Big Bang, a thermal substance at a cosmic scale. As time passed, the original thermal substance decomposed into ever smaller substances, first at the scale of galaxy clusters, then at that of galaxies, then solar systems, and finally planetary components. Particles have always had only virtual presence within substances.

I think that the same top-down perspective would restructure our inquiry into the origin of life. Instead of thinking of the original organisms as resulting from the clumping together of molecules in a pond, we should look first at the whole pond, or indeed at the whole solar system. The original organisms must have resulted from the partial disintegration of some larger pre-organic system, a system that encompassed the precursors of both the population of living things and their environment. Similarly, we shouldn't think of multicelled organisms as resulting from the clumping together of one-celled organisms, but rather as the breaking off of multicelled organisms from a pre-existing community of simpler, less differentiated life.

Let's turn next to the questions of individuation.[7] *How many thermal substances are there? How are they individuated?* For instance, is the earth a single substance? The lithosphere of the earth? The mantle, core, or crust? Tectonic plates? Mountain ranges? Rocks or pebbles? Homogenous crystals? Or are all of these mere *groups* or *heaps* of substances? How many substances do the world's oceans contain? Or the earth's atmosphere? How many substances occupy interplanetary or interstellar space?

In my view, these are open, empirical questions. We cannot settle them from the armchair or by careful phenomenological examination of ordinary experience. We need to develop full theories of collective phenomena. The study of such phenomena (which physicists term "emergence") is still in its infancy. It is only in the last 40 years or so that sustained investigation into these matters has been undertaken. Hylomorphism can be helpful, by ruling out facile, microphysicalist answers, answers that suggest that there is nothing fundamental or deep to study here, since everything is supposedly reducible "in principle" to microphysics. Ernest Rutherford is reported to have said that all of science is either 'atomic physics or stamp collecting' Such microphysical imperialism relegates all the "special" sciences to second-class status, simply arranging on the page facts that are fully explained only by so-called fundamental physics.

If hylomorphism true, each of the special sciences is equally fundamental. The world cannot be captured in microphysical terms alone. The natures and accidents of thermal substances and organisms do not even *supervene on* the character and arrangement of micro-particles. (This is consistent with admitting that no macroscopic *change* can occur without concurrent microscopic change.) As we descend to the quantum scales, things become less definite and more dependent, and not the reverse. It is actually finite, "realistic" quantum physics that is *non*-fundamental, since there are no "quantum substances" per se, but only quantal aspects (accidents) of thermal substances and organisms. The role of particle physics is simply to provide the base models from which the truly realistic, infinite algebras of quantum chemistry and thermodynamics can be built, characterizing the essences of thermal substances (both actual and virtual).

How big can thermal substances be? Thermal substances in principle can exist at any scale, from single particles (or even fraction of a particle) to the entire cosmos. I conjecture that very small substances are quite short-lived – substances in the late stages of corruption or the early stages of generation. Very small substances can perhaps be sustained in laboratory conditions. In the wild, they will, I think, generally be much larger.

In the absence of empirical inquiry, I can't answer the questions about the individuation of thermal substances with any confidence, but I can suggest some criteria for individuation:

1. Sharp boundaries or discontinuities, in both space and time (i.e., sharp transitions) are a *necessary* condition for distinguishing two thermal substances. But such boundaries may not be a sufficient condition. Some thermal substances (like perhaps convection cells) might include some internal boundaries. Nonetheless, where there are no sharp boundaries, where there is perfect continuity in

temperature, chemical composition, and density, we should count the continuum as contained by a single, enduring substance.[8]
2. Strongly collective powers are a *necessary* condition for substantial unity, both at a time and through time. A substance must have causal powers, both active and passive, that do not supervene upon and so are not determined by the powers and arrangements of its parts. As we have seen, this condition is met by all bodies with chemical and thermodynamic properties. Again, such strongly collective powers may not be a *sufficient* condition for substantial unity at a point in time: it could be that a *group* of substances possesses some strongly collective powers, over and above the powers of the individuals. This happens in the case of human societies, for example.
3. The *complete* absorption of the causal powers of parts is a *sufficient* condition for substantial unity at a point in time. Partial absorption of powers results in *groups*, not in the *per se* unity of a *substance*. In contrast, the parts of a substance are so completely absorbed into the nature of the whole that they cannot simultaneously belong in the same way to two distinct wholes.

6. Irreducible Powers of Organisms

How do organisms fit into the world of thermal substances? Thermal substances have a *virtual* presence within an organism. These virtually present thermal substances correspond to actual quantitative parts of the organism, contributing to the explanation of the causal powers of those parts. Consequently, there is a metaphysically fundamental difference between inorganic water (for example) and water as it exists in organisms, although clearly inorganic water can play a role of material causation or explanation in relation to organic processes, even if organic and inorganic water are empirically indistinguishable in their chemical actions. The chemical properties of the water have different metaphysical explanations, depending on the kind of substance (thermal or organic) to which it belongs.

The chemical and thermodynamic properties and the associated causal powers that the quantitative parts of the living body possess are partly determined by the *soul*, the substantial form of the body, along with the *holistic* accidents of the organism, like perception or thought. The interaction is not one of action/passion, as between two substances, but top-down formal determination. Nonetheless, changeable mental attributes can make a real difference to the operation of bodily parts, and vice versa. The soul can guide the breaking of microscopic symmetries, imposing asymmetric accidents on the results, without requiring any novel force (such as Bergson's *élan vital*) or violation of conservation laws.

Is there immanent teleology in nature outside of human thought and intention? Thomists and other Aristotelians argue that the answer is 'Yes'.

In fact, whenever a thing acts according to its intrinsic power and potentialities, immanent teleology exists (Rota 2011). Fundamental causal powers as Aristotle conceives of them are *inherently teleological*. To have the power to produce E in circumstances C is to have the C-to-E transition as one of one's natural functions. Indeed, as George Molnar (2003) has pointed out, the ontology of causal powers builds *intentionality* into the very foundations of natural things. To have a power is to be in a kind of intentional state, one that is in a real sense "about" the effects one is predisposed to produce.

On the Aristotelian model, biological teleology requires just two things: a robust causal powers metaphysics and *real causal powers* at the level of biological organs and organisms. Such real powers require, in turn, substantial forms at the level of whole organisms. The substantial form of an organism is called its soul (*psyche*). In nonhuman animals and in plants, the soul is nonrational. Human souls possess additional rational powers, powers of scientific understanding and deliberation about the good.

This emergence of new powers at the macroscopic, biological scale should be unsurprising, given the fact that, according to our most recent quantum mechanical models, we see strong (ontological) emergence at the mesoscopic scale in solid-state physics and chemistry. Mesoscopic systems, like ferromagnets, superconductors, and Bose-Einstein condensates, all exhibit dynamical behaviors that are irreducible to the microstates of the constituent particles, namely spontaneous symmetry breaking and thermodynamic irreversibility. In a similar way, we should expect the biological functioning of organisms to be irreducible to the chemical and thermodynamic facts about the virtual thermal substances that correspond to their actual quantitative parts.

Evolution itself presupposes teleology in the very idea of *reproduction*, and so evolution requires irreducible causal powers at the organismic level. No organism ever produces an exact physical duplicate of itself. In the case of sexual reproduction, the children are often not even close physical approximations to either parent at any stage. An organism successfully *reproduces* itself when it successfully produces another instance of its own *biological kind*. This presupposes a form of teleological realism, since biological kinds are individuated teleologically, that is, in terms of their fundamental causal powers.

Richard Dawkins has suggested that we think of organisms as mere "robots" that our DNA molecules have "programmed" for reproducing themselves (Dawkins 1976, xxi). In fact, DNA molecules never succeed in producing perfect physical duplicates of themselves, and even if they did, the mere physical duplication of the molecule would not constitute reproducing oneself. Suppose, for example, that an eccentric billionaire builds a chemical factory that does nothing but fill barrels with copies of his own genome, launching them into deep space. No one would think that such a man had succeeded in procreating trillions of descendants. A

DNA molecule counts as a copy of one of one's genes only when it is successfully fulfilling the function of a gene within a living organism, indeed, within a living organism of the appropriate teleologically defined kind.

Alexander Pruss and I have argued that functionalist theories of mind require an account of *normativity* (Koons and Pruss 2017). The argument can be extended to functionalist accounts of biology. The functional dispositions that are supposed to be definitive of mental or biological states can only be defined relative to the *normal* state of the organism, where the "normality" involved is a normative notion, *not* merely a matter of averages or actual frequencies. There are two *prima facie* plausible accounts of the natural basis of normativity: Aristotelian powers and evolutionary accounts.

An Aristotelian can give a straightforward account of such normativity:

> A substance is *supposed to* produce *E* on occasions of *C* if and only if its nature includes a *C*-to-*E* power.

The other potential source of normativity is evolutionary selection. For example, Ruth Millikan attempted define normality in terms of adaptations:

> If a system *x* belongs to a reproductive family *F*, then *x* is supposed to produce *E* under circumstances *C* if and only if doing so is one of *F*'s *adaptations*.

This seems to be the most promising alternative to the Aristotelian account. However, such evolutionary accounts are highly vulnerable to hypothetical counterexamples. Pruss proposed (in Koons and Pruss 2017) the thought experiment of the Great Grazing Ground: a hypothetical world in which organisms in our history were maximally proficient in reproduction, thanks to the intervention of benevolent aliens. In such a world, even if the causal path leading to each of us were identical to the actual historical path, none of us would be conscious, since no distinction between normal and abnormal states could exist. Without that distinction, the relevant functional states supposedly defining consciousness could not be instantiated.

Pruss's thought experiment brings out very vividly how Millikan's definition of biological teleology fails to capture any form of immanent teleology. The present function of an organ or organelle depends on her definition on remote facts in the past, and even on past facts that are causally unrelated to the present. If human thought and intention depend on the teleology of the human body, then thought and intention are also extrinsic to our present constitution and operation, which is incredible.

As I mentioned in Section 2, an Aristotelian account of organisms provides clear advantages for epistemology. Take, for example, our perception of secondary qualities. Unless we are perceiving real qualities in nature, and qualities that really are as we perceive them to be, all of our empirical knowledge is vulnerable to skeptical challenge. Microphysicalists cannot suppose that secondary qualities (as we perceive them) are real, since scientific theory has no place for any counterpart to color, smell, and so on at the microphysical level. In contrast, hylomorphists can suppose thermal substances to have fundamental powers of mutual interaction that correspond closely with the appearance of color, sound, and odor. The quantum-level interactions of particles are less, rather than more, fundamental than these chromatic, acoustic, and olfactory interactions between thermal substances. Organisms have evolved fundamental passive powers of responding reliably to these active powers, resulting in veridical perception of the qualitative features of inorganic substances. This provides a metaphysical foundation for J. J. Gibson's (1979) ecological theory of color, rehabilitating the "secondary" qualities to first-class status.

Anti-realists about secondary qualities could object that the hylomorphic view fails to secure the veridicality of color perception, since colors *as they appear to us* are categorical (non-dispositional) and non-relational, while the qualities of thermal substances are merely powers to affect other substances. But in a causal-powers ontology, the activation of a causal power *is* a categorical and intrinsic property of its bearer. When we perceive the color of a substance, we are perceiving an accident of *action*, the actualization of a corresponding power to act. An accident of action can both be intrinsic to a substance and make essential reference to something beyond it. The critic is right in thinking that colors as we perceive them are not perceived as the actualization of something relative to *us*, but as the actualization of a mind-independent feature. That aspect of our phenomenology is preserved in the Aristotelian account, since the qualities involve powers to act on *both* inorganic thermal substances and our sensory organs.

But is the Aristotelian account of organisms compatible with the facts of biological evolution? Wasn't Aristotle committed to the eternal fixity of the species? In fact, the fixity of species is no more central to Aristotle's system than is the constancy of the celestial spheres. Aristotle's natural philosophy depends on the existence of individual substantial forms and on the existence of relations of objective resemblance between those forms, resulting in a nested, species-genus structure of taxonomy. All of these features are fully compatible with (and even partly explained by) the theory of evolution. And, as I argued earlier in this section, evolution actually *depends on* the existence of organismic substantial forms.

In principle, there would be no problem for hylomorphism even if every biological individual were ontologically *sui generis*. And the transition from one species to another is not a problem. Aristotle recognized that the environment plays a role, along with the parents, in every case of reproduction: "man and the sun beget man" (*Physics* ii.2, 194b13).

But Aristotle's theory does require a principled distinction between substantial forms and mere accidents, and a neo-Darwinian theory would seem to blur that distinction, supposing that the essence of a biological individual consists of nothing but the accumulation of favored accidents. Darwinian evolution depends on a pre-existing genetic variety within species, which corresponds (in Aristotelian terms) to the members' possession of contrary contingent accidents. As a new species emerges, what had been mere contingent accidents take on new functions, enabling the organisms with those accidents to better exploit some ecological niche. Therefore, it seems, at least *prima facie*, that all evolutionary change involves merely changes in the distribution of accidents within related populations. Where is the need for the substantial form and its essence?

For Aristotelians, the distinction between substantial form and accident depends on a set of asymmetric explanatory relations. A substantial form explains the organism's potentiality for certain accidents, and not vice versa. This is compatible with neo-Darwinian theory, which is silent on the explanatory priority between biological forms.

For hylomorphists, there is a traditional distinction between "proper" and contingent accidents. An accident is proper (a *proprium*) if it flows from the specific nature of the substantial form; otherwise, it is contingent.[9] Among contingent accidents, some are permanent (like sex or handedness) and others are changeable. The permanent but contingent accidents are explained by the combination of the nature of the substantial form with certain contingent facts about the process by which the organism was generated and originally developed. Changeable accidents are explained by combining the nature of the substantial form with contingent facts about the subsequent history of the organism.

Now, the crucial question is: can the Aristotelian explain how some accident could be a contingent accident of an ancestral form of the organism but a proper accident of the organism itself (or vice versa)? Doesn't this require a sharp, un-Darwinian transition between one generation (for which the accident is contingent) and the next one (for which the accident is proper)?

Not necessarily. It could be that during evolution a population comes to realize (unstably) substantial forms that belong simultaneously to two distinct species. The substances in such a population would have two, contrary propria, each one a differentia of a different species. Each member of the population would be abnormal relative to one or both of its species, lacking one or both of the contrary propria. Relative to one species, the accident is permanent but contingent, and relative to the other it is proper. In such a population, there would be an unusual and unstable overdetermination in the explanation of the possession of certain proper accidents. The presence of a proper accident that is a differentia of one of the two species would be explained twice over: once by direct implication from one of the specific natures of the substantial form and in another way by contingent factors in the substance's generation and development that result in the organism's deformation relative to the other species. The transitional organism's substantial form would have a natural disposition toward both contrary differentiae. This would be an unusual situation but not an impossible one.

Alternatively, even if it were true that each organism must belong to a unique species, this would not create an insuperable problem for reconciling Aristotle and evolution. We could suppose that transitional populations consist of a mixture of two species, with members of each species able to mate with the other, and with offspring of both species possible from a single pair of parents.[10] The coexistence of distinct species would reflect the fact that the population stands on a borderline between two competing explanatory schemes. Some organisms will fall on one side of the boundary or the other, due to its particular configuration of accidents.

Eventually, selective pressures could eliminate the representation in the population of the older species, completing the origin of a new species, which would eventually become reproductively isolated. The Aristotelian concept of species would not perfectly coincide with modern biological uses in evolutionary settings, but the correspondence would in general be quite close.

7. Conclusion

Aristotelian pluralism carves a middle path between atomism and cosmic monism, securing a foundation for the manifest image of human life. It acknowledges the homeliness of the world – a place in which human freedom, agency, and knowledge can exist without threat of nihilism or corrosive skepticism. Modern science seemed to threaten this world with a universal acid of atomistic reductionism, but the implications of the quantum revolution enable us to set the world right again.

Notes

1. See, for example, Lewis (1947, chapter 2), Plantinga (2010, chapter 10), Koons (2017, 2018c), and Steward (2012).
2. I side here with Thomas Aquinas (and, I believe, with Aristotle himself) in affirming the "unicity" of substantial form: that is, the thesis that every substance has a single substantial form. Some contemporary theorists (e.g., Jaworksi 2016) side instead with Scotus and most later scholastic philosophers in allowing for multiple substantial forms. They face what I take to be a decisive objection: if the substantial form is that by which everything in the substance (both material parts and accidents) receive their actual existence, then multiple substantial forms would introduce an unacceptable form or overdetermination or redundancy in nature.
3. My views about the role of matter have changed significantly from my 2014 paper (Koons 2014). I now think that matter's role as an enduring substrate through change (emphasized in Aristotle's *Physics*) is secondary to its more

central role as individuator. I now think of the persistence of matter through substantial change as non-fundamental, as the persistence of a kind of *ens successivum* (a series of fundamentally distinct, time-bound entities that are tied together into a kind of causal sequence). Thus, I have moved somewhat in the direction of Scaltsas (1994) and Marmodoro (2013). However, unlike Scaltsas and Marmodoro, I still believe that there are real and not merely conceptual distinctions among a substance, its form, and its matter. The three must be really distinct in order to play three distinct explanatory roles in metaphysics.

4. In the GRWm ontology, parcels of material "gunk" do have definite locations, but particles are not part of the fundamental ontology.
5. The Drossel-Ellis account, like GRW, involves objective quantum collapses, but in their account the collapses are precipitated in a top-down fashion by thermal properties of the system.
6. To be absolutely complete, I would have to add heaps of groups and groups of groups to the list.
7. These were pressed at an American Catholic Philosophical Association meeting in 2019 by physicist Stephen Barr.
8. Is the existence of sharp boundaries an ontological or merely an epistemological condition? That is, could there be two thermal substances in contact with each other, where the boundary in space (or time) is merely a metaphysical boundary but not a physical or chemical discontinuity? If such were possible, it would be difficult for us to detect the existence of two adjoining thermal substances, as opposed to a single one. Perhaps we could use facts about the past or future history of the substances to make the distinction, relying on empirical laws of the generation and corruption of thermal substances.
9. Although propria are fully explained by a substance's essence, it is possible for a substance to lack one of its propria, through genetic defect or injury. Being bipedal is a proprium of human nature, but not all human beings have two legs in fact.
10. It is important to note that metaphysical species do not necessarily correspond one to one with what biologists mean by "species". Biologists use a number of criteria to distinguish one species from another, and none of these criteria will always carve nature at the joints, metaphysically speaking. Nonetheless, just as new species in the various biological senses arise by descent with modification, the same must be true of metaphysical species.

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